Illuminating Engineering Society

THE LIGHTING HANDBOOK

Tenth Edition | Reference and Application



David L. DiLaura
Kevin W. Houser
Richard G. Mistrick
Gary R. Steffy

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Tenth Edition: Reference and Application

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Illuminating Engineering Society, The Lighting Handbook, Tenth Edition

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FOREWORD

In the early years, the Illuminating Engineering Society, founded in 1906, waited 41 years before issuing the first edition of the Handbook. Technical information was not lacking but the preferred method of publication were Transactions of the Society, not as widely disseminated or conveniently available to as broad an interested audience as a Handbook. Between the 1st edition in 1947 and this 10th Edition there have been revisions in 1952, 1959, 1966, 1972, 1981, 1984 (partial), 1987 (partial), 1993, and 2000.

In each book an ever-broadening range of technologies, procedures, and design issues has been addressed to ensure that the Handbook is the principal source for lighting knowledge. The emphasis in each edition has changed to reflect current application trends and needs of the many and varied readership. Some editions placed more importance on quantitative issues; in more recent years, quality earned important recognition.

The Tenth Edition Handbook has taken cognizance of several issues that impact designs of today: energy limits, the spectral effects of light on perception and visual performance, and the need for flexibility in an illumination determination procedure that takes into account factors such as observer age, task reflectance, and task importance in its illumination determination procedure. This book will return to a more "analytical" approach to recommendations and allow the individual committees' publications, such as Recommended Practices, Design Guides, and Technical Memoranda to fully address appropriate and specific design details for a given application.

The professional editorial team brought talent and discipline to the project. This was not a simple revision to an existing book but an entirely new approach. David DiLaura, Kevin Houser, Richard Mistrick, and Gary Steffy have earned our appreciation for their contributions in developing new material, editing, and designing the overall appearance of the book.

The Lighting Handbook represents the most important reference document in the lighting profession. It is one by which the Society accomplishes its mission: To improve the lighted environment by bringing together those with lighting knowledge and by translating that knowledge into actions that benefit the public. We hope that you, the reader, will find the Tenth Edition your principal reference source for lighting information.

William H. Hanley
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Director of Technology

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PREFACE

The Illuminating Engineering Society produces The Lighting Handbook to guide and give authoritative recommendations to those who design, specify, install, and maintain lighting systems, and as an impartial source of information for the public. Like previous editions, the Lighting Handbook contains a mix of science, technology, and design; mirroring the nature of lighting itself.

Three sections make up this edition: *Framework*, *Design*, and *Applications*. *Framework* chapters describe the science and technology related to lighting, including vision, optics, non-visual effects of optical radiaton, photometry, and light sources. *Design* chapters include not only fundamental considerations and special issues of daylighting and electric lighting design, but also energy management, controls, and economics. Applications chapters establish the design context for many lighting applications, provide illuminance recommendations for specific tasks and areas, and identify some of the analytic goals of lighting design using science and technology.

In the decade since the last edition, the science, technology, and design practice related to lighting have advanced significantly. Vision and biological sciences have deepened knowledge of the complex relationship between light and health, adding both opportunity and responsibility to the work of those who design lighting systems, and heightened the awareness of the public of how lighting affects our lives. Technology has transformed lighting with the light emitting diode, now a practical source for general illumination. New equipment, new testing procedures, and new application considerations have all arisen in response to this development. And the philosophy, goals, and practice of architectural design have been deeply affected by concerns for the natural environment and desires for more sustainable buildings. New developments in daylighting, sustainable practices, and lighting control technology provide ways to respond to these concerns and expectations. This edition of The Lighting Handbook describes all of these important advances and changes, providing overviews, descriptions, data and guidance.

New and extensive coverage of lighting design is provided in the *Design* chapters. Daylighting and lighting controls are treated in particular detail. This reveals daylighting's potential and subsequent effects on building design, so that daylighting and electric lighting may act in concert to produce better luminous environments. The consequences of this for building energy can be very large if controls are an integral part of lighting systems, and the chapter on lighting controls shows how this can be done. Related to this and to augment the technical information provided in a *Framework* chapter, the *Design* section of The Lighting Handbook includes a chapter on the application issues involved in electric light sources.

The public hope and expectation of diminishing the energy allotted to buildings have increased the challenge of providing the lighting required for comfort, performance, safety, and the appropriate lighting of architecture. In response to these constraints, the IES has established a new illuminance determination system to generate new recommended illuminance targets cited in the *Applications* chapters of this edition of The Lighting Handbook. The new system uses a series of closely spaced increments of illuminance that are assigned to tasks. This finer granularity, in comparison to that used in earlier editions, gives the designer and client the ability to more carefully match illuminance targets with visual tasks. Additionally, most recommendations now account for the age of the occupants: lower values for young occupants, higher values for older occupants. The effects of

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mesopic adaptation on the spectral sensitivity of the visual system are now accommodated with multipliers based on adaptation luminance that can be used to adjust recommended illuminance targets. Finally, recommended illuminance targets for outdoor applications now account for activity level and environmental conditions. All of these features of the new illuminance determination system give extensive flexibility that enable the designer to address lighting needs and promote the control of light in time. The recommended illuminance targets given in each of the application chapters are based on this new system.

One of the many significant changes in The Lighting Handbook has been in the intent and form of the application chapters: they no longer contain a full description of lighting practice. Rather, they give only a brief context for the principal aspects of the application and a detailed table of analytic recommendations for the tasks involved. The complete description of all aspects of a particular application is now contained only in the Society's respective Recommended Practice, Design Guide, or Technical Memorandum publication. This separation of intended coverage permits handbook chapters to make stable analytic recommendations, while allowing more flexibility for timely revisions to the more practice-based Recommended Practices, Design Guides, and Technical Memoranda.

Among the many effects of the new technology and understanding of light and well-being, has been the emergence of wide interest in new lighting technologies and large questions of public policy regarding lighting, energy, sustainability, and health. For these reasons this edition of The Lighting Handbook has been designed and written for a very wide audience, changing the form, content, and style from past editions. Unlike those, this has been written, literally, by its four editors, permitting a certain uniformity of approach, scope, level of detail, and target audience. This has also helped reduce redundancy and assure the accessibility required to reach a wide audience. Every effort for concision has been made, and wherever possible, important data, material, check lists, or key factors have been summarized in tables. Though written by a small group, the recommendations and content of each chapter has been widely reviewed by experts in each topic, the appropriate application committee, and the Society's Technical Review Council and Board of Directors.

This edition of The Lighting Handbook provides information and recommendations that can guide designers and users of lighting systems in a world of both reduced lighting energy expectations and undiminished needs for attractive, comfortable, productive luminous environments.

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FRAMEWORK

This section of The Lighting Handbook describes topics from science and technology that relate directly to lighting. Though such information is now available from a wide variety of conveniently accessed sources, what is presented in this section has the benefit of being in one place and the reader being certain that it has a clear and important relationship to lighting. In that regard, these chapters bring together descriptions of the concepts, data, terminology, equipment, and procedures from various fields of science or technology that are used in lighting.

The content and style of these chapters is such as to remind and point out, rather than to teach. The latter would require much more space than is available here. Additionally, these chapters are summaries, and though the coverage is meant to be inclusive, it is not exhaustive. And so, wherever appropriate, references have been supplied to point the user to more detailed information in the literature.

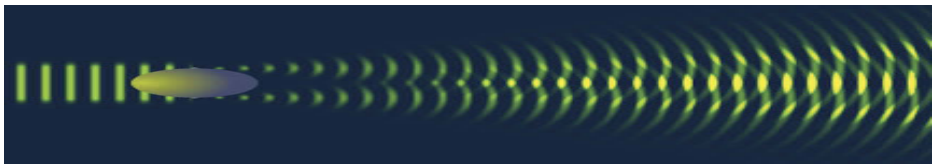
The chapter on the technical aspects of light sources is a unique and complete presentation of lamps. Importantly, it should be considered as one of a pair, along with the chapter on lamps in the *Design* section of the book. There the user will find the application issues associated with lamp operation and characteristics. Together, these chapters present information on how lamps work, their operating characteristics, and application issues such as lumen maintenance and dimming. As such, these chapters describe generic types of lamps; detailed and specific data for a particular lamp is best obtained from manufacturers' catalogs.

The color chapter is greatly expanded from its predecessors, with full color printing affording the opportunity to deepen, elaborate, and clarify the discussion of color phenomena. Additionally, an emphasis has been placed on those issues in the color field that relate directly to lighting and lighting design. The emphasis in the chapter on lighting calculations has been shifted to computer-based calculations and new material on computer graphic renderings has been added.

This section also contains Chapter 4, Perceptions and Performance. The new Illuminance Determination System is described here. The effects on recommended illuminances of observer ages, outdoor nighttime lighting zones, activity levels, and adaptation states are all described. The background and details of this new system are described here. The consequences of this mix of vision science and practical experience are apparent in the tables of recommended illuminances and uniformities found in each of the chapters in the *Applications* section of the handbook.

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1 | PHYSICS AND OPTICS OF RADIANT POWER

For the rest of my life I want to reflect on what light is.
Albert Einstein 1916

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Anyone dealing with lighting profits greatly from a basic understanding of the physics of light. Even if only qualitative, such an understanding makes clear how light stimulates the visual system and ultimately produces perceptions, how light interacts with materials to provide for its own control and distribution by luminaires, how light makes materials luminous and participates in the generation of color perceptions, how light is produced by electric light sources, and why light from the sun and sky can greatly enhance the quality of an interior environment.

1.1 Optical Radiation

For the sake of clarity "optical radiation" is used here to name that phenomenon which transports power by radiant means. That phenomenon can be described by a shower of photons, propagating electromagnetic radiation, or a bundle of rays, depending on the detail of description that is required. Optical radiation is a physical quantity. "Light" is reserved to describe optical radiation that has been evaluated with respect to its ability to stimulate the visual system. Light is a psychophysical quantity and is fundamentally, a perception.

1.1.1 Physical Models of Optical Radiation

Two physical models have long been used to explain the properties of optical radiation and how it interacts with materials. These are the wave and the particle models. In 1690 Christiaan Huygens proposed that optical radiation be considered advancing waves in an ethereal medium [1] [2]. In later editions of his 1704 work on optics, *Isaac Newton* proposed that optical radiation be considered a stream of very small particles [3]. Modern concepts conceive optical radiation as a wave-particle duality that manifests wave or particle properties depending on circumstances.

Isaac Newton systematically studied the properties of dispersed light, correctly theorizing that the light of different colors has different "refrangibility". He was the first to note that light of diffent colors had different brightness and varied in their power to envoke the visual sensation.

In illuminating engineering and lighting design the wave model underpins the understanding and use of optical radiation, while in the physics and chemistry of light source development the particle model is the underpinning.

1.1.2 Maxwell's Waves

Various forms of the wave model of optical radiation were developed and worked on by Leonard Euler [3] [4], Thomas Young [5], and Augustine Fresnel [6]. In 1873 James Clerk Maxwell described an electromagnetic model of optical radiation that is still used today [7]. In its modern form Maxwell's model has an electric vector and a magnetic vector oriented perpendicular to each other, oscillating in phase, and propagating in the direction perpendicular to their oscillation. As these vectors propagate and oscillate they can be considered to define an electric wave and a magnetic wave. In some special circumstances the orientation of the planes in which these vectors oscillate is fixed and this simple, though special, case is shown in Figure 1.1.

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The energy transported by these vectors is determined by the Poynting Vector, formed by the vector cross product of the electric and magnetic vectors and so points in the direction in which the electric and magnetic vectors propagate. The Poynting Vector's magnitude is the energy being transported and it can be considered as an optical ray. This ray, the electric and magnetic vectors, and their waves, are shown in Figure 1.2.

The electric and magnetic vectors, E and H, are described by

$$\mathbf{E} = \mathrm{E}\sin\left(\frac{2\pi c}{\lambda}\mathrm{t}\right)$$
$$\mathbf{H} = \mathrm{H}\sin\left(\frac{2\pi c}{\lambda}\mathrm{t}\right) \qquad (1.1)$$

Where:

E and H = the maximum amplitude of the vectors
c = speed of light
λ = distance between successive complete reversals in polarity, which is wavelength
t = time

The Poynting Vector, **P**, or optical ray is described by

$$\mathbf{P} = \frac{c}{4\pi}\mathbf{E}\times\mathbf{H} \qquad (1.2)$$

Figure 1.1 | Propagating and Oscillating Electric and Magnetic Vectors
The electric vector is shown in blue (vertical), the magnetic vector in red (horizontal). The vectors are propagating from back to front, oscillating as they propagate. Their position, size, and direction in past moments are shown receding into the background.

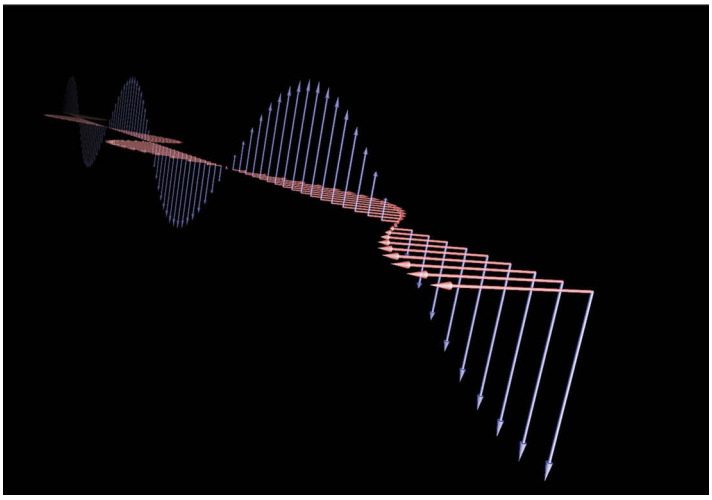
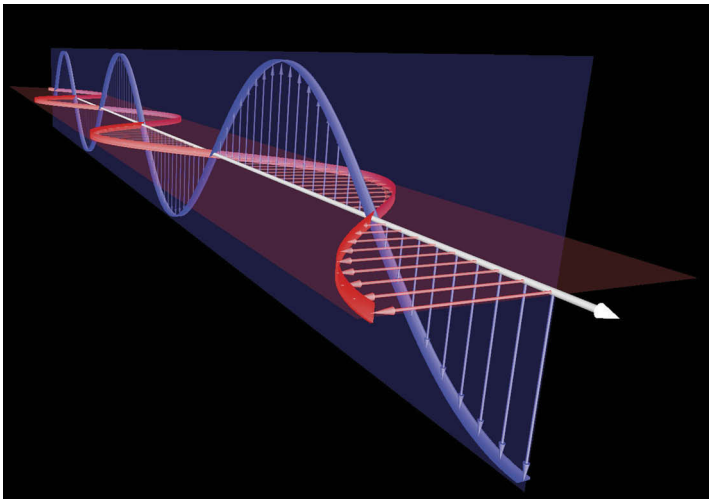


Figure 1.2 | Electromagnetic Radiation and the Poynting Vector
The two planes that contain the oscillating electric and magnetic vectors are shown in blue (vertical) and red (horizontal), respectively. These planes contain the electric and magnetic waves traced out by the propagating, oscillating vectors. The Poynting Vector is shown in white.



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1.1.3 Einstein's Photons

In 1905, *Albert Einstein* proposed a model for optical radiation that assumed its particulate nature [8] [9]. Earlier, Max Planck showed how the assumption that energy is emitted and absorbed only in discrete amounts, or quanta, explained the energy distribution of perfect thermal radiators – something for which wave theories could not account. Einstein proposed that this quantum of energy was carried by a tiny particle. That is, optical radiation was a stream of particles, consisting of so-called photons, massless particles that moved through empty space with a velocity long-known as the "speed of light." Though a particle, the photon is considered to have a vibration frequency, ν, and together with a constant, h, identified by Planck, defines the quantum of energy, Q, transported by a photon:

$$Q = h\,\nu \tag{1.3}$$

Albert Einstein suggested in 1905 that "from a purely heuristic point of view" light be considered as discrete corpuscles of energy. This very bold idea was proposed in the face of the electro-magentic wave formalation of light that by then had been developing for 50 years. It would be years later that Millikan provided experimental verification of predictions that resulted from Einstein's proposal.

1.2 Working Models of Optical Radiation

As outlined above, physics presents optical radiation as a wave-particle duality. From this, four particular models of optical radiation are used in electric light source development, illuminating engineering, and lighting design. They are briefly described here, in an order of decreasing complexity, increasing antiquity, and general utility.

1.2.1 Quantum Optics

In this model the photon is considered the primary physical representation of optical radiation. The photon is considered an indivisible massless particle, traveling at the speed of light. Though a particle, it is considered to exhibit a wavelength and therefore a frequency of vibration or oscillation. The photon possesses energy proportional to its frequency. Quantum optics is used in the understanding and development of light emitting diodes and electric discharge sources.

1.2.2 Physical Optics

In this model, radiant power is considered electromagnetic radiation and the primary physical representation is a pair of vectors, electric and magnetic, inseparably coupled, traveling transversely, that is sideways, at the speed of light. As they travel, their polarity oscillates sinusoidally from positive to negative with a particular frequency. This motion traces out electromagnetic waves that exhibit a wavelength determined by the frequency. This model will be described more carefully below.

1.2.3 Geometric Optics

In many cases, the effects of radiant power are to be predicted in an environment which has dimensions many orders of magnitude larger than the electromagnetic wavelengths of interest. A very useful approximation results from considering wavelength to be vanishingly small, and replacing the electromagnetic waves with a vector in the direction of their propagation [10]. This vector is taken to be a single ray of radiant power. A number of rays are grouped into a cone of small divergence and this group is called a pencil of rays. This pencil forms the fundamental unit of optical radiation at the level of geometric optics. Pencils of rays allow optical effects to be described entirely in the language of geometry. Geometric optics is used in the development of optical control elements and luminaires.

1.2.4 Radiative Transfer

When we are interested in what might be called the "bulk transfer of radiant power," rays are grouped together into pencils, and pencils grouped into beams. The amount of radiant power involved is that which we encounter in everyday life and can measure conveniently. Radiative transfer is used in illuminating engineering and lighting design.

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1.3 Properties of Optical Radiation

Lighting uses an amalgam of the second and third models of optical radiation to formulate a definition of radiant power, and ultimately light, that fills the requirements of illuminating engineering and lighting design. In this model, the fundamental unit of radiant power is a pencil of rays having the quantitative properties of propagation direction, transported power, wavelength, and polarization.

1.3.1 Propagation

A pencil of rays is defined by a vanishingly small cone of rays emanating from a point. The apex of the cone is at this emanating point. This is shown at top of Figure 1.3. For all practical optical work it is more convenient to represent the entire pencil with a single vector, as shown on the bottom in Figure 1.3. In these cases, the cone is usually omitted from the representation, leaving only the vector to represent the pencil of rays.

1.3.2 Transported Power

In Equation 1.1, the E and H are the maximum extents of the waves, and are said to be their amplitude. The angle between the vectors **E** and **H** is $\pi/2$, so their cross product, **P**, can be expressed as [10]

$$\mathbf{P} = \frac{c}{4\pi}\mathbf{E}\times\mathbf{H} = \frac{c}{4\pi}|\mathbf{E}||\mathbf{H}|\sin\left(\frac{\pi}{2}\right) = \frac{c}{4\pi}EH\sin^2\left(\frac{2\pi c}{\lambda}t\right) \tag{1.4}$$

Where:

E and **H** are the electric and magnetic vectors, respectively
c is the speed of light in m/s
λ is wavelength in m
t is time in s

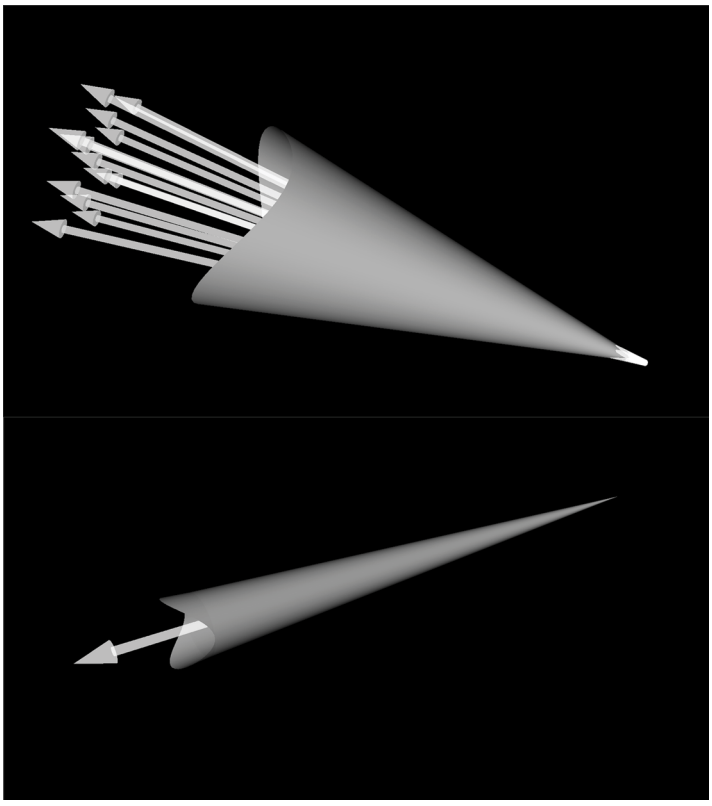


Figure 1.3 | A Pencil of Rays
Pencil of rays (top) defined within a cone of solid angle, and a single vector (bottom) in a solid angle cone representing the entire pencil of rays.

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The amplitude E and H are the same, so the power propagated is proportional to the square of the amplitude of the wave, and varies with time. In lighting, instantaneous values are rarely of interest since responses to radiant power are usually the result of an integration over time—however short—giving the time-averaged power being propagated. If the last term in Equation 1.4 is integrated over the time, $t = \lambda/c$, required for one wavelength to propagate, and the result divided by that length of time, the result is

$$\langle \mathbf{P} \rangle = \frac{c}{8\pi} E\, H \qquad (1.5)$$

Time-average power is one the two aspects of radiant power required to characterize it as a stimulus for vision.

1.3.3 Wavelength

Wavelength is the other aspect of radiant power required to characterize it as a stimulus for vision. The trace of the motions of the electric and magnetic vectors define waves, as shown in Figure 1.2. The distance between successive crests or troughs of the waves, λ, is said to be the wavelength of the electromagnetic radiation. In lighting it is customary to express wavelength in nanometers: 10^{-9}m or nm. Radiant power can be ordered according to the wavelengths it exhibits and this arrangement is its spectrum. Table 1.1 shows ranges of wavelengths of optical radiation, in logarithmic steps, in a spectrum covering 15 orders of magnitude of wavelength. The range of wavelengths pertaining to lighting is from approximately 250 nm to 2000 nm. This region is usually divided as follows:

- Wavelengths that produce vision: 380-760 nm
- Wavelengths that activate the human circadian system: 400-550 nm
- Wavelengths that are biologically active, the UV region: 250-400 nm
- Wavelengths that contain thermal radiation, the infrared region: 750-2500 nm

Radiant power is said to be monochromatic if the wavelength of all the radiation has a single, or nearly single, value. Hetrochromatic or broadband radiation exhibits many different wavelengths.

1.3.4 Polarization

Polarization is another characteristic of electromagnetic radiation that is carried over to lighting's model of radiant power. Polarization refers to the orientation of the plane in which the electric vector oscillates as it propagates [10] [11]. The radiant power most commonly generated and used in lighting has the plane containing the electric vector changing orientation in a random way as it propagates. This condition is described as un-

Table 1.1 | The Spectrum of Electromagnetic Radiation

Wavelength (nm)	Radiation Type
10^{-3}	Cosmic rays
10^{-2}	Gamma rays
10^{-1} - 1	X-rays
10^{1}	Vacuum ultraviolet
10^{2}	Ultraviolet
10^{3}	Visible
10^{4} - 10^{5}	Infrared
10^{6}	Radar
10^{7}	Television
10^{8}	Radio
10^{9} - 10^{10}	Shortwave broadcasting
10^{11} - 10^{12}	Longwave broadcasting

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polarized. If the orientation of the plane containing the electric vector oscillation is fixed, as in Figure 1.1, the radiant power is said to be linearly polarized. The plane that contains the electric vector is said to be the plane of polarization. Under certain circumstances, it is possible for the plane of electric vector oscillation to rotate in a smooth and continuous way around the axis of propagation as the electric vector oscillates and propagates. This is circular or elliptical polarization. The most common type of polarization that occurs in lighting is partial linear polarization: some of the electromagnetic radiation having a fixed plane of electric vector oscillation, produced by it passing through a pane of glass. If n_{glass} is the index of fraction of glass, then the closer the incident angle is to $\tan(n_{glsss})$, the more complete the linear polarization.

When dealing with unpolarized electromagnetic radiation, the instantaneous orientation of the electric vector is of little interest, so we consider its time-averaged orientation. The result is that it is in one or the other of two perpendicular orientations half the time. This is convenient, since it is equivalent to saying that unpolarized radiant power is comprised of equal amounts of two types of linearly polarized radiant power, the two planes of polarization being perpendicular. This way of thinking about unpolarized radiant power is important when predicting how it interacts with materials used to control it, such as metals, glass, and plastics.

1.4 Production of Optical Radiation

IESH/10e Light Source Resources

> 7.2 Filament Lamps

> 7.3 Fluorescent

> 7.4 High Intensity Discharge

> 7.5 Solid State Lighting

- all the above sections give a technical description of lamp operation and their characteristics

> 13.3 Life and Lumen Maintenance

> 13.6 Color

The production of optical radiation is linked to the structure of matter in its solid and gaseous states, and by both the acquisition and relinquishing of energy by matter.

1.4.1 Atomic Structure and Optical Radiation

To explain how optical radiation is generated by electric sources it is necessary to begin with an overview of the atomic theory of matter and describe atomic structure [12]. The atomic theories first proposed by Rutherford and Bohr in 1913 have since been expanded upon and confirmed by an overwhelming amount of experimental evidence. These early models of the atom resembled a minute solar system, with the atom consisting of a central nucleus possessing a positive charge +n, about which revolve n negatively charged electrons. It is more accurate to visualize layered electron clouds around the nucleus, as shown in Figure 1.4 for the hydrogen atom, in which an orbit is the average distance the electron is from the nucleus.

In the normal state the electrons remain in particular orbits, or energy levels, and radiation is not emitted by the atom. The orbit described by a particular electron rotating about the nucleus is determined by the energy of that electron. In other words, there is a particular energy associated with each orbit or energy level. The system of energy levels is characteristic of each element and remains stable unless disturbed by external forces.

The electrons of an atom can be divided into two classes. The first class includes the inner shell electrons, which are not readily removed or excited. The second class includes the outer shell (valence) electrons, which cause chemical bonding into molecules. Valence electrons are readily excited by UV radiation, visible radiation, or impact from other electrons and can be removed from their orbit with relative ease. When valence electrons are removed from their orbit, they are free to drift through the material and provide for electrical conductivity. Electrons in the outer or valence orbit have a narrow range of energies that are said to define a valance energy band. Electrons that have been excited and moved outside the valence orbit and are free to become conduction electrons, are said to be in the conduction energy band. The energy of electrons in the conduction energy is higher than the energy of those in the valence orbit, so the conduction energy band is said to be higher than the valance energy band.

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Upon the absorption of sufficient energy by an atom in the gaseous state, the valence electron is pushed to a higher energy level further from the nucleus. When the electron returns to the normal orbit, or an intermediate one, the energy that the atom loses is emitted as a quantum of radiation. The wavelength of the radiation is determined by Planck's formula:

$$E_2 - E_1 = h\,\nu_{21} \tag{1.6}$$

Where:

E_2 = energy associated with the excited orbit
E_1 = energy associated with the normal orbit
h = Planck's constant
ν_{21} = frequency of the emitted radiation as the electron moves from level 2 to level 1

This formula can be converted to a more usable form:

$$\text{wavelength} = \frac{1239.76}{V_d}\ \text{nm} \tag{1.7}$$

Where:

V_d = potential difference in *electron-volts* between two energy levels through which the displaced electron has fallen in one transition

Electron-Volt is the energy lost or acquired by one electron deaccelerating or accelerating through an electric potential difference of 1 volt. It is a very small unit of energy, equal to about 1.6×10^{-19} Joule.

The same relationship holds for absorbed energy as shown schematically in Figure 1.5. Absorption of energy moves an electron to a higher energy level and larger orbit, emission of energy moves an electron to a lower energy level and a smaller orbit. An electron transition that produces emission generates optical radiation at a wavelength that is given by Equation 1.6. All optical radiation is generated in this manner, with different sources using different means to produce atomic excitation that leads to optical radiation emission. Filament lamps use electrically generated thermal agitation, metal halide and sodium lamps use electrical conduction through a gas of vaporized metals and salts, and light emitting diodes use electrical conduction in semiconducting material. The energy transitions involved in incandescence, gaseous conduction, and semiconduction are multiple and different, and so the wavelengths of optical radiation produced are different.

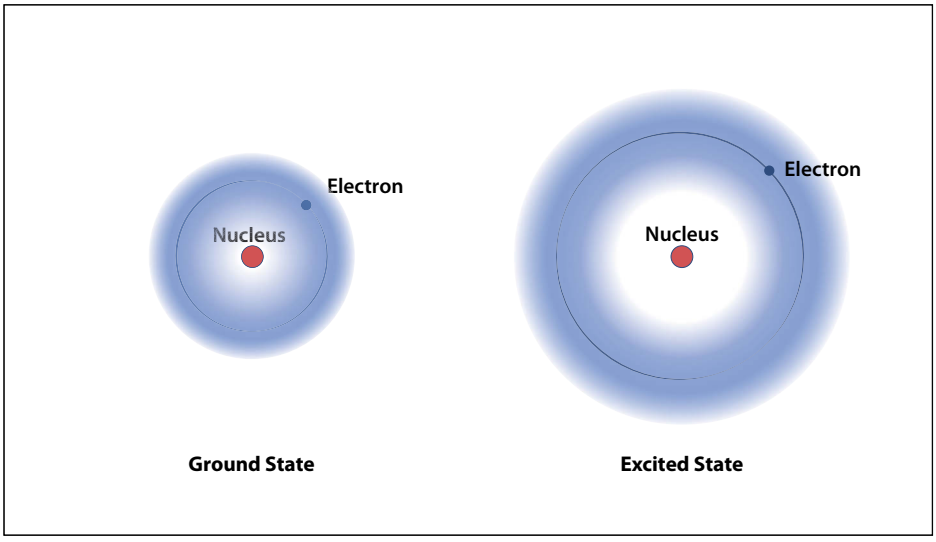


Figure 1.4 | Hydrogen Atom Model
Layered electron cloud model of the hydrogen atom. In the ground state (left) the electron position can be considered to form cloud of possible positions around the protron, with the average distance being the ground state orbit. In the excited state (right) the average positiion of the electron defines a cloud with a greater average distance from the proton.

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1.4.2 Spectral Power Data

Different sources produce different distributions of power throughout the electromagnetic spectrum. The equipment and procedure for measuring these distributions are described in 9.1 Spectroradiometers. This spectral power data is commonly visualized in two ways: a one-dimensional chromatic representation, and a two dimensional plot. One-dimensional representations (which can actually be photographs) are scans through a wide range of wavelengths, with relative radiant power emitted at each wavelength represented by the brightness of the line of color at that wavelength. This is shown at the left in Figure 1.6 which displays the emission spectrum of a high pressure mercury discharge. Though intuitive, this representation suffers from the fact that greater radiant power needs to be represented by brighter colors and wider lines, and radiant power at closely neighboring wavelengths is blurred.

Johann Lambert, in 1760, was the first to systematically study and intercompare light of different colors for brightness. He also devised purely visual photometric means to determine the relative amount of different colors of light that different sources emitted.

Two-dimensional plots are histograms consisting of bars with heights proportional to the radiant power at a wavelength. Color is often added to the bars to help indicate the position in the visible spectrum. This is shown on the right in Figure 1.6. For a continuous spectrum, the bars of the histogram merge. Unlike the one-dimensional plot, a spectrum histogram conveys information about the amount of radiant power at a wavelength by the height of an individual bar and not a color brightness.

Two-dimensional plots are always linear with respect to wavelength, whereas if the one-dimension scans are from spectrometers they are presented either linearly or non-linearly with respect to wavelength. If the spectrometer uses a prism for example, the resulting spectrum will be presented non-linearly. If it uses a grating, the spectrum will be presented linearly. See 9.7.1 Using Spectroradiometers.

Color is often used in the display of spectral power data. Histograms or continuous plots of radiant power as a function of wavelength often show the prismatic spectrum below the line of the plot, as shown for example in Figure 1.7 which displays the optical radiant power distribution of the sun [25]. Each wavelength in the visible spectrum is associated with the monochromatic color produced by that wavelength. Power at wavelengths outside the visible region is usually represented with gray.

Though helpful and suggestive of the spectral distribution of radiant power for a particular source, the total chromatic effect of the source usually cannot be inferred from these colors. Additionally, the medium used to display spectral data in color (printing, computer displays, LCD projectors) usually cannot accurately reproduce monochromatic colors, further limiting the information conveyed by these colors. See 6.6 Color Appearance.

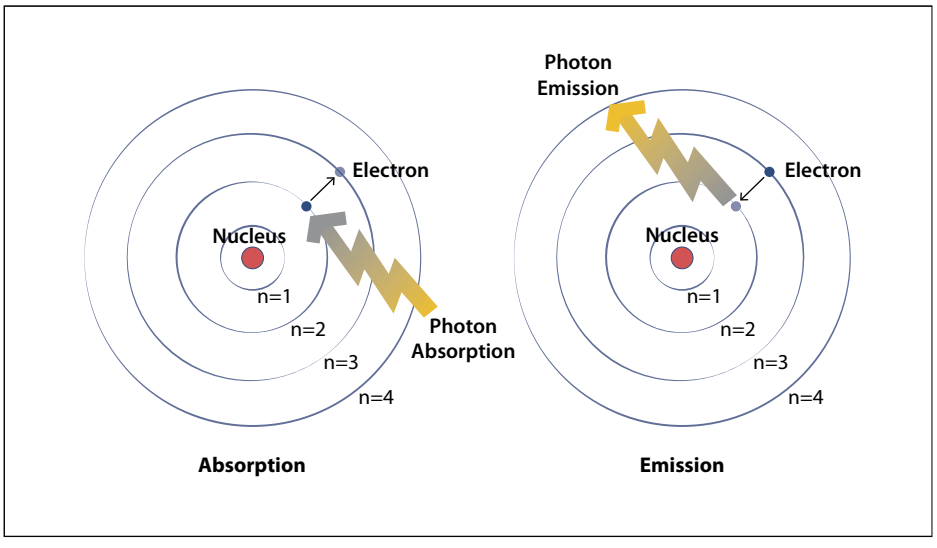


Figure 1.5 | Atomic Absorption and Emission
In this schematic diagram of atomic absorption and emission of energy, a change in stable electron orbit n=1, 2, 3, 4 is represented by the stable orbiting positions of an electron around the nucleus and the energy associated with them.

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1.4.3 Gas Discharge Production of Optical Radiation

Gas discharge is the mechanism by which many modern lamps convert electrical power to radiant power. The spectral composition, and therefore the practical utility for lighting, of this conversion depends on the constituents of the gas and its pressure.

1.4.3.1 Characteristics of Gas Discharges

A gas discharge produces optical radiation by having free or conduction electrons, moving under the influence of a relatively high electric field, strike an atom in the gas and raise it to an excited state by moving one or more of its orbiting electrons to a greater orbit. When the atomic electrons return to a lower state, they emit electromagnetic radiation. The wavelengths of the electromagnetic radiation emitted by this process depend on the energy levels of the atomic orbits characteristic of the gas in the discharge and the interaction between atoms determined by the pressure of the gas [13] [14]. At higher pressures the spectral distribution broadens and contains more wavelengths.

Figure 1.8 shows the optical radiation distribution of a low pressure mercury discharge. A significant portion of the total radiated power is in the UV at 253.7 nm which is not included in the data. Figure 1.9 shows the discharge operating at high pressure, exhibiting a significant change in spectrum. The pressure of the gas participating in the electric discharge has a large effect on the spectral distribution of radiated power and is an important aspect of modern electric discharge sources.

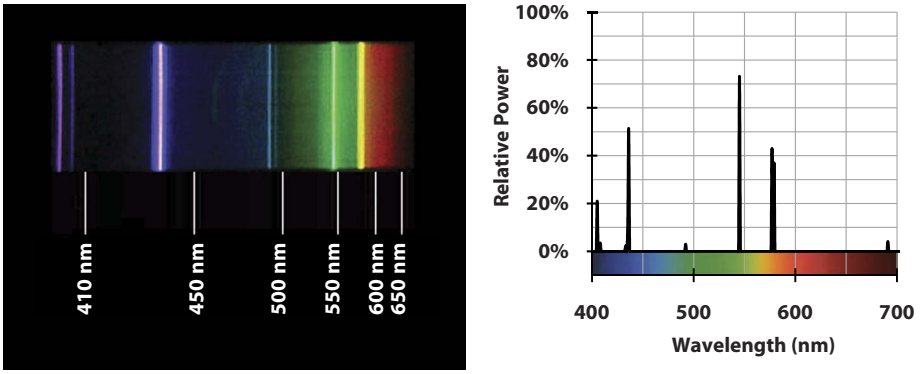


Figure 1.6 | Spectrum of Optical Radiation from Mercury
Two representations of an optical radiation from a high pressure mercury discharge. On the left is an image produced by optical radiation passing through a narrow slit aperture and dispersed by a diffraction grating. The relative amounts of power are indicated by the brightness of the lines. On the right, the values recorded from a radiant power detector that scanned the same dispersion are plotted in a graph.

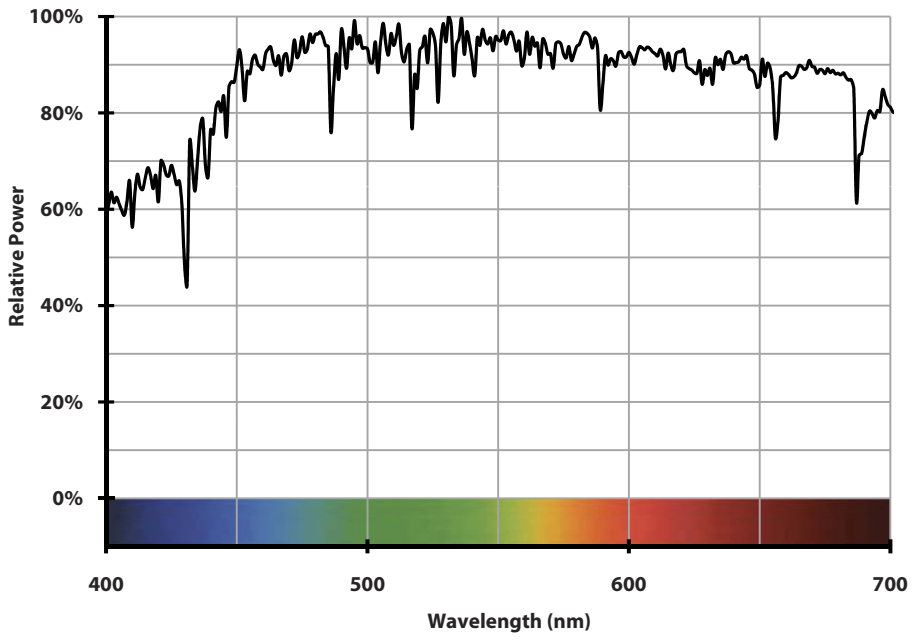


Figure 1.7 | Spectrum of Optical Radiation from the Sun
Optical radiation from the sun at sea level, showing the relative power at each wavelength and the approximate color associated with those wavelengths. The dips show the power that is absorbed by the atmosphere at various narrow wavelength bands from the otherwise nearly continuous solar spectrum.

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Figure 1.8 | Low Pressue Mercury Discharge Spectrum
Optical radiation distribution from a low pressure mercury discharge.

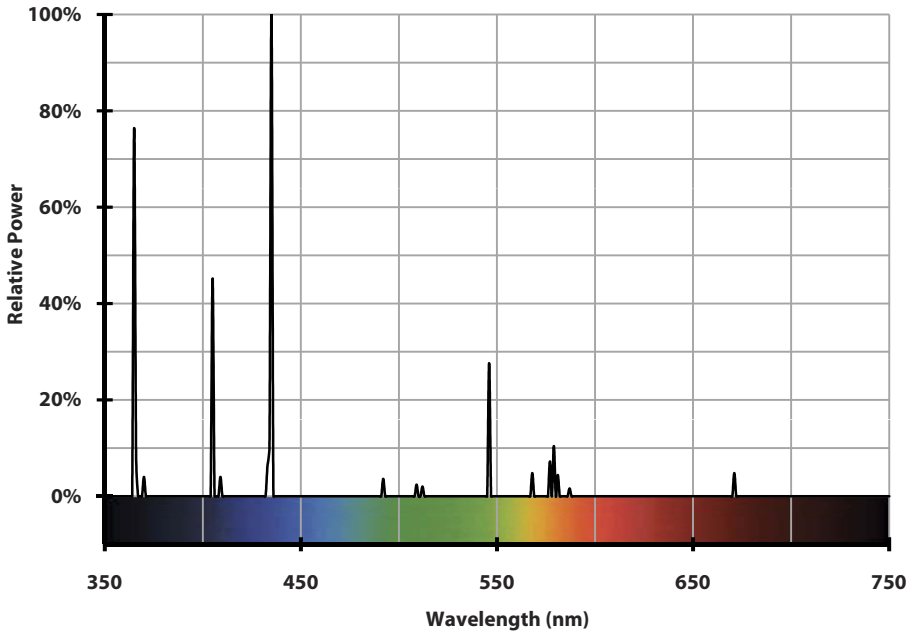
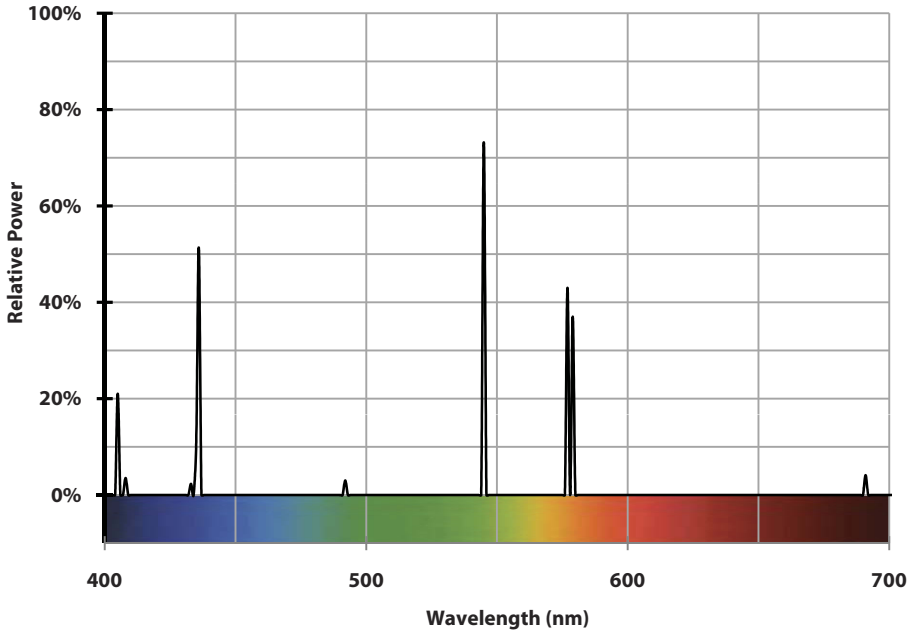


Figure 1.9 | High Pressure Mercury Discharge Spectrum
Optical radiation distribution from a high pressure mercury discharge.



1.4.3.2 Practical Gas Discharge Sources

Most modern electric discharge sources use mercury to provide the conduction electrons and have one or more additional elements comprising the gas and participating, often dominating after the lamp has stabilized, in the generation of optical radiation. Figure 1.10 shows the spectral distribution of a lamp using mercury and sodium operating at high pressure. Figure 1.11 shows the distribution for a metal halide lamp using mercury, sodium, and scandium.

1.4.4 Incandescent Production of Optical Radiation

Incandescence is the process by which optical radiation is emitted by a material due to its temperature alone; that is, radiation for a source that results from the irregular excitation of the free electrons of innumerable atoms due to atomic motion. Heat is atomic motion and temperature is a measure of heat. The higher the temperature of a body, the greater is the atomic movement, and the greater and more frequent is the atomic excitation and

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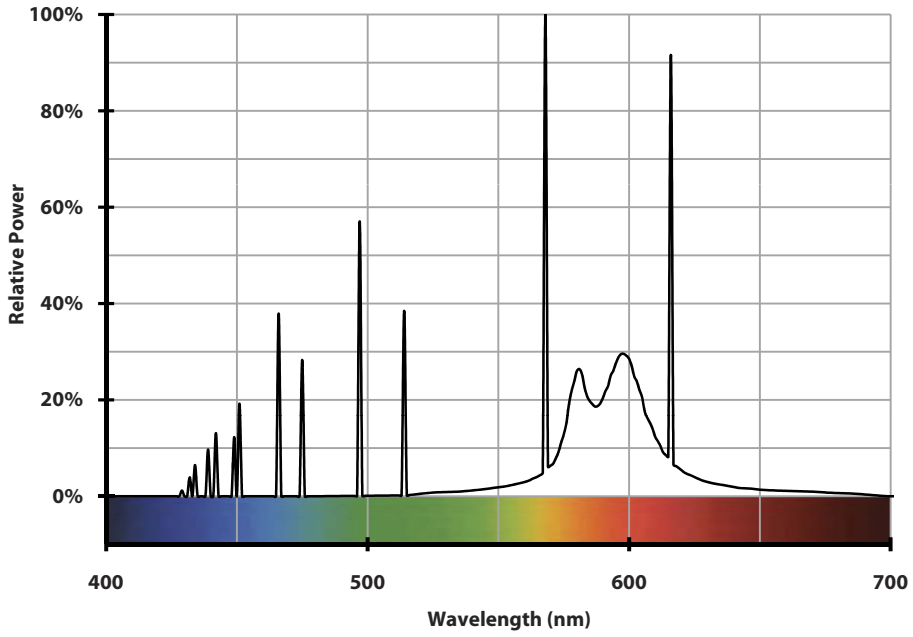


Figure 1.10 | Spectrum of a High Pressue Sodium Discharge
Optical radiation from a high pressure sodium discharge.

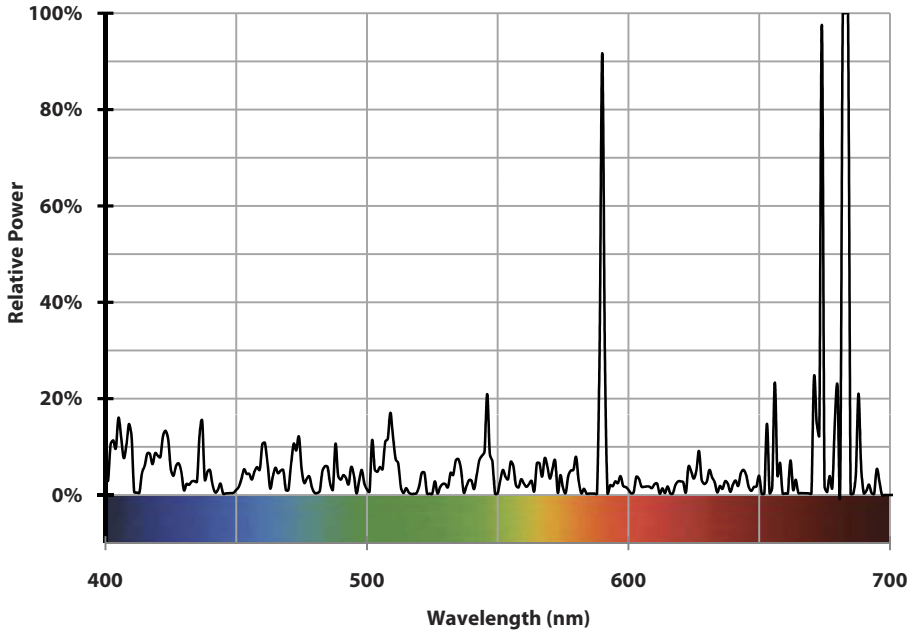


Figure 1.11 | Spectrum of a Metal Halide Discharge
Optical radiation from a metal halide lamp using mercuy, sodium, and scandium.

generation of photons. This thermal excitation involves many differently-sized electron transitions and energy levels and so gives rise to many wavelengths of radiation, forming a more or less continuous spectrum.

At temperatures below approximately 873 K (600°C), only optical radiation in the IR range is emitted by a body. A coal stove for example, or an electric iron. Electronic transitions in atoms and molecules at temperatures above approximately 600°C result in the release of optical radiation in the visible as well as IR regions. The incandescence of a lamp filament is caused by the heating action of an electric current. This heating action raises the filament temperature substantially above 600°C, producing visible optical radiation.

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1.4.4.1 Blackbody Radiation

A blackbody is an object or material that absorbs all incident electromagnetic radiation; none is transmitted, none is reflected. Such an idealized object, if it were cold, would appear black. Thus the name. In 1860 Gustav Kirchhoff [15] showed from equilibrium conditions that if a cavity made from such material were heated, the radiation inside it would have a spectrum of emitted radiant power that depended only on its temperature. This is a so-called blackbody radiator and the particular spectrum of power it produces is blackbody radiation. Figure 1.12 shows the spectral radiant power per unit area of a blackbody, on a logarithmic scale, as a function of wavelength for several absolute temperatures. Figure 1.13 shows similar data over the visible wavelength range.

If a small hole is made in such a cavity any radiation entering the hole would be absorbed in the cavity, regardless of wavelength, and none would come back out. This is an accurate approximation to a blackbody. If the cavity is heated, the radiation emitted from the hole is very nearly blackbody radiation. Data describing blackbody radiation curves were obtained in this way by Lummer and Pringsheim [16] using a specially constructed and uniformly heated tube as the source. Attempts to predict the spectrum of this radiation failed until Planck, introducing the concept of discrete quanta of energy, developed an equation that successfully depicted these curves. Planck's equation can be formed to give a spectral power distribution of a blackbody as a function temperature:

$$P(\lambda) = \frac{c_1 \lambda^{-5}}{e^{\frac{c_2}{T\lambda}} - 1} \tag{1.8}$$

Where:

$P(\lambda)$ = radiated power density at wavelength λ in $w/m^2/\lambda$
$c_1 = 3.7415\ 10^{-16}$ w m^2
$c_2 = 1.43878\ 10^{-2}$ K m
T = temperature in *kelvins*
λ = wavelength in meters

Kelvin is the absolute unit of temperature measurement and use the symbol K. Absolute, so-called, because its zero point is fixed at absolute zero, defined as the cessation of all thermal motion. Physics, and by adoption, lighting, characterizes the temperature of sources using this temperature scale. Room temperature is approximatley 300 K. The filament of an filament lamps operates at approximatley 2850 K.

A blackbody radiator is a perfect incandescent radiator. In theory, all of the energy emitted by the walls of the blackbody radiator is eventually reabsorbed by the walls; that is, none escapes from the enclosure. Thus, a blackbody radiates more total power and more power at a given wavelength than any other source with the same area and temperature.

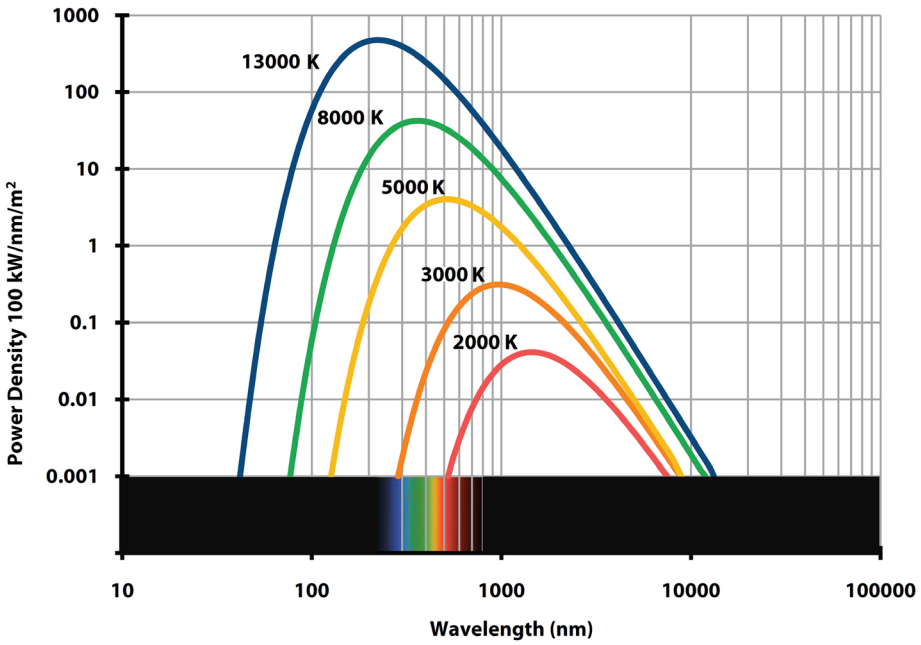


Figure 1.12 | Spectrum of Blackbodies
Spectral radiant power per unit area of a blackbody radiator for several operating temperatures.

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1.4.4.2 Practical Incandescent Sources

No known radiator has the same emissive power as a blackbody. The ratio of the output of a radiator at any wavelength to that of a blackbody at the same temperature and the same wavelength is known as the spectral emissivity, ε(λ), of the radiator. Radiant power from a practical source, particularly from an incandescent lamp, is often described by comparison with that from a blackbody radiator.

When the spectral *emissivity* is constant for all wavelengths, the radiator is known as a graybody. No known radiator has a constant spectral emissivity for all visible, IR, and UV wavelengths, but in the visible region a carbon filament exhibits nearly uniform emissivity; that is, a carbon filament is nearly a graybody for this region of the electromagnetic spectrum. In the visible region, tungsten has a nearly constant emissivity of 0.44.

Emissivity describes the radiative power of a material compared to a blackbody radiator at the same temperature. It is the ratio of the radiant watts at a given wavelength emitted by the material, to the radiant watts emitted by a blackbody at the same wavelength and temperature. "Spectral Emissivity" is this ratio as a function of wavelength, while "Emissivity" often refers to a value resulting from integration over a range of wavelengths.

The spectrum in the visible region of a tungsten halogen lamp operating at 3000 K is shown in Figure 1.14. It has very nearly the spectrum of a blackbody radiator operating at 3010 K.

1.4.5 Luminescent Production of Optical Radiation

Luminescence is the process by which optical radiation is emitted by a material when it absorbs energy that is re-emitted as photons. Radiation from luminescent sources results from the excitation of single valence electrons of an atom, either in a gaseous state, where each atom is free from interference from its neighbors, or in a crystalline solid or organic molecule, where the action of its neighbors exerts a marked effect. In the first case, line spectra result, such as those of mercury or sodium discharge. In the second case, such as with light emitting diodes, narrow emission bands result, which cover a portion of the spectrum, usually in the visible region.

Two kinds of luminescence are used in modern electric sources. Photoluminescence describes the process by which a substance absorbs a photon (electromagnetic radiation) of a particular wavelength and re-radiates electromagnetic radiation at a longer wavelength. Electroluminescence describes the process by which a substance absorbs an electron and radiates electromagnetic radiation. The electron absorption process of electroluminescence is usually part of electrical conduction in the substance.

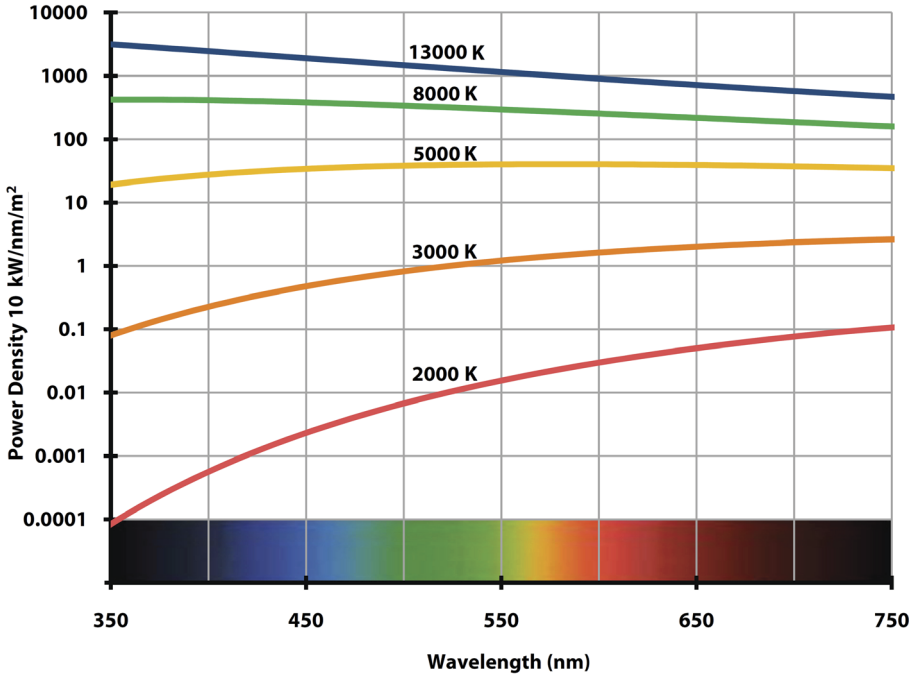
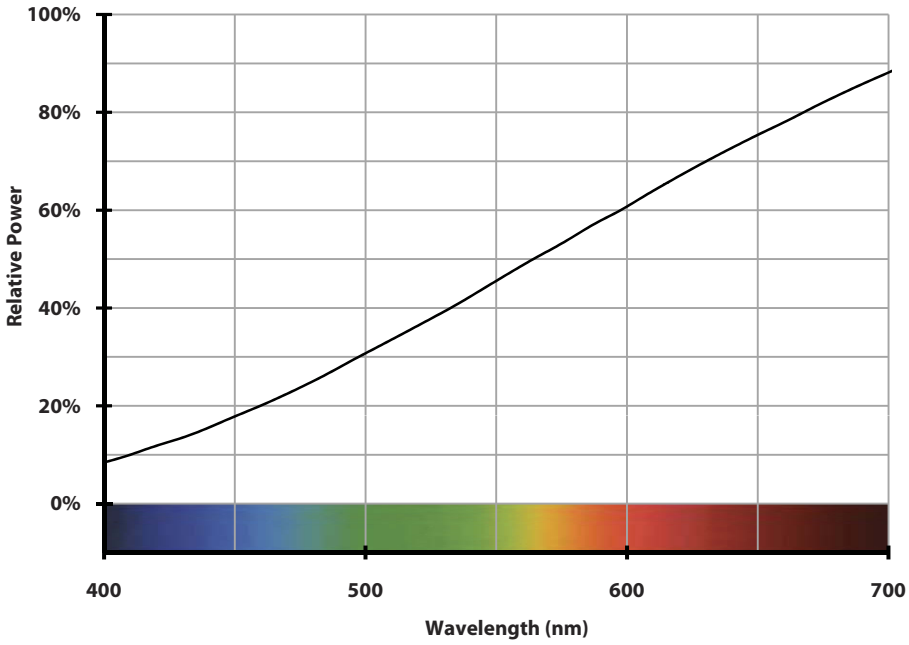


Figure 1.13 | Spectrum of Blackbodies in the Visible Range
Spectral radiant power per unit area of a blackbody radiator in the visible region of the spectrum for several operating temperatures.

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Figure 1.14 | Spectrum of a Tungsten Halogen Lamp
The optical radiation spectrum of a tungsten halogen lamp operating at 3000K. Values are relative to the maximum power emitted in the extended visible region.



IESH/10e Color Resources

> 4.8.4 Depth Perception
- in the context of colored surfaces

> 6.25 Color Temperature and Correlated Color Temperature
- in the context of energized lamp appearance

> 6.3 Color Rendition
- in the context of energized lamp effect on surfaces

> 6.4 Materials Color Specification
- in the context of surface color and reflectance

In some electric sources both gas discharge and photoluminescence are used, as with the fluorescent lamp. In this case, a conductive low pressure mercury discharge produces UV optical radiation. Photoluminescence of a phosphor layer on the lamp's bulb wall absorbs the UV optical radiation and re-radiates visible optical radiation.

Some light emitting diodes use only electroluminescence. Electrical conduction across a semiconductor junction has atoms absorbing electrons and emitting optical radiation. Other types of light emitting diodes use both electroluminescence and photoluminescence. Electroluminescence at the semi-conductor junction produces short wavelength optical radiation. Photoluminescence of phosphor on top of the junction absorbs this optical radiation and re-radiates visible optical radiation. See 7 | LIGHT SOURCES: TECHNICAL CHARACTERISTICS.

1.4.5.1 Photoluminescence: Fluorescence

Fluorescence describes a type of photoluminescence in which a molecule of a substance absorbs a photon and immediately emits a photon of longer wavelength. Fluorescence is the basis of light production in the fluorescent lamp: UV optical radiation produced by an electric discharge in mercury vapor is converted to visible optical radiation by the lamp's phosphors. See 7 | LIGHT SOURCES: TECHNICAL CHARACTERISTICS.

The phosphors used in fluorescent lamps are crystalline inorganic compounds of exceptionally high chemical purity and of controlled composition to which small quantities of other substances (the activators) have been added to convert them into efficient fluorescent materials. With the right combination of activators and inorganic compounds, the color of the emission can be controlled.

For the phosphor to emit light it must first absorb radiation. In the fluorescent lamp this is chiefly at a wavelength of 253.7 nm. The absorbed energy transfers an electron to an excited state. After loss of excess energy to the lattice of the phosphor as vibrational energy (heat), the electron oscillates around a stable position for a very short time, after which it returns to its original orbital position and energy level, with simultaneous emission of a photon of radiation. Stokes' law states that the radiation emitted by this process must be of longer wavelength than that absorbed. Because of the electron's oscillation around both a stable and excited orbital position, the excitation and emission processes cover ranges of wavelength, commonly referred to as bands. In some phosphors two activators are present. One of these, the primary activator, determines the absorption characteristics and can

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be used alone, as it also gives emission. The other, the secondary activator, does not enter into the absorption mechanism but receives its energy by transfer within the crystal from a neighboring primary activator. The emitted light from the secondary activator is longer in wavelength than that from the primary activator. The relative amount of emission from the two activators is determined by the concentration of the secondary activator.

The phosphors used in most "white" fluorescent lamps of earlier technology were doubly activated calcium halophosphate phosphors in combination with rare-earth-activated phosphors. Modern fluorescent lamps use rare-earth-activated triphosphors that emit in bands in the blue and green from europium-actived barium magnesium aluminate and terbium-activated cerium magnesium aluminate, and emit in bands in the red from yittrium oxide.

Figures 1.15 and 1.16 show the optical radiation emitted as a function of wavelength for two types of triphosphors: one producing optical radiation with a correlated color temperature of 2700 K and another at 4000 K. Both are stimulated with optical radiation with wavelengths of 185 and 253.7 nm.

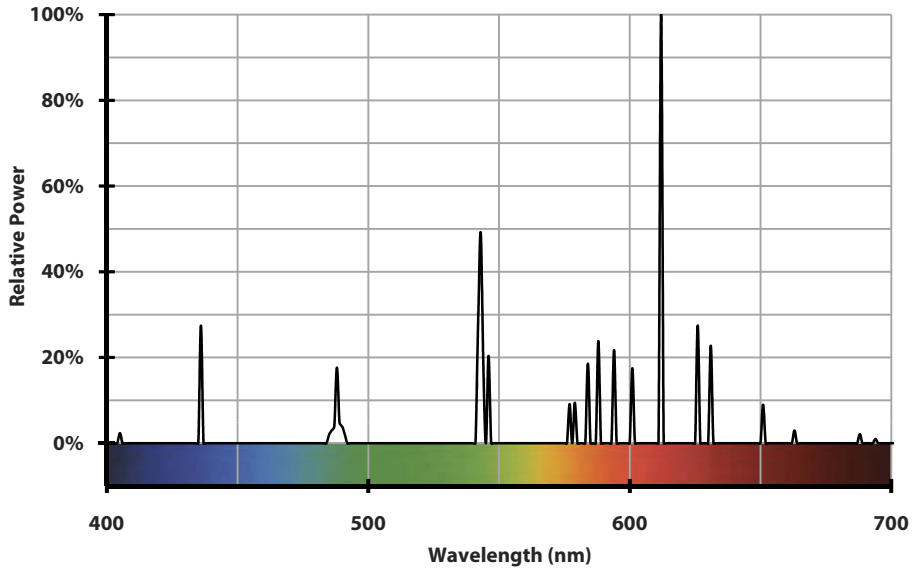


Figure 1.15 | Spectrum of a Triphosphor 2700 K Lamp
Optical radiation from a triphosphor fluorescent lamp designed to produce visible radiation with a correlated color temperature of 2700 K.

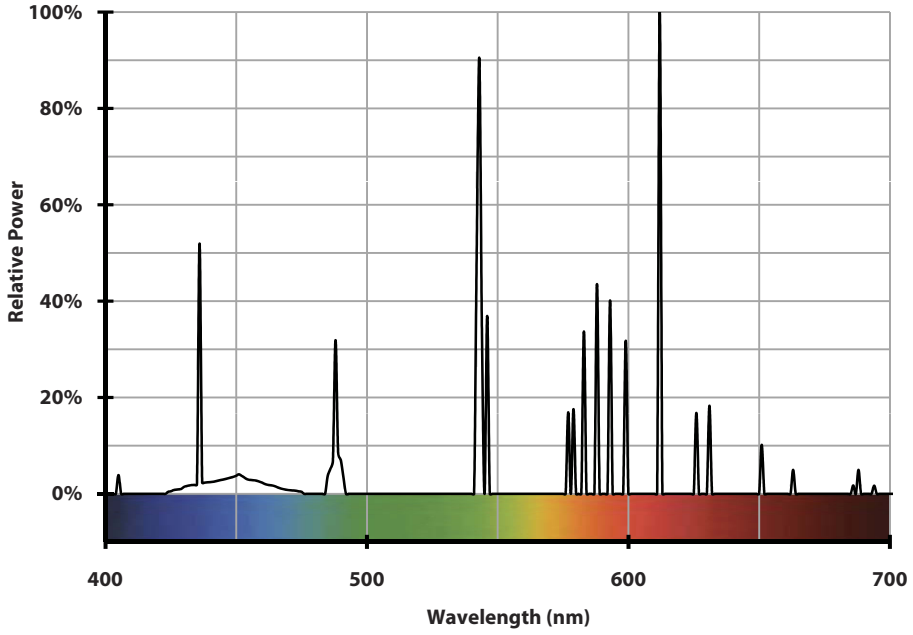


Figure 1.16 | Spectrum of a Triphosphor 4000 K Lamp
Optical radiation from a triphosphor fluorescent lamp designed to produce visible radiation with a correlated color temperature of 4000 K.

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1.4.5.2 Photoluminescence: Phosphorescence

Phosphorescence describes a type of photoluminescence in which the time between absorption and emission of photons is significantly longer than that observed in fluorescence. The transition from an excited to a stable state in phosphorescent materials can take minutes or hours. That is, they exhibit long luminous persistence. Phosphorescence is not common in architectural lighting sources, but is used in some wayfinding markers.

1.4.5.3 Electroluminescence: Electroluminescent Lamps

Certain phosphors convert energy directly into optical radiation, without using an intermediate step as in a gas discharge, by utilizing the phenomenon of electroluminescence [18]. An electroluminescent lamp is composed of a two-dimensional area conductor (transparent or opaque) on which a dielectric-phosphor layer is deposited. A second two-dimensional area conductor of transparent material is deposited over the dielectric-phosphor mixture. An alternating electric field is established between the two conductors with the application of a voltage across the two-dimensional (area) conductors. Under the influence of this field, some electrons in the electroluminescent phosphor are excited. During the return of these electrons to their ground state the excess energy is emitted as optical radiation. See 1.4.1 Atomic Structure and Optical Radiation.

The color of the light emitted by an electroluminescent lamp is dependent on the phosphor, the luminance is dependent on frequency and voltage; the effects vary with phosphor type. The efficacy of electroluminescent devices is low compared to even filament lamps. It is of the order of a few lumens per watt. See 5.5.5 Luminous Efficacy of a Source.

IESH/10e Solid State Lighting Resources

> 7.5 Solid State Lighting
- the technical characteristics of LEDs

> 13.3 Life and Lumen Maintenance
- describes important pratical characteristis of LEDs and their use in architectural lighting

1.4.5.4 Electroluminescence: Light Emitting Diodes

A diode is a semiconductor solid state electronic device with two electrodes, anode and cathode, and usually conducts electricity only in one direction. Conduction takes place across a solid state positive-negative (p-n) junction. Ultra-pure silicon is doped with elements from column III and V of the periodic table of elements to produce two types of silicon. In one, the doping element has electrons that are easily freed from an outer-most orbit of the doping atomic element; this is negative or n-doped silicon. In the other, the doping element has an outer-most orbit that would readily accept one more electron. Locations of this doping element within the silicon are said to have "holes" for accepting electrons. This is positive or p-doped silicon.

If these two materials are placed in contact, electrons close to the junction will move to fill the holes and a narrow neutral gap or depletion zone is established. Without outside energy, no further electron-hole recombination takes place. The energy required for electrons to bridge the gap depends on the structure and material of the junction. If the correct polarity of sufficient low-voltage direct current is applied to the junction, electrons and holes move across the depletion zone, permitting electrons to combine with holes, and the junction becomes electrically conductive.

Under certain conditions and if made of certain materials, a diode will emit optical radiation as it conducts electricity. Light emitting diodes (LEDs) produce optical radiation by electroluminescence when free electrons moving in a semiconductor material in the process described above, become attached to an atom that has an outermost layer or shell that can accept an electron. In the process of falling into such an orbit, the electron releases energy and the material emits optical radiation.

That is, when the forward biased current I_f is applied, electrons are injected into the p-region and holes are injected into the n-region. Photon emission occurs as a result of electron-hole recombination in the p-region. The energy that is released from these recombinations is the energy band gap E_g. It is the energy difference or separation between the conduction energy band of the n-doping material and the valence energy band of the p-doping material.

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Electron energy transitions across the energy gap, called radiative recombinations, produce photons, while shunt energy transitions, called nonradiative recombinations, produce a short-term local vibration in the silicon lattice structure, called phonons. This later type of recombination produces heat. The efficiency with which photons are produced by electron-hole recombinations is the quantum efficiency of the junction. Figure 1.17 schematically represents these two types of outcomes of electron-hole recombinations [19].

The characteristics of E_g determine the quantum efficiency and the radiative wavelengths of the LED device. For example, the radiative energy wavelength, λ, is given by

$$\lambda = \frac{h\,c}{E_g} \tag{1.9}$$

Where:

h = Planck's constant
c = speed of light

The spectrum produced by radiative recombinations in LEDs depends on the doping material, junction temperature, and to some extent the physical structure of the junction. Figure 1.18 shows the spectral distribution of optical radiation for three types of LEDs [20].

The radiant output of LEDs in the visible region of the spectrum can decrease significantly with increasing junction temperature. Figure 1.19 shows this effect for three LEDs with various amounts of indium used in doping [21].

1.4.5.5 Electroluminescence: Organic Light Emitting Diodes

LEDs can also be made from organic semiconductor material. In this case the structure is thin-film and layered, rather than a small block of material, as in silicon LEDs. In one form of OLED, thin-film layers of organic semiconductors are sandwiched between a thin layer of aluminum and a transparent layer of indium oxide; all supported by a transparent substrate of glass or plastic. OLEDs are area sources of optical radiation, rather than the tiny luminous junctions of silicon as in LEDs. The active elements of an OLED can be deposited onto a substrate in patterns, much like printing, and so provide for OLED-driven displays, signage, and active fenestration systems.

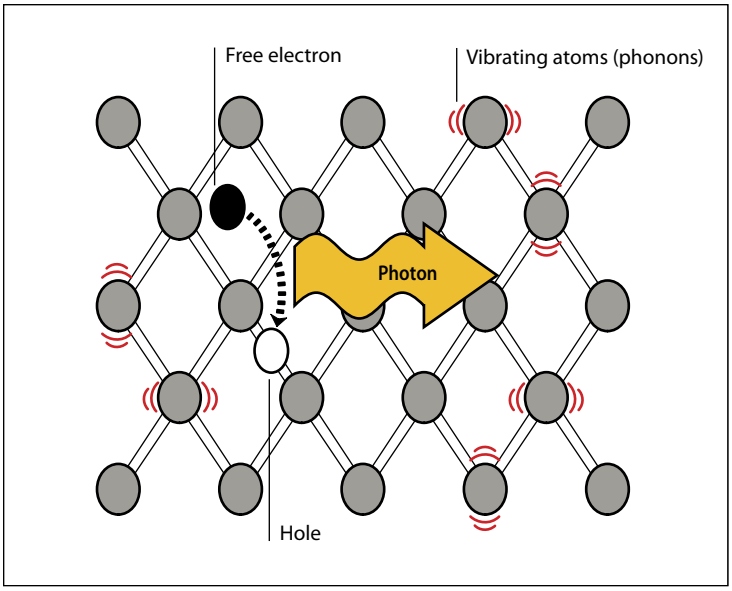


Figure 1.17 | LED Operation
Electron-hole recombinations in an LED, producing photons and phonons. The gray circles represent atoms of silicon, bound in a lattice structure established by mutual bonds involving valence electrons in their outermost orbit. White circle is an impurity (positive doping atom) that lacks one outermost electron and so is called a "hole"; that is, it provides a hole for an electron. The black circle represents an electron from an impurity (negative doping atom) that has a single outermost orbital electron that it can relatively easily give up and thus provide a free, conducting electron.

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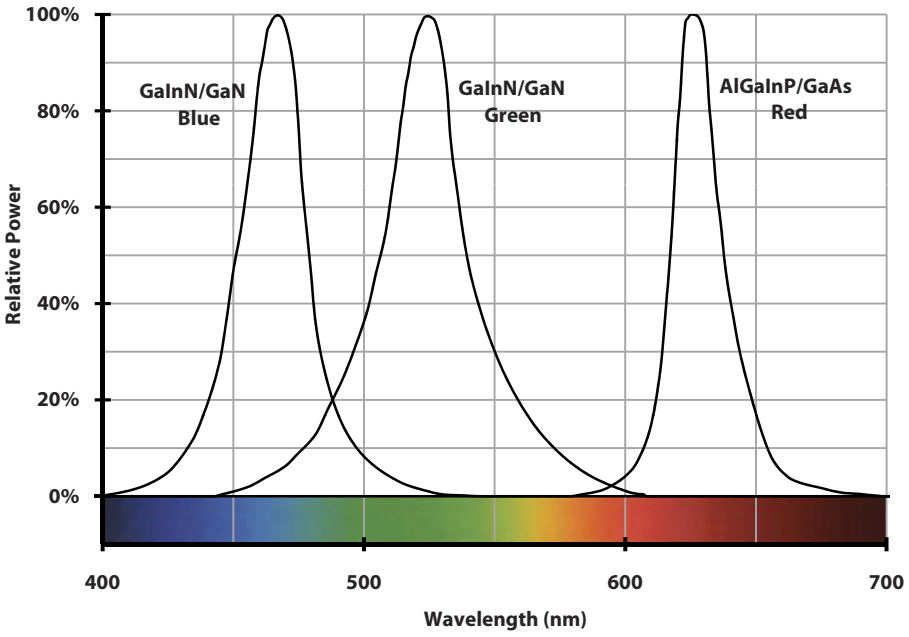


Figure 1.18 | Spectra of LEDs
Optical radiation from three types of LEDs. Two made with gallium indium nitride (GaInN) and gallium nitride (GaN) which produce blue and green light. A third made from aluminum gallium indium phosphide (AlGaInP) and gallium arsenide (GaAs) which produces red light.

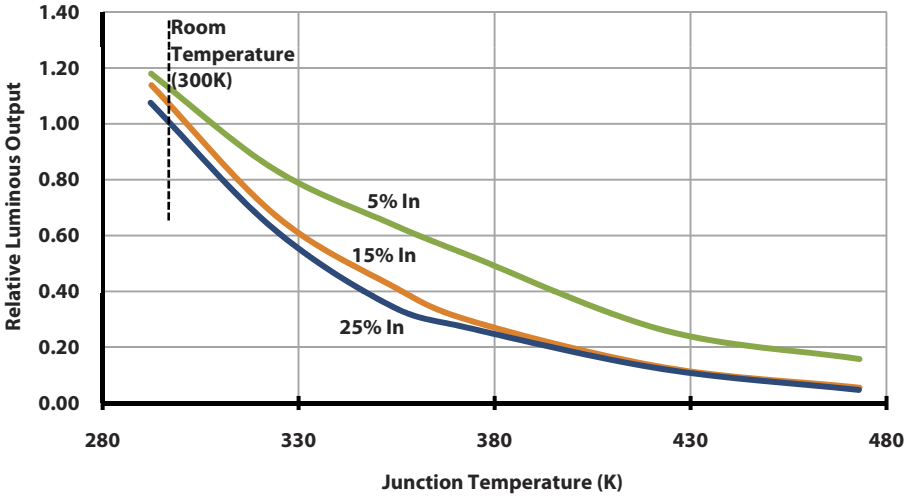


Figure 1.19 | Effect of LED Junction Temperature
Effect of junction temperature on luminous output of LEDs with varying amounts of indium doping. Radiative output is normalized to that at room temperature, 300K.

1.5 Optics for Lighting

Most electric sources generate optical radiation in a spatial distribution that is not well suited for use in architectural lighting. The form of the primary generator, and therefore the manner in which it distributes optical radiation, is usually constrained by the physics that governs light production: thin coiled incandescent filaments, layers of phosphor, or columns of luminous gas. The necessary gathering and redistribution of optical radiation is accomplished using several optical phenomena as the basis for optical control elements.

1.5.1 Important Optical Phenomena

Reflection, transmission, refraction, interference, diffraction, and dispersion are the optical phenomena used to control optical radiation in lighting.

1.5.1.1 Reflection

Reflection is the process by which a part of the optical radiation falling on a material leaves that material from the incident side. The amount of optical radiation leaving the material varies with incident and exitant directions and incident wavelength of optical radiation. The geometry of the exitant radiation (independent of amount) is used to

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describe reflection. Three types are generally described: specular, diffuse, or spread. The dependency on incident wavelength is described as spectral reflectance.

Specular Reflection

If a surface has irregularities that are small compared to the wavelength of the incident optical radiation, and is locally smooth, it is said to be polished and reflects specularly; that is, the angle between the reflected ray and the normal to the surface will equal the angle between the incident ray and the normal, as shown in Figure 1.20. For non-electrical conducting materials that are optically smooth, *Fresnel's equation* describes the amount of optical radiation reflected by a surface. Table 1.2 shows typical ranges of specular reflectance for materials used in luminaires and buildings.

Augustine Fresnel, in 1823, provided the first complete wave theory of light that was capable of predicting most of the then-available experimental results involving reflection, diffracton, and interference. Fresnel's radical idea was that light was characterized by a wave, but oscillations were transverse–that is, perpendicular–to the direction of propagation. Using Fresnel's formulation it was possible for the first time to predict the reflective power of a polished surface of glass. Specular reflection from non-conducting polished surfaces is known as Fresnel Reflection.

Spread Reflection

If a reflecting surface is not smooth (that is, rough, corrugated, etched, or hammered), it spreads parallel rays into a cone of reflected rays. Additionally, some optically smooth surfaces such as polished marble spread reflected light by subsurface scattering. The reflected direction and the degree of spread depend on the geometry of the reflecting surface. Table 1.2 shows typical ranges of spread reflectance for materials used in luminaires and buildings.

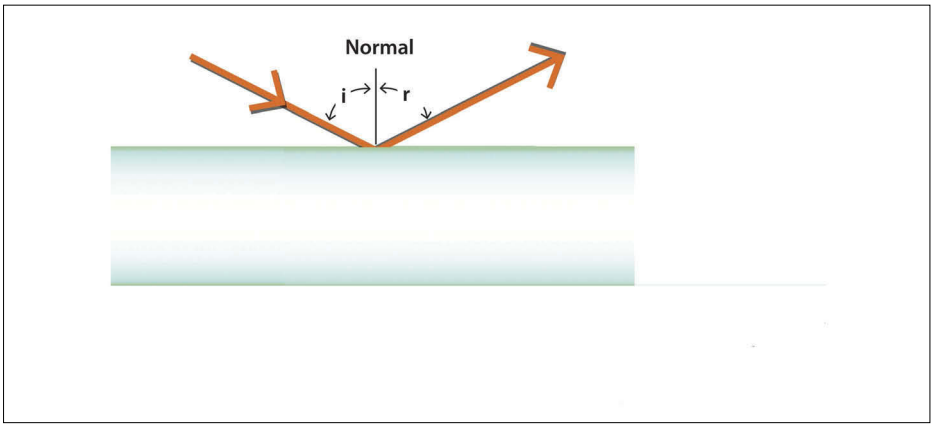


Figure 1.20 | Specular Reflection
Specular reflection from a non-conducting surface. Long described by Snell's Law for Reflection, specular reflection is defined by incident and exitant angles that are equal when measured from the surface normal. Additionally, that normal, and both the incident and exitant directions are in the same plane.

Table 1.2 | Reflectances for Some Common Materials

Reflectance Type	Material	Reflectance
Specular	Mirrored and optical coated glass	0.80-0.99
	Metalized and optical coated plastic	0.75-0.97
	Processed anodized and coated aluminum	0.75-0.95
	Chromium	0.60-0.70
	Stainless steel	0.60-0.65
	Black structural glass	0.05
Spread	Processed aluminum	0.70-0.80
	Etched aluminum	0.70-0.85
	Satin chromium	0.50-0.55
	Porcelain enamel	0.65-0.90
	White structural glass	0.75-0.80
	Brushed aluminum	0.55-0.60
	Aluminum paint	0.60-0.70
Diffuse	Diffuse white plaster	0.90-0.93
	White paint	0.75-0.90
	White terra-cotta	0.65-0.80
	Limestone	0.35-0.65

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Diffuse Reflection

If a surface has irregularities that are large, not locally smooth, or is composed of minute pigment particles, it is said to be a rough surface and the reflection is diffuse. Each ray falling on an infinitesimal particle obeys the law of reflection, but as the surfaces of the particle are in different planes, they reflect the optical radiation at many angles. An idealization of this is Perfectly Diffuse Reflection, which produces a density of reflected radiation that varies with the cosine of the exitant angle, regardless of the incident angle. This idealization is often used in lighting calculations as it can radically simplify the computational work, yet provide a good representation of actual diffusely reflecting surfaces.

Total Internal Reflection

Total internal reflection of optical radiation at the interface of two transmitting media occurs when the angle of incidence, θ_1, exceeds a certain value whose sine equals/, the ratio of indices of refraction of the two media. If the index of refraction of the first medium (n_1) is greater than that of the second medium (n_2), sin θ_1 will become unity when sin θ_2 is equal to n_2/n_1. At angles of incidence greater than this critical angle, the incident rays are reflected totally. In most glass total reflection occurs whenever sin θ_1 is greater than 0.66, that is, for all angles of incidence greater than 41.8° (glass to air).

Spectral Reflectance

Spectral reflectance defines the reflectance for optical radiation of a material at a series of narrow wavelength bands. Figure 1.21 shows examples of spectral reflectance data.

1.5.1.2 Transmission

Transmission is the process by which a part of the optical radiation falling on a material passes through it and emerges from it. Transmission is affected by surface reflections and absorption within the material. The geometry of the exitant radiation is used to describe transmission as: image preserving, diffuse, and spread. The dependency on incident wavelength is described as spectral transmittance. The absorption of optical radiation within a material can be described by the Beer-Lambert Law of Absorption. Transmission through practical materials involves reflections at the exterior and interior of its interfaces as well as absorption within the material itself. This is shown in Figure 1.22. Summing the infinite number of transmission paths gives the total transmission:

$$\tau(1-\rho)^2(1+\rho^2\tau^2+\rho^4\tau^4+\rho^6\tau^6+\rho^8\tau^8+\cdots)=\frac{\tau(1-\rho)^2}{(1-\rho^2\tau^2)} \tag{1.10}$$

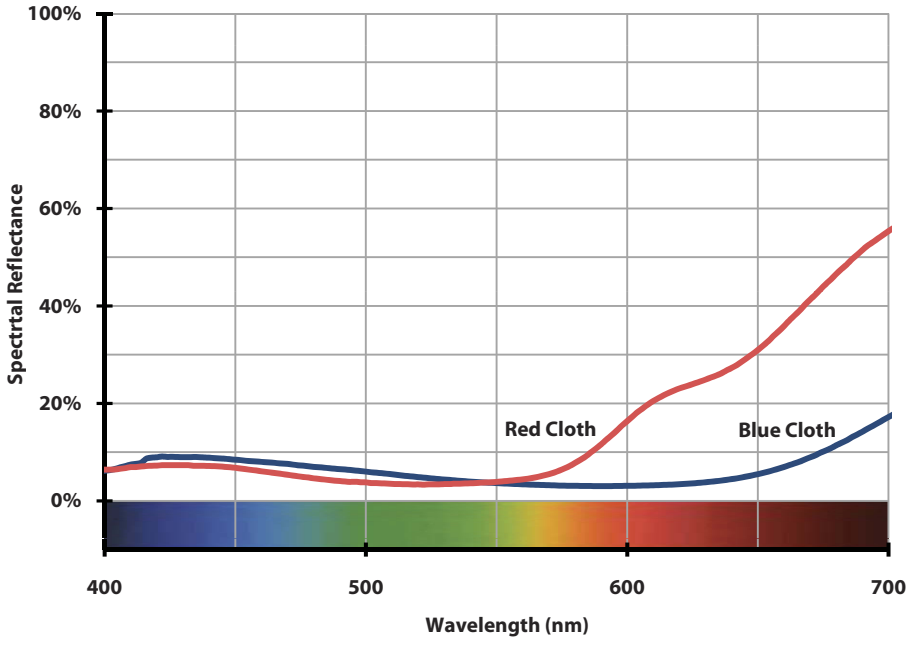


Figure 1.21 | Spectral Reflectance
Spectral reflectance of red and blue cloth.

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Image Preserving Transmission

If transmissive material does little or no scattering and if the incident and exitant planes of the material are parallel, then rays are offset, but have the same direction. In this case the material is said to be "transparent". That is, an image of an object viewed through such a material is essentially undisturbed. Figure 1.23 shows this type of transmission.

Spread Transmission

Spread transmission materials combine varying surface geometry and varying absorption to scatter and refract incident radiation into a relatively wide exitant cone. This is usually produced by surface roughness. Table 1.3 shows typical ranges of transmittance for materials used in luminaires and buildings.

Diffuse Transmission

Diffusing materials scatter optical radiation more or less in all forward directions. Perfectly diffuse transmission is an idealization in which the transmitted radiation has a density that varies with the cosine of the exitant angle, regardless of the incident angle. This idealized material is often used in lighting calculations as it can radically simplify the computational work yet provide a good representation of diffusely transmitting surfaces.

Spectral Transmittance

Spectral transmittance defines the transmittance for optical radiation of a material at a series of narrow wavelength bands. Figure 1.23 shows examples of spectral transmittance data for three types of fenestration glass [22].

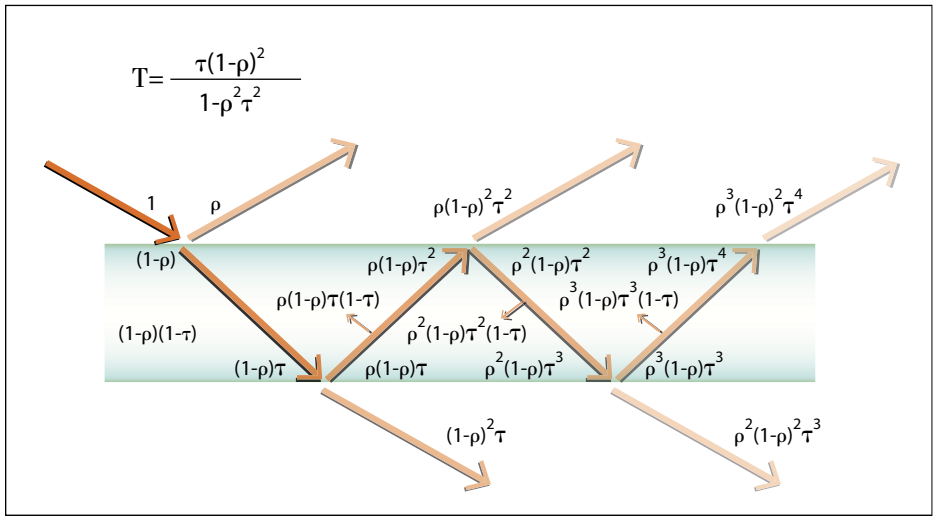


Figure 1.22 | Components of Transmittance
Transmittance through a slab of material involving absorption and reflection. T is the total transmittance, ρ is the reflectance at an interface, τ is the transmittance within the material along the path of travel. Total transmittance involves multiple paths through the material.

Table 1.3 | Transmittances for Some Common Materials

Material	Form or Treatment	Transmittance
Glass	Clear and optical coated	0.80-0.99
	Configured, etched, ground, or sandblasted	0.75-0.85
	Opalescent and alabaster	0.55-0.80
	Flashed opal	0.30-0.5
	Solid opal	0.15-0.40
Plastic	Clear prismatic lens	0.70-0.95
	White structural glass	0.30-0.70
	Colored	0.05-0.30
	Marble	0.05-0.30
	Alabaster	0.20-0.50

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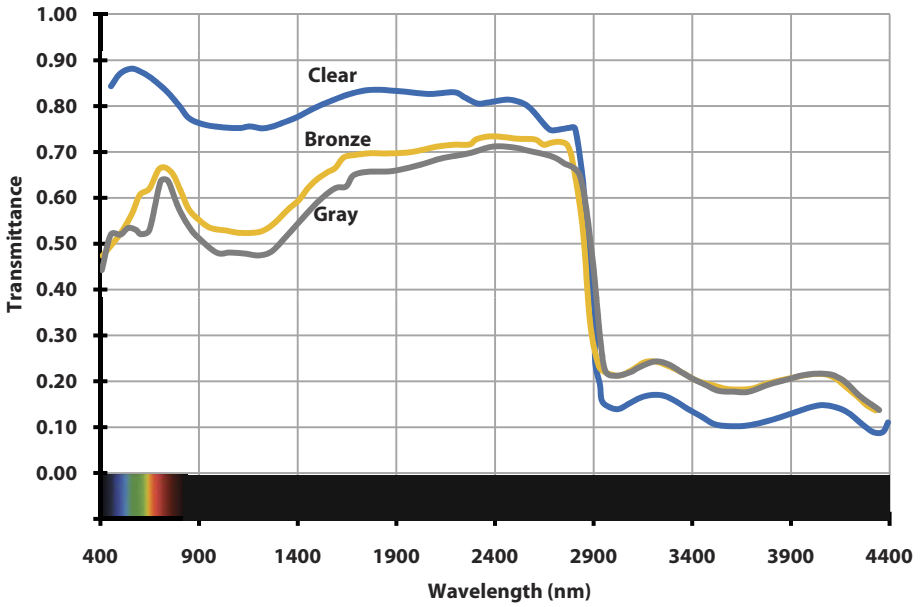


Figure 1.23 | Spectral Transmittance
Spectral transmittance from the visible to the far infrared of three types of glass used in building fenestration systems.

Willebrord Snell, early in the 17th century, found the simple relationship bewtween the sines of the incident and refracted angles, and the refracting material's index of refraction. Snell never published his results but **René Descartes** found the same relationship (or saw Snell's manuscript and plagerized it) and published it in 1637 in his famous work on optics. One measure of the success of the wavetheory proposed by Augustine Fresnel was its ability to predict the amount of refraction.

1.5.1.3 Refraction

A change in the velocity of optical radiation occurs when it leaves one material and enters another of different optical density. The speed will be reduced if the medium entered is denser, and increased if less. Except at normal incidence, the change in speed always is accompanied by a bending of the optical radiation from its original path at the point of entrance. This is known as refraction. The degree of bending depends on the relative densities of the two substances, on the wavelength of the optical radiation, and on the angle of incidence, being greater for large differences in density than for small. The optical radiation is bent toward the normal to the surface when it enters a denser medium, and away from the normal when it enters a less dense material. The change in direction is governed by *Snell's Law*:

$$\sin(\theta_1)n_1 = \sin(\theta_2)n_2 \qquad (1.11)$$

Where:

n_1 = index of refraction of first medium
n_2 = index of refraction of second medium
θ_1 = incident angle rays make with the plane separating the media
θ_2 = refracted angle rays make with the plane separating the media

Figure 1.24 shows refraction at the two air-glass interfaces. Materials exhibit an index of refraction that changes with wavelength, so the refracted angle depends on wavelength.

1.5.1.4 Interference

When two optical radiation waves of the same wavelength come together at different phases of their vibration, they can combine to make a single wave. If the phases are opposite the waves subtract and the resulting amplitude is the difference of the two amplitudes, possibly zero. If the phases are the same the waves add and the resulting amplitude is the sum of the two amplitudes. Figure 1.25 shows the resulting interference when optical radiation refracts and reflects from thin films. Part of the incident optical radiation ab is first reflected as bc. Part is refracted as bd, which again reflects as de, and finally emerges as ef. If waves bc and ef have wavefronts of appreciable width, they will overlap and interfere.

1.5.1.5 Diffraction

Due to its wave nature, optical radiation will be redirected as it passes by an opaque edge or through a small slit. The wavefront broadens as it passes by an obstruction, producing

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an indistinct, rather than sharp, shadow of the edge. The intensity and spatial extent of the shadow depends on the geometric characteristics of the edge, the physical extent (size and shape) of the source, and the spectral properties of the optical radiation. Optical radiation passing through a small slit will produce alternating light and dark bars as the wavefronts created by the two edges of the slit interfere with one another.

1.5.1.6 Dispersion

Since the velocity of light is a function of the indices of refraction of the media involved and also of wavelength, the exit path from a refracting element will be different for each wavelength of incident optical radiation and for each angle of incidence, as shown in Figure 1.26 for a glass prism. This orderly separation of incident optical radiation into its spectrum of component wave lengths is called dispersion.

Separation of optical radiation into its component wavelengths can also be produced by the fine, orderly rippled or ribbed structure on metal surfaces during manufacturing. The consequent appearance of colors by reflection is called iridescence.

1.5.2 Optical Elements in Lighting

Using several kinds of material, including metals, plastics, and glass, optical elements are formed and positioned around a light source to provide the necessary optical control. Reflectors, lenses, prisms, diffusers, and thin-films are forms of optical elements commonly used.

Francesco Grimaldi, SJ found and identified diffraction during optical experiments he was conducting with very small pencils of light. Grimaldi coined the term "diffraction". His results appeared in his posthumously published book in 1665. It was through Grimaladi that Newton learned of diffraction. In 1803 **Thomas Young** give his famous demonstration of interference and diffraction. By then it was clear that, like refraction, the amount of diffraction depended on wavelength. And screen of very finely-spaced hairs wound on small, accuratley made brass screws was first used by the American **David Rittenhouse** in 1785 to disperse white light into its component parts. In 1813 the German optician **Joseph Fraunhoffer** first made diffraction gratings with a ruling engine. Diffraction gratings became, and are still, the principal component of equipment to spectrally analyze optical radiation.

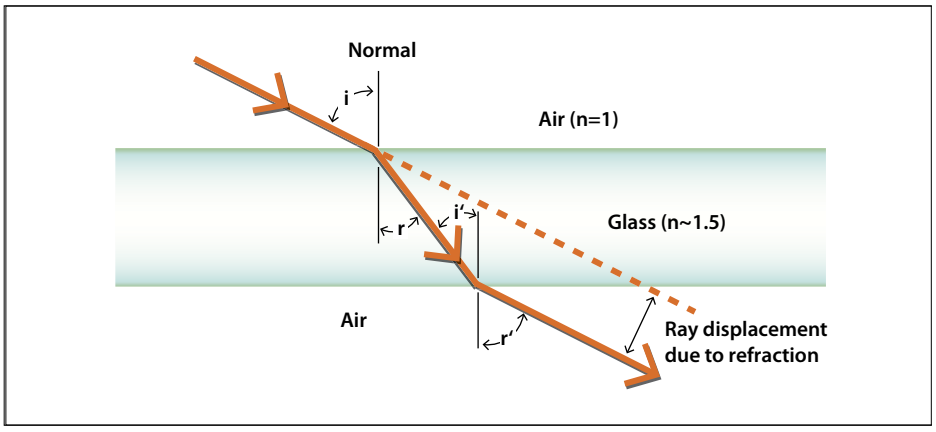


Figure 1.24| Image Preserving Transmittance
Image preserving transmission through a sheet of glass. Though a pencil of rays is offset by an amount that depends on the material thickness, the transmitted pencil emerges in the same direction as the incident pencil of rays.

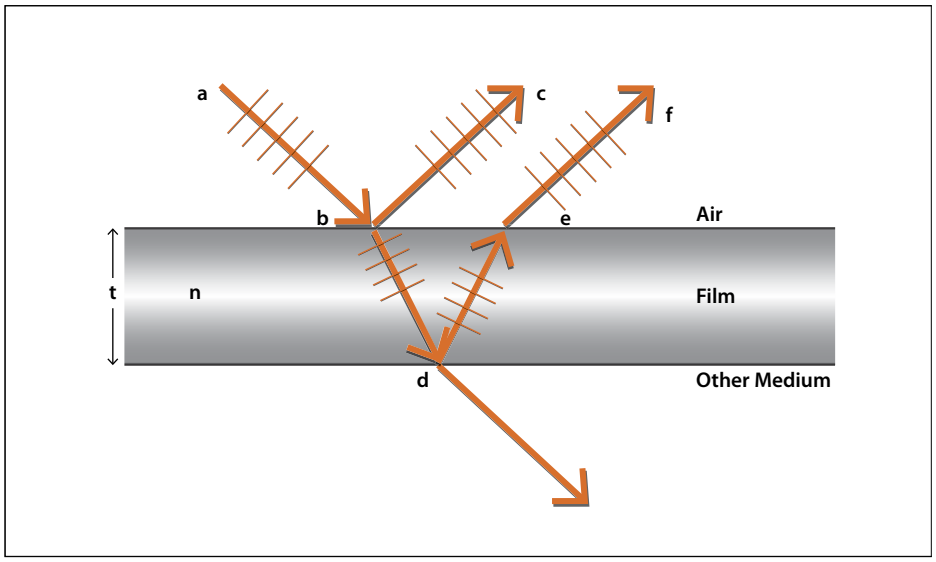


Figure 1.25 | Interference
Interference produced by one of a successive layer of thin films. If the thickness of the film is correct, optical radition that emerges from the top surface (reflects or emerges by multiple internal paths) will constructively or destructively interfere, enhancing or reducing the amount of emerging radiation. This interference depends on wavelength and so depends on the path traveled in the material. Thus, there is an interaction between wavelength and the reflected angle, and radiation of particular wavelengths are reflected more strongly at certain angles. This is why colored bands can appear on materials coated with this films, as with some reflectors used in luminaires. This is called iridescence.

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1.5.2.1 Reflectors

Smooth polished metal and aluminized or silvered smooth glass or plastic surfaces are used in luminaires to control the amount and direction of luminous output. Metal can be spun or formed into desired shapes, with the required surface finish being preserved during these processes or altered by post-processing.

Spread reflectors are slightly textured or hammered surfaces that reflect individual beams at slightly different angles, but all in the same general direction. These are used to smooth beam irregularities and where moderate control or minimum beam spread is desired. Reflector lamps use first-surface reflection when the bulb interior is coated with a thin metal reflecting mirror surface.

Total internal reflectors are used in light piping, edge lighting, and light transmission through rods, tubes, and plates.

1.5.2.2 Lenses

Optical lenses are very often circular, axially symmetric, and have surfaces that are sections of spheres or near-spheres and are made of a material that has an optical density greater than air. The change in optical density at their curved surface produces refraction that can focus optical radiation from a wide field to a point if the surfaces are convex, or spread the radiation if the surfaces are concave. A typical way to characterize a simple convex lens is to determine the distance at which it brings light to a focus if the light originates from a very great distance; that is, the incident light is collimated. For a thin lens, the distance between the center of the lens and this point is the focal length, f′. The focusing power of a lens is defined as the reciprocal of this distance expressed in meters. This unit of focusing power is the diopter, D, defined by

$$D = \frac{1}{f'} \tag{1.12}$$

Where:

f′ = focal length in meters

Concave lenses are assigned negative focusing power, since the divergent radiation appears to be coming from a point behind the lens.

A single, simple lens cannot produce a perfect image with heterochromatic radiation. Refraction depends on wavelength and this means that a single, simple lens has a different f' for

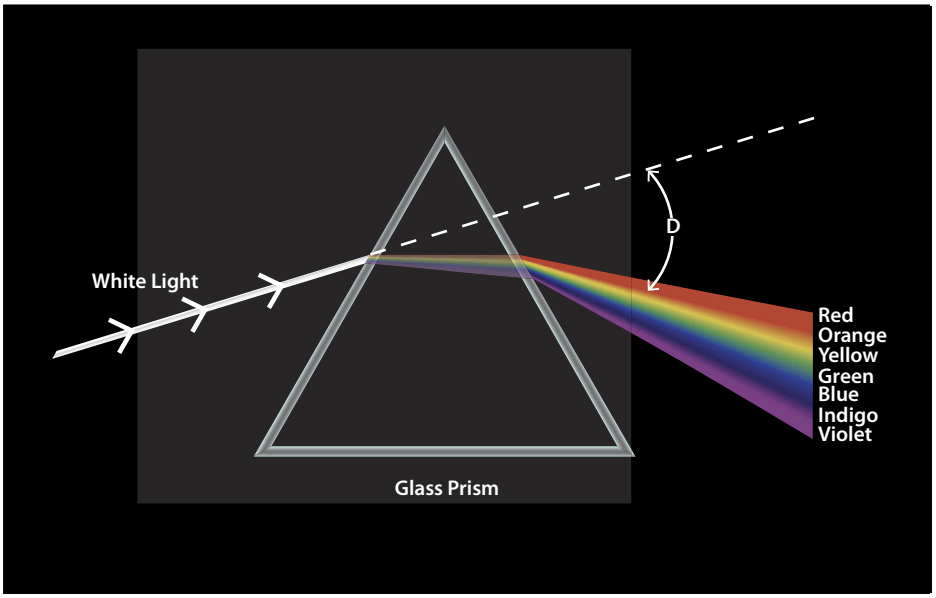


Figure 1.26 | Dispersion
Dispersion of optical radiation through a prism. This action is nonlinear, since the refractive index of glasses does not change linearly with wavelength. It can, though, be accurately measured, and so accurate spectral analysis can be done with prisms.

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different wavelengths. An image composed of such radiation is blurred. This is chromatic aberration.

The focusing power of a lens determines the maximum angle through which incident light is bent, so if incident rays are not collimated but divergent, the bending they undergo cannot be sufficient to have them converge at f′; instead they converge at a point further behind the lens. Thus, as an object moves closer to a lens, its image moves farther away. If d_1 is the distance of the object in front of the lens, and d_2 the distance of the resulting focus behind the lens, then for lenses that are not very thick and surrounded by air with an index of refraction of 1, the relationship between these distances has this equation:

$$D = \frac{1}{f'} \equiv \frac{1}{d_2} + \frac{1}{d_1} \tag{1.13}$$

A similar equation expresses the total focusing power of two lenses that are not very thick or far apart:

$$D = \frac{1}{f'} \equiv \frac{1}{f'_1} + \frac{1}{f'_2} \tag{1.14}$$

Where f'_1 and f'_2 are the focusing powers of the first and second lens. This is true whether f′ is positive or negative. From this it is clear that we can add and subtract focusing powers expressed in diopters:

$$D_t = D_1 + D_2 \tag{1.15}$$

Lenses are used to form convergent beams and real inverted images, or divergent beams and virtual, inverted images as in Figure 1.27.

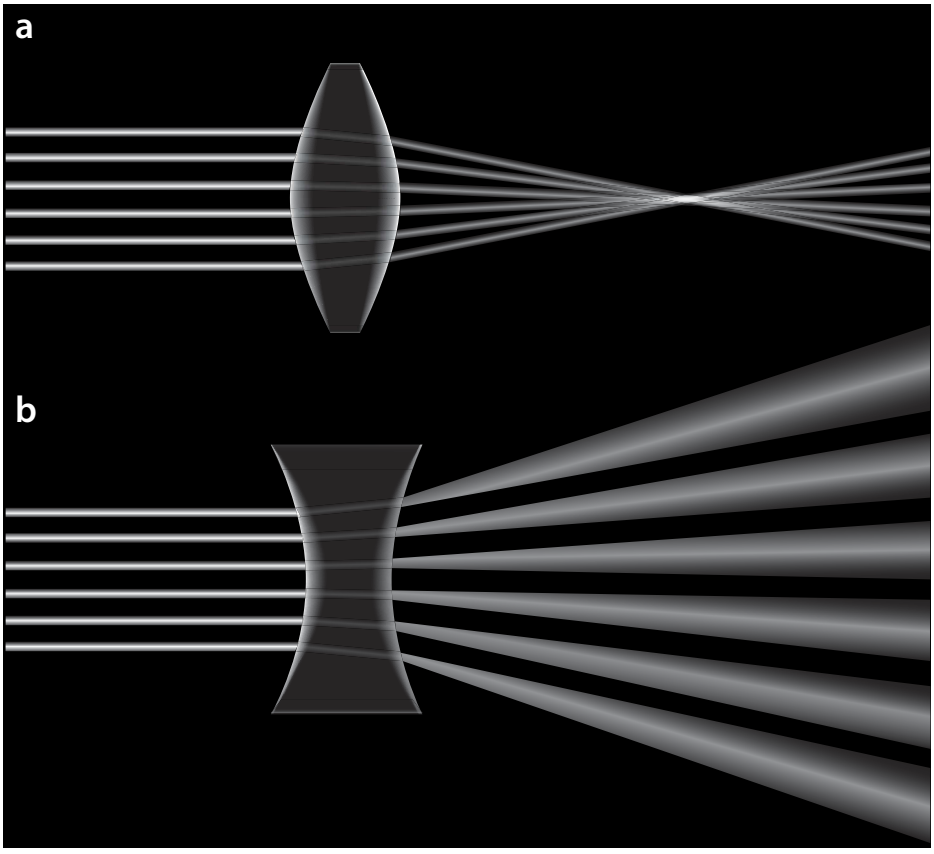
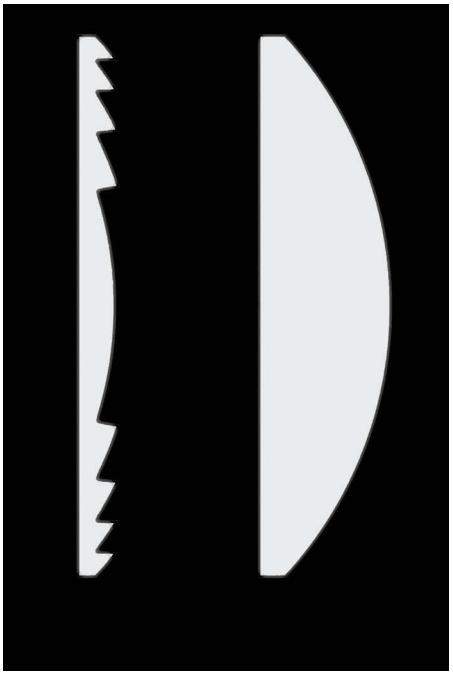


Figure 1.27 | Lenses
Convergent (convex) and divergent (concave) lenses. Refractive light control optics makes use of these lenses, or sections of these lenses, to produce most control effects where refraction is used in luminaires.

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Figure 1.28 | Fresnel Lens
The Fresnel lens (left) has it optically active, curved surface formed from annular sections of the full lens (right). The annular sections of the Fresnel lens are separated by cylindrial steps.



The weight and cost of glass in large lenses used in illumination equipment can be reduced by making cylindrical steps in the flat surface. The hollow, stepped back surface reduces the total quantity of glass used in the lens. In a method developed by Fresnel the curved face of the stepped lens becomes curved rings and the back is flat. Both the stepped and Fresnel lenses reduce the lens thickness, and the optical action is approximately the same. Although outside prisms are slightly more efficient, they are likely to collect more dust and therefore prismatic faces are often formed on the inside. Figure 1.28 shows the cross section of a circular fresnel lens.

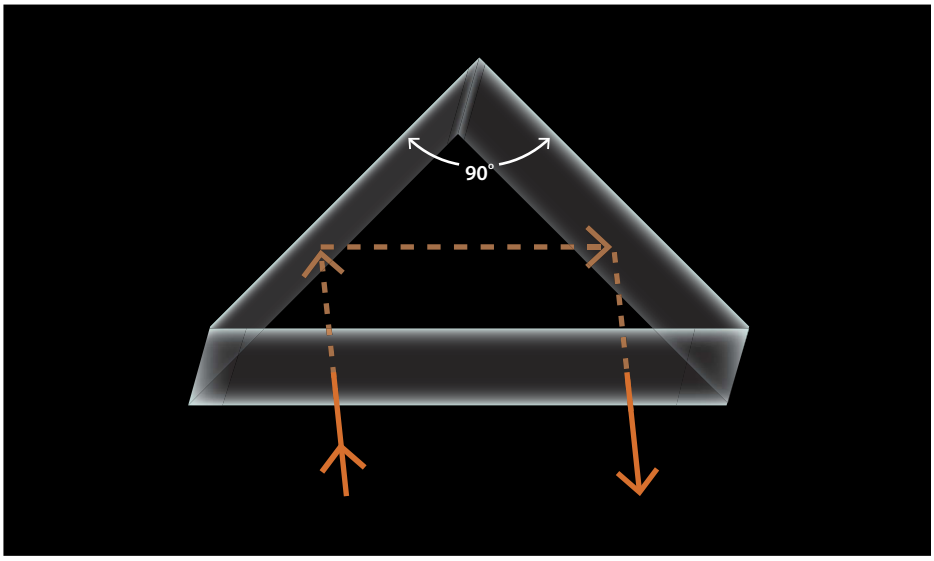
1.5.2.3 Prisms

Prisms are wedges of transparent material in which the degree of bending of optical radiation at each surface is a function of the refractive indices of the media and the prism angle, the angle between the incident and exitant prism faces. Optical radiation can be directed accurately within certain angles by having the proper angle between the prism faces. Refracting prisms are used in such devices as spot and flood lamp lenses and refracting luminaires. In the design of refracting equipment, the same general considerations of proper flux distribution hold true as for the design of reflectors. Following Snell's law of refraction, the prism angles can be computed to provide the proper deviation of the rays from the source. For most commercially available transparent materials like glass and plastic, the index of refraction lies between 1.4 and 1.6.

Often, by proper placement of the prisms, it is possible to limit the prismatic structure to one surface of the refractor, leaving the other surface smooth for easier maintenance. The number and the sizes of prisms are governed by several considerations. Among them are ease of manufacture and convenient maintenance of lighting equipment in service. Use of a large number of small prisms may magnify the effect of rounding of prisms that occurs in manufacture; on the other hand, small prisms produce greater accuracy of light control.

Ribbed and prismed surfaces can be designed to spread rays in one plane or scatter them in all directions. Such surfaces are used in lenses, luminous elements, glass blocks, windows, and skylights. Reflecting prisms reflect optical radiation internally, as shown in Figure 1.29, and are used in luminaires and retrodirective markers. Their performance quality depends on the flatness of the reflecting surfaces, accuracy of prism angles, elimination of dirt in optical contact with the surface, and elimination (in manufacturing) of prismatic error. Some luminaires use arrays of identical prisms on a flat sheet, called lenticular prisms, for light control and to reduce or hide high lamp luminance.

Figure 1.29 | Total Internal Reflection
Total internal reflection in a prism used to produce retroreflection.



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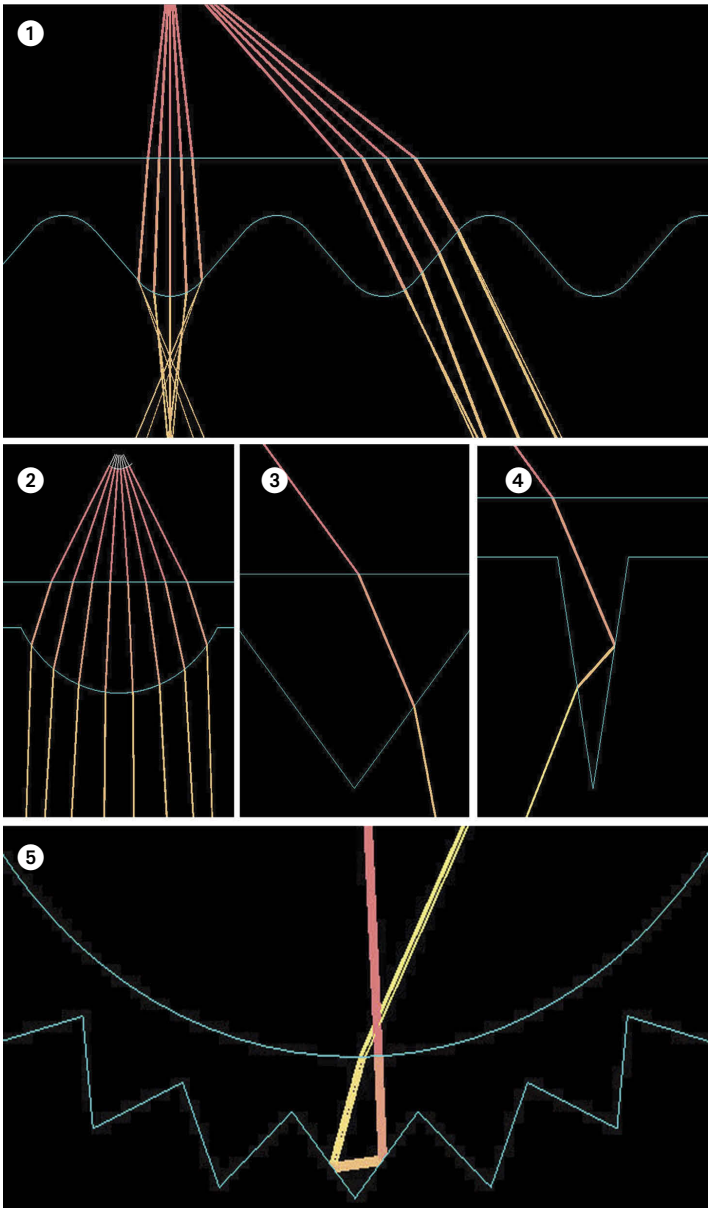


Figure 1.30 | Prisms in Light Control

1. Linear prisms running perpendicular to the plane of the figure are designed to limit the high-angle flux emerging from the primatic material.
2. One of a series of domed prisms forming a lenticular array, set over a field of LEDs to narrow their collective distribution.
3. A field of pyramidal prisms in a lenticular lens in a fluorescent luminaire, designed to limit high-angle flux.
4. A narrow, linear prism used to reflect and control.
5. Linear prisms on the outside of the optical element using total internal reflection to generate a prismatic reflecting surface.

» Images ©LTI Optics

1.5.2.4 Diffusers

Using Reflection

Diffuse reflectors are produced by flat paints and other matte finishes and materials that reflect into most directions and exhibit little directional control. These are used where wide distribution of optical radiation is desired.

Using Transmission

Spread transmission materials offer a wide range of optical control. They are used for brightness control, as in frosted lamp bulbs, in luminous elements where accents of brilliance and sparkle are desired, and in moderately uniform brightness luminaire-enclosing globes.

Using Holography

The kinoform diffuser was invented in 1971 and is a phase-only, surface-relief hologram of a conventional diffuser [23]. Though highly efficient, it suffered chromatic dispersion and transmitted a considerable portion of the zero-order beam, making the light source visible through it. Recent developments [24] have produced a class of kinoform diffusers with

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Figure 1.31 | Spun Aluminum Reflector
A spun, metallic reflector. The general shape is determined by assuming a relatively small source of light, such as the filament of a filament lamp, that radiates in a nearly uniform manner and that the desired distribution is a narrow beam. This gives a shape close to a paraboloid of revolution. The interior surface is finished with small, concentric ridges that spread the reflected flux through a small angle. This smooths the beam pattern and helps eliminate striations and other unwanted patterns in the beam.
» Image ©B&H Photo, Inc.



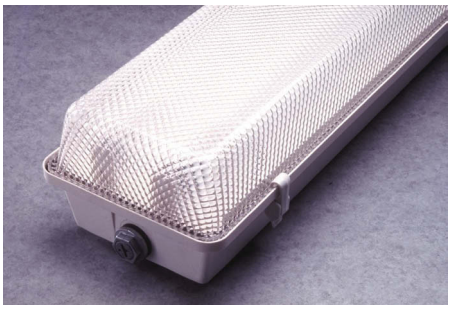
Figure 1.32 | Extruded Aluminum Specular Reflector
Design for a linear, axially symmetric source, such as a linear fluorescent lamp, this extruded specular reflector combines a section of a parabola to produce a nearly collimated beam in the plane perpendicular to the lamp axis. It also contains a section of an ellipse that has one of its foci at the lamp and the other out in the distribution.
» Image ©Elliptipar, Inc.



Figure 1.33 | Total Internal Reflection
This high bay luminaire optic controls the flux from an HID arc tube by total internal reflection. Linear prisims run vertically on the exterior of the acrylic reflector and have angles such that much of the incident flux is totally internally reflected. Some light passes through for some incident angles and due to the inevitable rounding of prism peaks and valleys.
» Image ©Acuity Brands, Inc.



Figure 1.34 | Lenticular Prismatic Refractor
Lamp hiding and distribution control are produced by an array of rectangular, negative prisms on the interior of this lenticular prismatic refractor.
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desirable beam distributions that permit customized light shaping. The diffusers transmit up to 95%, have no chromatic dispersion, and completely eliminate the zero-order beam. Their distributions can be controllably varied from Gaussian through uniform to a batwing shape, and also can be shifted off-axis

1.5.2.5 Thin Films

Optical interference coatings have been used for many years in cameras, projectors, and other optical instruments and can reduce reflection from transmitting surfaces, separate heat from optical radiation, transmit or reflect optical radiation according to color, increase reflections from reflectors, or perform other optical radiation control functions. Naturally occurring examples of interference are soap bubbles and oil slicks. Also, many birds, insects, and fish get their iridescent colors from interference films. The application of interference coatings can significantly increase the reflectance of reflectors and the transmittance of luminaire glass or plastic enclosures.

1.5.3 Examples of Light Control

Reflection

Figure 1.31 shows how a specular reflector, spun from coated aluminum, redirects the radiation from a tungsten halogen lamp to produce a narrow distribution downlight luminaire. Figure 1.32 shows how an extruded specular reflector redirects the radiation from a fluorescent lamp to produce a very asymmetric, narrow distribution wallwash luminaire. Figure 1.33 shows how total internal reflection inside a ribbed or linear prism refractor acts as a specular reflector by using total internal reflection to redirect the radiation from a metal halide lamp to produce a very wide distribution for a highbay industrial luminaire.

Transmission and Refraction

Figure 1.34 shows how a lenticular prismatic refractor acts as a diffuser in a fluorescent troffer luminaire. Total internal reflection is also used to constrain optical radiation to travel down a fiber optic element.

1.6 References

[1] Huygens C. 1690. Traité de la Lumière. Leiden.

[2] Huygens C. 1962. Thompson SP, translator.Treatise on light. New York. Dover

[3] Newton. 1717. Opticks. 2nd edition. London.

[4] Euler. 1746. Nova theoria lucis et colorum.

[5] Hakfoort C. 1995. Optics in the age of Euler. Cambridge.

[5] Young T. 1845. A course of lectures on natural philosophy and the mechanical arts. London. Taylor and Walton.

[6] Fresnel AJ. 1819. Mémoire sur la diffraction de la lumière. Annales de Chimie et de Physique. 10:288.

[7] Maxwell, CJ. 1954. A treatise on electricity and magnetism.3rd ed. NewYork. Dover Publications.

[8] Einstein A. 1905. Über einen die erzeugung und verwandlung des lichtes betreffenden heuristischen Gesichtspunkt. Annalen der Physik 17:132–148.

[9] Arons AB, Peppard MB. Einstein's proposal of the photon concept – a translation of the Annalen de Physik paper of 1905. Am J Physics. 33(5):367-374.

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[10] Born M, Wolf E. 1970. Principles of optics. 4th edition. Pergamon. 808 p.

[11] Shurcliff WA, Ballard SS. 1962. Polarized light. Harvard. 144 p.

[12] Richtmyer FK, Kennard EH, Cooper JN. 1969. Introduction to modern physics. 6th ed. New York: Mc-Graw-Hill.

[13] Elenbaas W. 1972. Light sources. New York. Crane, Russak & Co.

[14] Waymouth JF. 1971. Electric discharge lamps. MIT. 353 p.

[15] Kirchhoff G. 1860. Annalen der Physik. 109:275.

[16] Lummer O, Pringsheim E. 1898. Der electrisch geglühte 'absolut schwarze' körper und seine temperaturmessung. Annalen der Physik 17:106–111.

[17] Hoffman D. 2001. On the experimental context of Planck's foundation of quantum theory. Centaurus. 43(3):240-259.

[18] Ivey HF. 1963. Electroluminescence and related effects. NewYork. Academic Press.

[19] Schubert EF. 2006. Light Emitting Diodes. 2nd edition. Cambridge. 313 p.

[20] Liu M, Rong B, Salemink HWM. 2007. Evaluation of LED application in general lighting. Opt Eng. 46(7):1-7

[21] Huh C, Schaff WJ, Eastman L. 2004. Temperature dependence of performance in InGaN/GaN MQW LEDs with different indium compositions. IEEE Elct Dev Letters. 25(2):61-63.

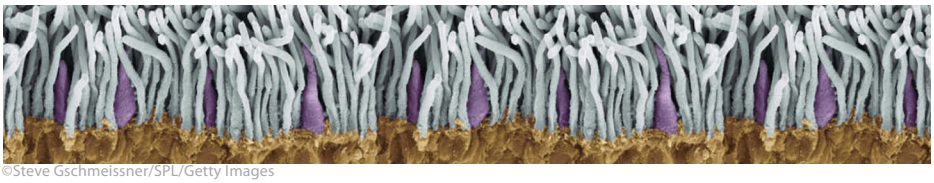
[22] Nicolau VdeP, Maluf FP. 2001. Determination of radiative properties of commercial glass. In: PLEA 2001. 18th Conference on passive and low energy architecture. Brazil.

[23] Caulfield HJ. 1971. Kinoform diffusers. In: Developments in Holography II, SPIE Proceedings Vol. 25.

[24] Santoro S, Crenshaw M, Ashdown I. 2002. Kinoform diffusers. J Illum Eng Soc.

[25] ASTM International. 2003. ASTM G173-03e1 Standard tables for reference solar spectrum irradiances. West Conshohocken, PA: ASTM. 20 p.

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2 | VISION: EYE AND BRAIN

The eye is the window to the world.
Lael Wertenbaker, 20th Century Author

The most complex of the senses, vision is perhaps the most important mechanism we have for apprehending the world. Vision results from the interaction of eye and brain, and from vision come perceptions, and from perceptions we build our individual worlds, always largely affected by the luminous environment. An understanding of this process guides the design of that environment, and to consider the eye and brain as a unity is the best way to understand the biological machinery that provides vision [1].

The eye contains components that work together to produce an image of the external world on a layer of photoreceptive cells in the retina at the back of the eye. This layer encodes information about this image as neutral signals which are conducted to the center of the brain, combined with similar signals from the other eye, processed further, and the result conducted to the area at the back of the brain which is primarily responsible for visual processing. Along the way, signals are generated to move the eyes to track visual targets and to change the shape of the eye's lens to bring the visual target into sharp focus. A combination of mechanical, chemical, and neural mechanisms change the system's sensitivity so that is can operate in light levels ranging from faint moonlight to noon sunlight. Complex neural circuitry is responsible, in part, for motion detection, color vision, and pattern recognition. Figure 2.1 shows the anatomical structure of the eye-brain system.

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2.2 Optics of the Eye 2.7
2.3 Visual System above the Eye . 2.10
2.4 Vision and the State of Adaptation 2.12
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2.6 Consequences for Lighting Design 2.18
2.7 References 2.22

2.1 Ocular Anatomy and Function

This section describes the components of the eye, giving their structure and their various mechanical, optical, and neural operation functions. Figure 2.2 shows the general structure of the eye.

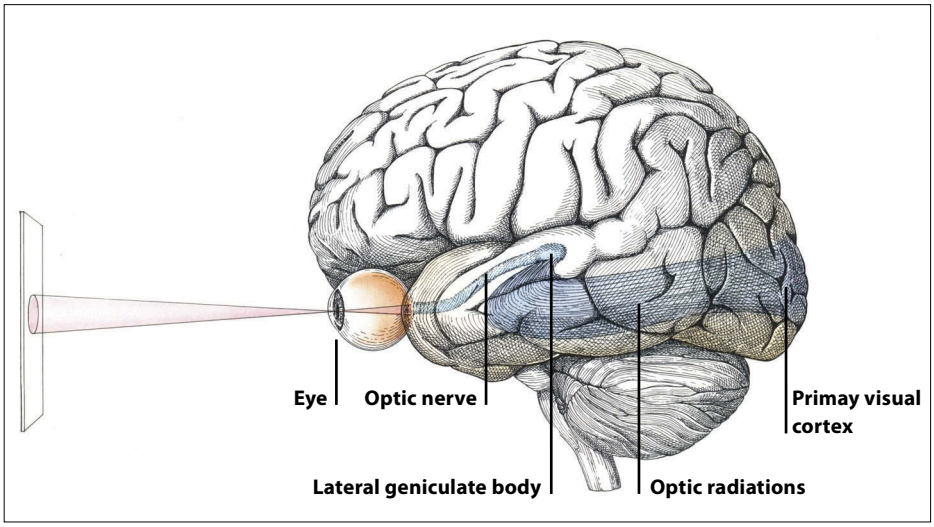


Figure 2.1 | Eye and the Principal Components of the Brain that Comprise the Visual System
The general structure of the visual system is a series of layers that receive, process, and transmit visual information. These layers are connected by neural pathways that convey visual information from one layer to the next. The principal layers are the retina, located in the eye, the lateral geniculate body, located in the brain center, and the primary visual cortex, located at the back of the brain. Though visual information is transmitted by the visual cortex to "higher" parts of the brain, the cortex is usually consider the last stage of the visual system proper.
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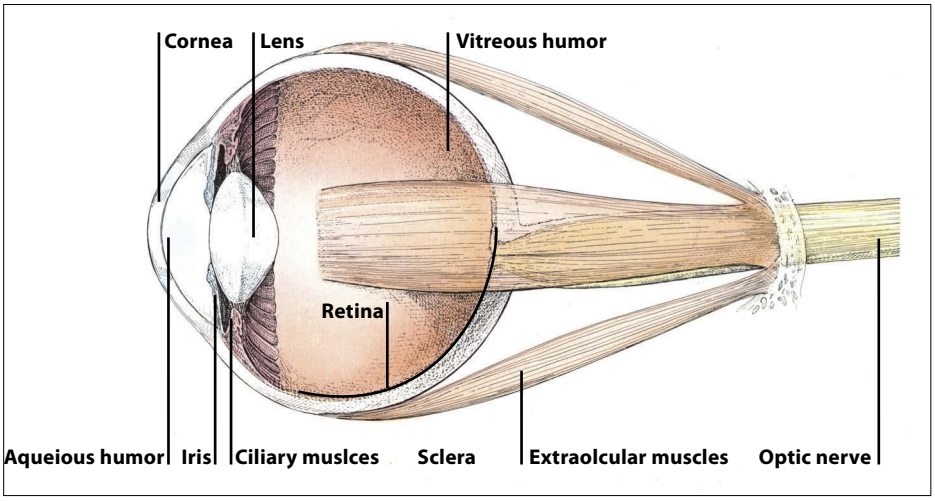


Figure 2.2 | Form and Structure of the Eye
Much of the eye functions purely as an optical machine, with the purpose of maintaining a focued image of the world on the retina at the back of the eye.
» ©David H. Hubel

2.1.1 Structure

The anatomy of the eye describes components that do the following: provide and hold its shape, comprise the optical elements that form an image, control the amount of optical radiation admitted into the eye, encode the image, and provide for movements required to track the image.

2.1.1.1 Tunics

The sclera is the relatively thick, opaque, white tough outer layer of the eye. Filled with blood vessels, the sclera is visible from the front and is what we call the "white of the eye." The choroid is a dark, thin layer just inside the sclera. It covers most of the back portion of the eye and brings blood vessels to the interior of the eye. It's inner most layer of cells, the pigment epithelium, has a very low reflectance and so absorbs light that would otherwise scatter within the eye.

2.1.1.2 Cornea

The cornea is the thin, clear extension of the sclera at the front of the eye. Unlike the sclera, the cornea contains no blood vessels but is richly endowed with pain receptors to help protect the eye. Its mounded form provides a strong curvature that produces more than 2/3 of the eye's focusing power. The lacrimal glands constantly produce tears that blinking washes over the front of the cornea. The cornea requires this constant moisturizing; the liquid also smooths its front surface to make it a better optical interface.

2.1.1.3 Iris and Pupil

The iris and pupil are the annulus of tissue and its round, center opening that control the amount of radiation entering the eye. The iris provides what we call "the color of the eye." The iris expands and contracts, making the pupil smaller and larger, in response to the brightness and size of objects in the eye's field of view. In general, the brighter the field of view, the smaller is the pupil.

2.1.1.4 Lens and Ciliary Muscles

The lens is a multilayered, double convex structure just behind the iris. It is nearly transparent and in the young, very elastic. In its relaxed state, the front surface of the lens bulges out, increasing its curvature and refracting power. In this state it can provide up to 25 diopters of focusing power. The layers of tissue in which the lens is encased separate the front from the back of the eye, and are held in place and tensioned by radial zonule fibers. These pull on the encasing tissue and flatten the lens, and in this flattened state it provides approximately 10 diopters of focusing power. An annulus of muscle, the ciliary, surrounds the lens and opposes the tension of the zonule fibers. Proper focusing is produced when the ciliary muscle contracts or relaxes, which slackens or tensions the lens casing, allowing the lens to bulge or causing it to flatten.

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2.1.1.5 Humors

Aqueous and vitreous humors are the liquids in the front and back chambers of the eye. The aqueous is very clear and watery, the vitreous is jelly-like and somewhat less clear. The aqueous is continuously generated and absorbed and the amount in the front chamber at any one time determines the pressure both fluids exert on the structures of the eye.

2.1.1.6 Retina

The retina marks the end of the optical pathway and the beginning of the visual pathway of the visual system. Because of its structure, function, and complexity, the retina is considered, anatomically, a part of the brain housed in the eye. The retina lines most of the back chamber of the eye and is highly structured in layers that contain three general types of cells: photoreceptors (rods and cones) that absorb optical radiation and produce electrical signals; horizontal, amacrine, and bipolar cells that perform signal processing functions; and ganglion cells that form the optic nerve and conduct these signals to the brain. A few of these ganglion cells are now known to be intrinsically photosensitive themselves, receiving signals from the rod or cone photoreceptors, and are part of the body's neuroendocrine system.

These layers are sandwiched between the choroid and the vitreous humor. Blood vessels to support these cells are adjacent to the innermost layer of the retina. Figure 2.3 is a peripheral cross section of the retina. From the outermost to inner most layer, these cells are: photoreceptors (rods and cones), horizontal cells, amacrine cells, bipolar cells, ganglion cells.

At the spot on the retina corresponding to the center of the visual field of view the retina thins and only cone photoreceptors are present. This area is the fovea and exhibits the densest packing of photoreceptors and so the most acute vision. This area and its immediate surround is covered with the macula lutea which acts as a yellow filter, absorbing short wavelength optical radiation.

2.1.2 Muscles and Eye Movement

The oculomotor components of the eye consist of three pairs of muscles (Figure 2.2). These muscles position the lines of sight of the two eyes so they are both pointed toward the same object of regard. The line of sight of the eye passes through the part of the retina used for discriminating fine detail, the fovea. If the image of a target does not fall on the fovea, the

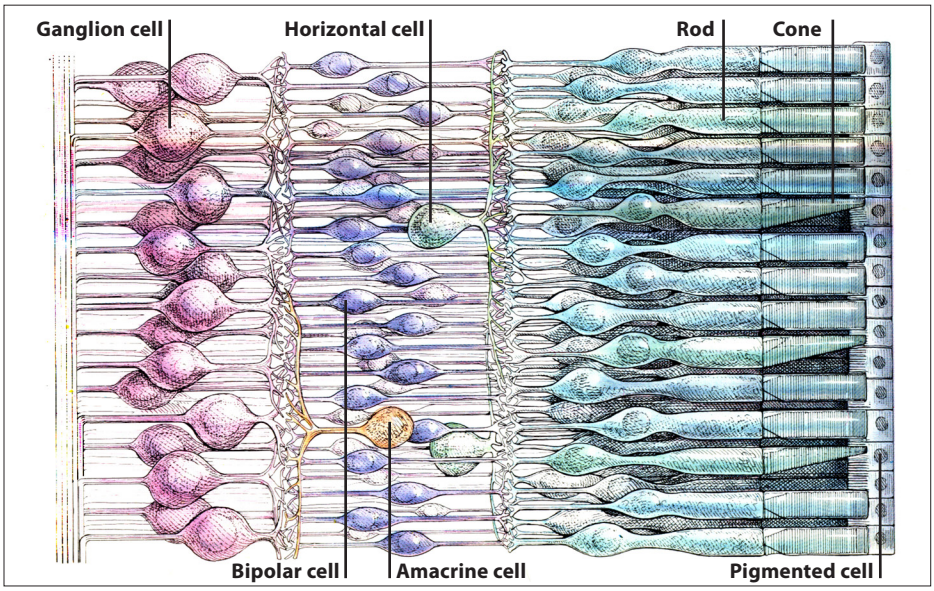


Figure 2.3 | Cross-Section of the Retina
Cross-section of the retina showing principal layers and cells. The back of the eye is at the right. Optical radiation moves from left to right in this diagram. Blood vessels (not shown) would be to the left of the ganglion cells in this diagram; that is in front of all the retinal layers.
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resolution of target detail will be reduced. Additionally, if the foveas of both eyes are not aimed at the same target, the target may be seen as double (diplopia). There are four principle types of eye movements: Saccades, pursuit, vergence, and version movements.

2.1.2.1 Saccades

Saccades are high-velocity monocular eye movements, usually generated to move the line of sight from one target to another. Velocities may range up to 1000 degrees per second, depending upon the distance moved. Saccadic eye movements have a latency of 150 to 200 ms, which limits how frequently the line of sight can be moved in a given time period; approximately five movements per second is the maximum. Visual functions are substantially limited during saccadic movements. Eye movements during reading characterize a series of alternate fixations and saccades, along a row of print.

2.1.2.2 Pursuit or Tracking

Pursuit or tracking is a smooth monocular eye movement used to follow a smoothly moving target after a saccade has been used to bring the retinal image of the target onto the fovea. The pursuit system cannot follow smoothly moving targets at high velocities, nor can it follow slowly but erratically moving targets. If the eye cannot follow the target, resolution of target details decreases because the target's retinal image is no longer on the fovea. To catch up, binocular pursuit and jump movements are made, which are referred to as version movements when they involve objects in a frontal plane. For these movements, the two eyes make equal movements in the same direction, so there is no change in their angle of convergence.

2.1.2.3 Vergence Movements

Vergence is disjunctive binocular movement of the two eyes that keep the primary lines of sight converged on a target or that may be used to switch fixation from a target at one distance to a new target at a different distance. The two eyes rotate in opposite directions. These movements can occur as a jump movement or can smoothly follow a target moving in a fore-and-aft direction. Both types of movement produce a change in the angle between the eyes. When the primary lines of sight drift apart and the eyes fail to converge at the intended fixation point, vergence movements play a major role in eye reconvergence.

2.1.2.4 Version Movements

Version is conjunctive binocular movement of the two eyes that keep the primary lines of sight converged on a target. The two eyes rotate in the same direction.

2.1.3 Photoreceptors, Neural Layers, and Signal Processing

The retina's photoreceptors, the cells they transmit signals to, and their interconnections form a layered signal generating and processing mechanism that initiates vision.

2.1.3.1 Photoreceptors

Considered anatomically, there are two types of photoreceptors, named according to shape: rods and cones. Each eye contains approximately 140 million photoreceptors; 100 million rods and 40 million cones. Photoreceptor cells convert optical radiation to neural signals. They house pancake-like discs that contain molecules of photopigment that absorb optical radiation and isomerize; that is, change shape. This change triggers a process that releases neutral transmitter chemical from the foot of the cell. The more radiation is absorbed, the more transmitter is released.

The photopigment contained in a photoreceptor absorbs optical radiation and causes isomerization of the molecule that, in turn, contributes to the generation of a visual signal. The isomerization fades pink or purple cell color (in the case of the rod photopigment), and thus the process has come to be called bleaching. While a molecule of photopigment is bleached, it cannot absorb radiation. Bleaching is a reversible process and with the passage of time, more quickly for rods than cones, the molecule assumes its former shape and is ready to absorb radiation and participate again in the processes of generating a visual signal.

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As a photoreceptor is flooded with more and more radiation, more and more of its photopigment is bleached, leaving less and less to isomerize. Further increments in incident radiation are able to bleach less and less pigment, and so the increment in the visual signal that can be generated decreases. This is part of the non-linear, compressive response that photoreceptors exhibit.

There are four types of photopigments: one type found in all rod photoreceptors and three types found in cones. The likelihood that these photopigments absorb radiation is a function of wavelength. The signal generated by a photoreceptor depends on the bleaching of its photopigment and that, in turn, depends on the amount of radiation reaching the photoreceptor. The cornea, lens, and humors form the optical path to photoreceptors and have spectrally selective transmittances that absorb some of the short wavelength radiation entering the eye. The spectrally selective absorption by the photopigments of this spectrally modified radiation defines the overall spectral response of photoreceptors. The action spectra of the three types of cones are graphed in Fig. 2.4. The three photopigments found in cones have peak sensitivities at about 575, 525, and 450 nm and are said to be long, middle and short wavelength cones, respectively.

2.1.3.2 Photoreceptor Distribution

The fovea is an area of the retina where the density of photoreceptors is greatest and consequently where the image is assessed most acutely. In this region of the retina, photoreceptors are thinnest thus permitting very tight packing; the layer of cells inward from the photoreceptors is significantly thinned thus permitting more certain absorption of incoming radiation, and blood vessels that elsewhere form a net that intercepts some of the radiation are absent. The absence of blood vessels and the thinning of inward layers produce a circular depression or pit—for which the Latin is fovea—that has the photoreceptors most exposed to incoming radiation.

The blind spot is that place in the retina where all axons from ganglion cells collect and exit the eye, and so it contains no photoreceptors. Between this minimum density and the maximum density at the fovea, photoreceptors are distributed throughout the retina in a non-uniform way shown in Fig. 2.5. The density of rods and cones shown in the figure is along a horizontal section of the retina, from ear-side to nose-side, passing through the blind spot and the fovea.

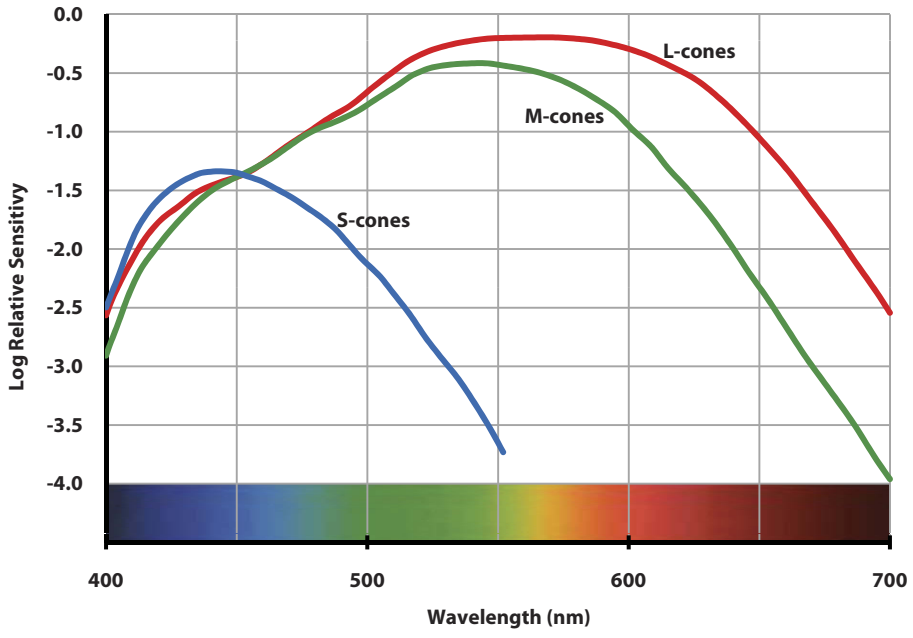
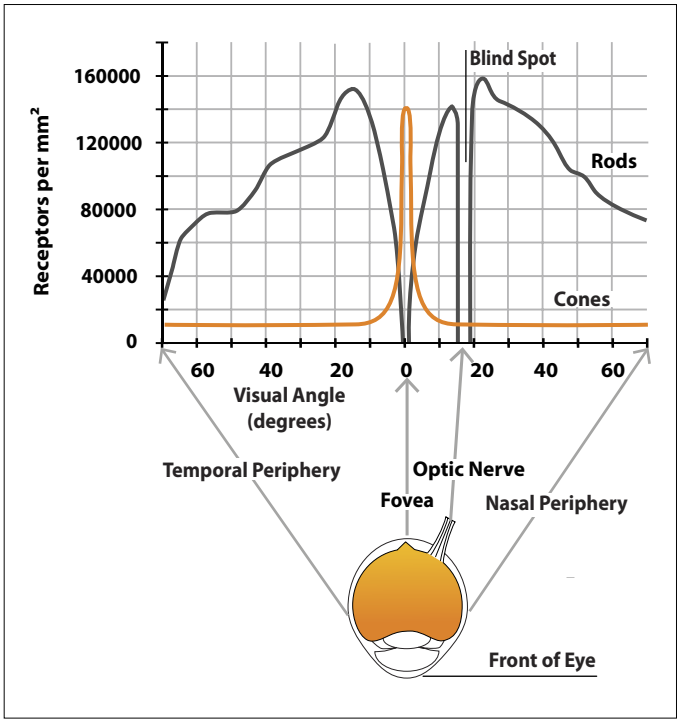


Figure 2.4 | Cone Sensitivities
Probabilities of absorbing optical radiation as a function of wavelength for the photopigments in the three types of cone photoreceptors. This is shown for S = short wavelength, M = medium wavelength, L = long wavelength cone photoreceptors.

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Figure 2.5 | Distribution of Rods and Cones in the Human Retina
This is a plot of photoreceptor density in the retina, across a horizontal line that passes through the blind spot. At the fovea the rod density is zero, while the cone density is maxium. Both distributions are zero at the place on the retina where the optic nerve exits the eye.



2.1.3.3 Horizontal, Amacrine, and Bipolar Cells

Horizontal, amacrine, and bipolar cells have components similar to other nerve cells in the body. These are:

•Cell body. This is usually globular in shape and contains the nucleus, mitochondria, and other organelles that keep the cell alive and functioning.

•Dendrites. Branching and tapering fibers coming off the cell body that receive signals from other cells.

•Axon. The single cylindrical fiber that transmits signals to other cells.

These cells collect and process the neural signals from the photoreceptors. Bipolar cells collect signals from photoreceptors and horizontal cells and transmit signals to the next layer in the retina, the ganglion cells. Horizontal and amacrine cells collect and distribute signals across photoreceptors and bipolar cells as input for ganglion cells.

2.1.3.4 Ganglion Cells and the Optic Nerve

A ganglion cell receives input from a nearby group of bipolar, horizontal and amacrine cells, and conducts away a resulting signal in its axon. The signal is established by retinal wiring that maps highly structured groups of photoreceptors to a ganglion cell. The wiring is such that some photoreceptors in the group will excite ganglion cell output, while other photoreceptors in the same group will inhibit it. In the retina, the grouping is usually circular with excitatory or inhibitory areas showing a circular center, annular surround arrangement. This structure and opponency constitutes a receptive field. See 2.3.4 Receptive Fields. The axons from all the ganglion cells extend to a spot just to the nose-side of the center of the back of the eye, where they form a bundle that surrounds the main artery and vein for the interior of the eye, and exit as the optic nerve. There are about 1.5 million ganglion cells in an eye and so about that many fibers in the optic nerve.

Information from the right and left halves of the visual field is kept separate. The two optic nerves join at the optic chiasm, a spot about one-third of the way back into the brain. From here, a small number of fibers go to parts of the brain that control eye movement and pupil size.

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Most fibers continue on, carrying information from the right half of the visual field of each eye (that is, from each optic nerve) and are joined to form the optic tract that travels to the left side of the brain. Fibers carrying information from the left half of the visual field of each eye travel to the right side of the brain.

It has been shown [2] that some few of the retinal ganglion cells function as a fourth type of photoreceptor, called intrinsically photosentive retinal ganglion cells (ipRGC). Unlike rods or cones, these cells contain melanopsin and respond in a low frequency, slow manner to irradiance. Rather than encode a retinal image, these cells react to the general diffuse irradiance of the retina. Signals from these ganglion cells reach the hypothalamus, the circadian pacemaker, and so are responsible for entraining the day/night cycle of humans. See 3 | PHOTOBIOLOGY AND NONVISUAL EFFECTS OF OPTICAL RADIATION.

2.1.3.5 Nerve Signals

The photoreceptors generate an analog (that is, continuous) electrical signal that is compressed. Greater amounts of optical radiation produce smaller increases in the output signal. This compression significantly widens the range of the response of photoreceptors. Cells in the first layers of the retina generate visual signals in this analog manner, but transmission of visual information through the rest of the system is a digital process. Beginning with the ganglion cells, information is transmitted by sending electrical pulses of approximately uniform magnitude along neurons. The information being transmitted is contained in the rate at which pulses are sent. Pulse rates vary between zero and approximately 100 per second.

The response of transmitting neurons is based both on the presence and absence of an input signal. Most neurons have a rate at which they spontaneously generate electrical pulses ("fire" or "chirp" are terms usually used to describe this). This rate is increased or decreased depending on the presence of an incoming signal. Cells that increase their firing rate when they receive input pulses, and are unaffected if they have no input are call excitatory neurons—their output is excited by input. Other neurons, however, fire rapidly when they receive no input and have low output pulse rates if they do have input. These are called inhibitory neurons—their output is inhibited by input. This opponency is a fundamental aspect of the visual system circuitry. See 2.3.4 Receptive Fields.

2.2 Optics of the Eye

2.2.1 Retinal Image Formation

2.2.1.1 Refraction and Image Formation

As described in 1.5.2.2 Lenses, the refractive power of a lens has units of Diopters (D) and is the reciprocal of distance in meters at which a lens can refract collimated radiation to a point. As an object moves closer to a convex lens of fixed refractive power, its image moves further away. The dynamic process of changing refractive power is referred to as focusing. Focusing power describes the ability to change refractive power. The eye has a fixed image distance and so as an object approaches the lens must increase refractive power by becoming more curved. The closer the object, the greater must be the refractive power to maintain a focused image on the retina. In the eye, the distance from lens to retina is about 1.7 cm, and so up to about 60 D of total focusing power is required to focus an object far from the eye. See 1.5.2.2 Lenses.

2.2.2 Accommodation

The cornea provides about 40 D of refractive power in the visual system. The lens changes shape to provide the focusing power (greater or lesser refraction) required to produce images of objects at varying distances from the eye. In young adults the lens can change shape sufficiently to produce 15 D of focusing power. This act of focussing is called accommodation.

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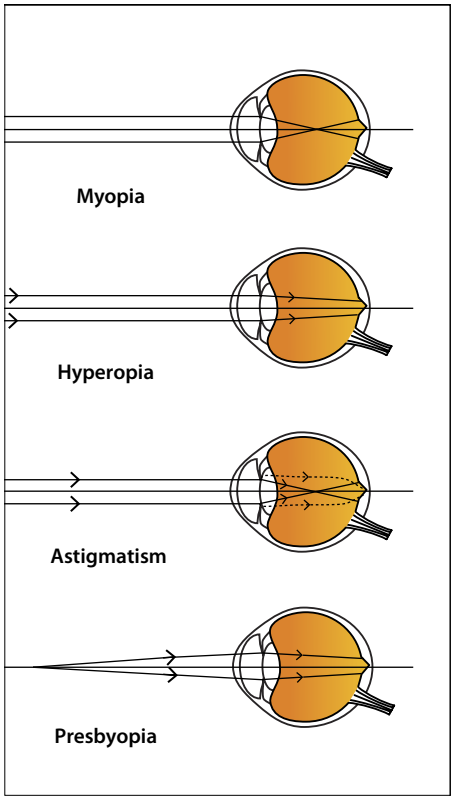


Figure 2.6 | Ray Geometry of Various Eyes
Ray geometry of (from top to bottom) myopia, hyperopia, astigmatism, and presbyopa. In first three images, the viewed object is at infinity. In the bottom image the viewed object is at the point of divergence in front of the eye.

Accommodation is always a response to an image of the target located on or near the fovea rather than in the periphery. It is used to bring a defocused image into focus or to change focus from one target to another at a different distance. It may be gradually changed to keep in focus a target that is moving across the visual field. Any condition, either physical or physiological, that handicaps the fovea, such as a low light level, will adversely affect accommodative ability. Blurred vision and eyestrain can be consequences of limited accommodative ability [3]. When there is no stimulus for accommodation, as in complete darkness or in a uniform luminance visual field such as occurs in a dense fog, the accommodation system typically accommodates to approximately one meter away [4].

2.2.3 Refractive Errors

Refraction provides the mechanism by which sharp images are produced on the retina. A sharp, focused image results when there is the correct amount of refraction provided by the eye. Emmetropia is the condition of the normal eye when parallel rays are focused exactly on the retina and near perfect focus is achieved. Hyperopia, or farsightedness, is the condition when focusing power is insufficient and objects are imaged behind the retina. Myopia, or nearsightedness, is the condition when focusing power is too great and objects are imaged in front of the retina. Hyperopia and myopia are usually caused by a mismatch between eye ball length and the optical power of the cornea and lens.

Presbyopia is the condition when focusing power is insufficient due to loss in flexibility of the lens with age. Nearby objects are imaged behind the retina.

Astigmatism is the condition when the focusing power is not equal around the visual axis. This is usually due to a deformation of the cornea. Most of these focusing problems can be corrected with spectacles, contact lenses, or surgical cornea sculpting. Figure 2.6 shows these focusing problems.

Even when the eye is perfectly corrected for refractive errors, a residual blur can remain due to spherical and chromatic aberrations. Shorter wavelengths are refracted more than longer wavelengths. As in spherical aberration, the results of the different foci cause blur. This is chromatic aberration. These aberrations (and others) are mainly of theoretical interest. They are partially compensated by the image processing of the visual system and usually can be neglected in practical lighting design. They may, however, be important in certain specialized applications, such as work under reduced illuminances where pupil sizes can be large.

2.2.4 Scatter

Optical radiation that enters through the periphery of the cornea is refracted more than that which enters through the central zones. Thus, radiation in the retinal image is partially redistributed over a larger retinal area than would be the case in an aberration-free system. This is spherical aberration. The amount and type of spherical aberration varies with the state of accommodation.

Intraocular media are not perfectly transparent and produce forward scattering of optical radiation. This scattering falls on the retina as a relatively uniform veil, increasing blur and reducing contrast. The effect becomes greater with age. Scattering within the eye is primarily large-particle scattering, which is not wavelength dependent. In young eyes, some 25% of the scattered light is produced by the cornea [5], another 25% by the back layers of the eye [6, 7, 8]

2.2.5 Retinal Irradiation

The spectral composition of optical radiation that reaches the retina is determined in part by the spectral transmittances of the intervening ocular materials. Figure 2.7 show these spectral transmittances. The composite transmittance describes the total filtering effect on optical radiation before it reaches the retina. The retina receives optical radiation in the range of 380 to 950 nm with little attenuation from ocular media. The cornea absorbs most

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optical radiation with wavelengths less than 300 nm. Wavelengths between 380 and 500 nm are increasingly attenuated with advancing age [9, 10]. Very little radiation beyond 1400 nm reaches the retina.

Advancing age reduces maximum pupil diameter and increases absorption by the lens. The two effects work in concert to produce a significant reduction in retinal irradiance with advancing age. Figure 2.8 show both effects [13].

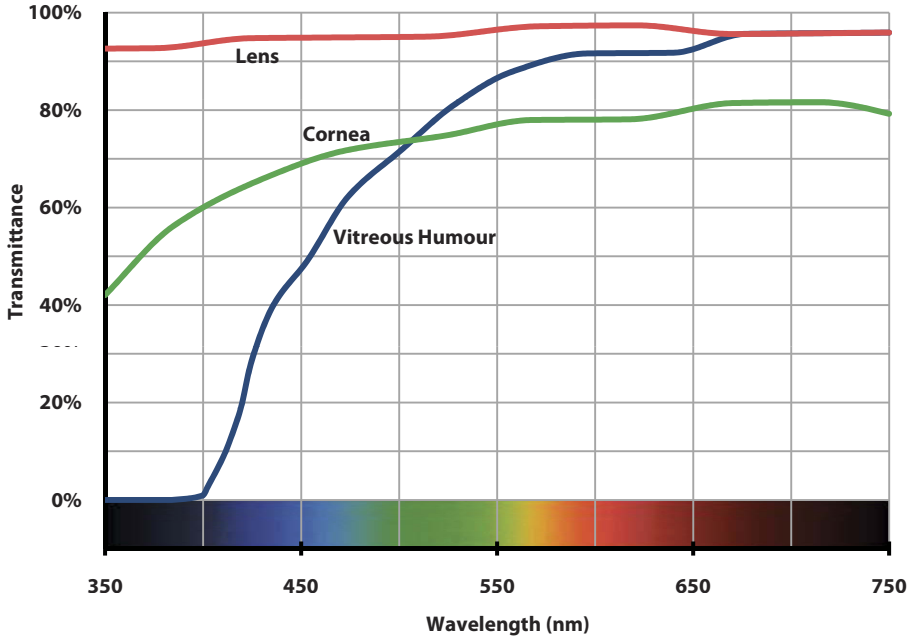


Figure 2.7 | Spectral Transmittances of Ocular Media
Spectral transmittances of ocular media, including the direct and forward scattered radiation, at each wavelength in the visible region.

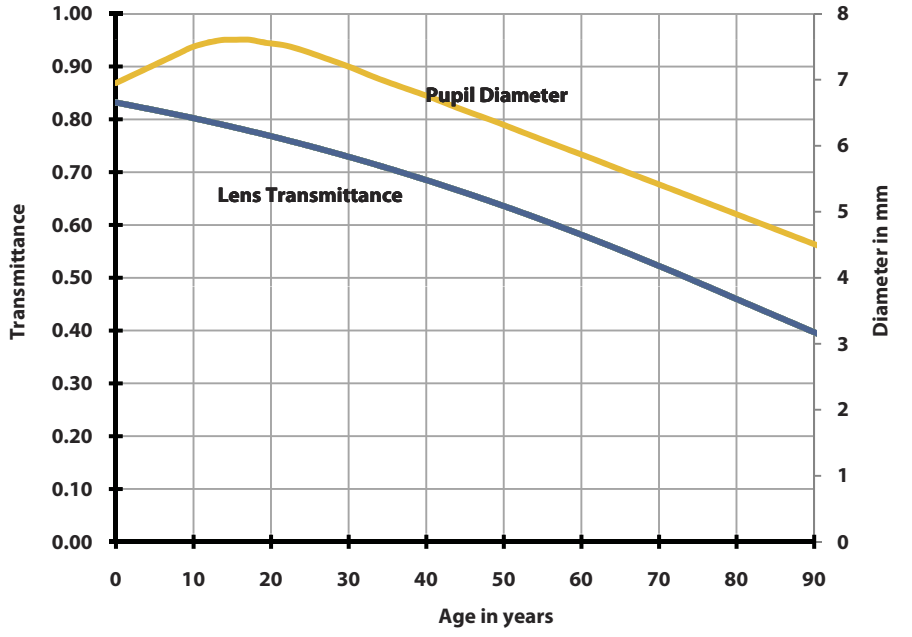


Figure 2.8 | Changes in Pupil Area and Lens Trasmittance with Age
Relative maximum pupil area and transmittance of lens for 550 nm optical radiation, as a function of age.

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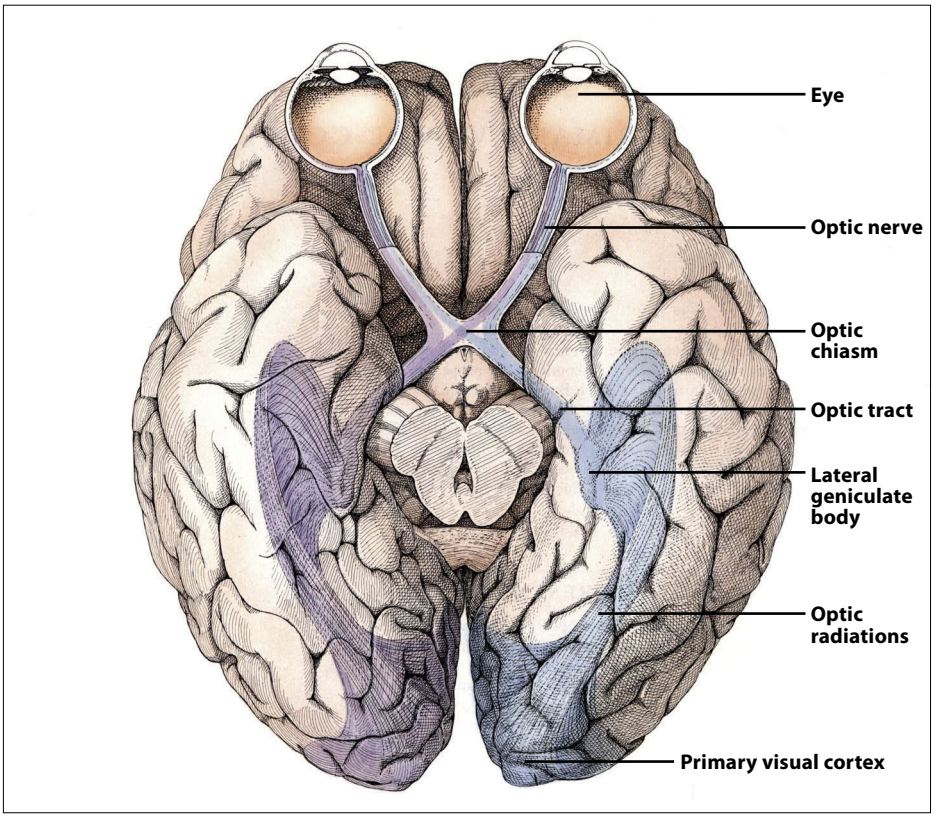


Figure 2.9 | Components of the Visual System above the Eye
Components of the visual system above the eye. Shown are the optic nerve, optic chiasm, optic tract, lateral geniculate nucleus, optic radiations, and the primary visual cortex.
» Image ©David H. Hubel

2.3 Visual System above the Eye

The neural aspects of the visual system are described as consisting of stages or layers, with the retina the lowest stage and the primary visual cortex the highest. The 'height' indicates complexity and the extent of input from previous stages. Information in the visual system is said to flow in channels 'upward', an abstraction for the apparent separate paths of luminance, chromatic, spatial, and temporal information moving from the eye up to higher stages of the visual system. Figure 2.9 shows all the anatomical components and most of the lower stages of the visual system.

2.3.1 Optic Nerve

Signals from the receptive fields of the retina are transmitted by the optic nerve, with most of its fibers projecting to the lateral geniculate nucleus. At the optic chiasm, the fibers from each eye divide into two sets: each eye contributes to bundles of fibers, one for each side of the head. These bundles are the optic tracts. One transmits signals from the left side of both eyes to the left side of the brain, the other transmits signals from the right side of both eyes to the right side of the brain.

2.3.2 Geniculate Nucleus

The geniculate nuclei on the right and left side of the brain receive signals from the optic tracts. On reaching the geniculate nucleus they produce an orderly representation of the retina. Like the retina, the geniculate nucleus is layered. Four layers have small cells, and process mainly temporal visual information coming principally from the periphery of the retina. These layers are called parvocellular, operate quickly but without detail, and are necessary for the perception of form and movement. Two layers have large cells, and process mainly spatial information coming principally from the center of the retina. These layers are called magnocellular and operate more slowly but with detail and are necessary for the perception of color. The temporal and spatial information flow is said to take place in two

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channels, the parvocellular and magnocellular channels. Fibers from these cells fan out in broad bands that are the optic radiations that eventually reach the back outer layer of the brain; the primary visual cortex.

2.3.3 Visual Cortex

The primary visual cortex also has a layered structure. Though it contains more than 200 million neurons, it is only 2 millimeters thick and, were it unfolded, would have a flat area of a few square inches. Information from the geniculate nuclei, and ultimately from the retinas, is processed here. Most of this processing area is devoted to analyzing the central 10° of the visual field. Interestingly, cortical neurons are connected so that almost none of them change their rest-state firing rate when we look at a uniformly luminous field, but are variously active when luminous patterns of specific edges, orientations, sizes, motions, directions, and colors are viewed. This detection and firing in the presence of edges, orientations, motions and colors form the input to high processing functions in the brain that give rise to perceptions.

2.3.4 Receptive Fields

Receptive field is the name given to the fundamental units by which the visual system apprehends the characteristics of the image on the retina. A receptive field describes a range of neurons over which signals are summed and the results input to one neuron, providing both processing and a type of data compression. The visual system exhibits layers of receptive fields, beginning with the retina and through to the visual cortex. Each layer provides input to the next.

The simplest receptive fields are those of the ganglion cells of the retina. These are circular areas of the retina that define a zone in which an individual neuron responds to a luminous stimulus The neural wiring provided by the bipolar, amacrine, and horizontal cells connects and processes signals from individual photoreceptors and takes them to a ganglion cell. Most, though not all, ganglion cells ultimately receive signals from two local fields of photoreceptors: a circular array surrounded by a larger annular area. The interconnections, and the neurons that provide them, are such that the center and surround contribute in opposite ways to the firing of the ganglion: center excitatory and surround inhibitory, or center inhibitory surround excitatory. These are usually referred to as on-center and off-center, respectively.

A ganglion cell with a receptive field that is either not illuminated at all or uniformly illuminated, usually exhibits a low, steady firing rate. Incident radiation limited to the center of an on-center receptive field increases ganglion cell firing rate. Radiation incident on only the inhibitory surround, suppresses firing. Uniform radiation on both center and surround produces a canceling effect, and the firing rate is unchanged. The opposite response occurs for off-center receptive field. Receptive field ganglion cell firing rate is the information output of the eye.

Retinal circuitry is such that neighboring ganglion cells receive input from an extensively overlapping field of photoreceptors; the signal from a single photoreceptor eventually provides input to more than one ganglion cell. Because of this, adjacent receptive fields almost completely overlap. Perhaps not surprisingly, receptive fields vary in size, with the smallest (assembled with signals from the fewest photoreceptors, sometimes only one) in the fovea, growing in size out to the periphery of the retina. The size of a receptive field center is expressed as a visual angle. Visual angle can be used to specify the apparent or visual size of an object that we view, or the equivalent size of a region on the retina. The smallest receptive fields involve cones and have centers with a visual angle less than 1 minute of arc. That is the angle subtended by a quarter at about 250 feet.

Many neurons beyond the retinal ganglion cells in the visual pathway have receptive fields. These receptive fields appear to be constructed from signals originating previously in the

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pathway; that is, from neurons with simpler receptive fields. In this way, simple receptive fields build complex ones, and increasingly complex receptive fields are found further along the visual pathway: from retina to geniculate nucleus to visual cortex. Receptive fields are not just spatial, but can be chromatic as well. The two types of chromatic receptive fields have center/surround red/green opponency, or yellow/blue opponency.

Receptive field complexity refers to the number and type of specific characteristics of a luminous stimulus required to provoke activity in a neuron. Some neurons have receptive fields that only require the stimulus of a small, round spot of light. Increasing in complexity, there are receptive fields that require bars of light, others that require bars of light with a specific orientation in the visual field, still more complex fields that require the oriented bars to move, and still more complex fields that require the oriented bars to move from left to right if the neuron is to fire. In this sense it can be said that these neurons have receptive fields that detect the presence of these various types of luminous stimuli.

More complex receptive fields are exhibited by cells that discriminate the spectral composition of the luminous stimulus. The most complex receptive fields are exhibited by cells in the visual cortex. Evidently, the output from cells with simpler receptive fields is the input to cells with complex receptive fields. This layering of complexity builds from the earliest stage in the visual pathway, the retina, through the geniculate nucleus, to the visual cortex. Our perceptions of edges, contours, motion, luminous gradients, and color apparently arise from the output of neurons that have these very complex receptive fields. Figure 2.10 shows the overall layered structure of the visual system.

2.3.5 Perceptions and Performance

Perceptions are part of the result of the visual system's processing of optical input. Information in chromatic, spatial, and temporal channels, originating in the photoreceptors and processed by multiple layers of receptive fields and opponent combinations, produce the basis for visual perceptions [11]. These include brightness, lightness, color, depth, and motion. This same information governs some aspects of visual performance. See 4 | PERCEPTIONS AND PERFORMANCE.

2.4 Vision and the State of Adaptation

2.4.1 Adaptation

For the visual system to be able to function well, it has to be adapted to the prevailing light condition. The human visual system can process information over an enormous range of luminances, from 10^{-6} cd/m^2 to 10^{+6} cd/m^2 (approximately 12 log units), but not all at once.

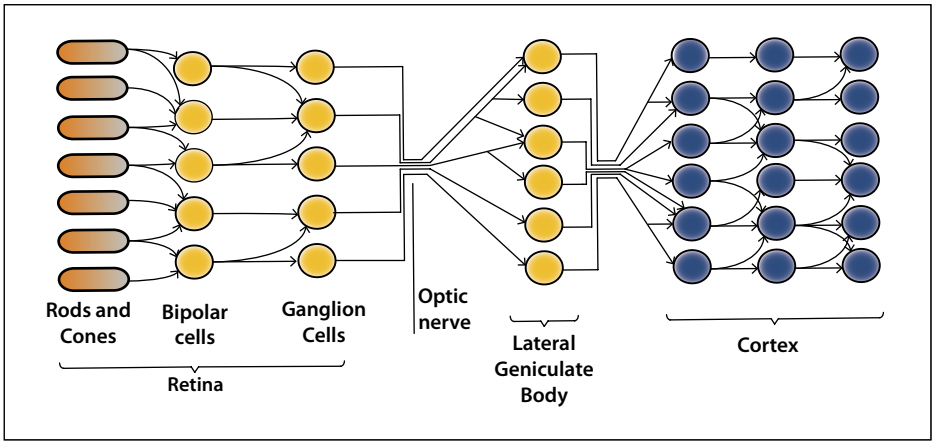


Figure 2.10 | The Layered Structure of the Visual System
The layered structure of the visual system showing, in order of processing, the retina, optic never, geniculate body, optic radiations, and the visual cortex. After the photoreceptors of the retina, input to each layer consists of signals from previous layers that have been mixed, added, or subtracted.

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To cope with the wide range of retinal illumination to which it might be exposed, from a dark night (0.01 lx) to a sunlit beach (100,000 lx), the visual system changes its sensitivity through a process called adaptation. Adaptation involves three distinct processes: pupil size, photochemical change, and neural changes. Since retinal irradiance can vary considerably across the retina, adaptation is a local phenomenon and the visual system can have very different states of adaptation across the visual field. This can be important for non-foveal or low spatial frequency tasks.

2.4.1.1 Mechanical Change: Pupil Size

The iris (Figure 2.1) constricts and dilates in response to increased and decreased levels of retinal illumination. Iris constriction has a shorter latency and is faster (approximately 0.3 s) than dilation (approximately 1.5 s) [12]. There are wide variations in pupil sizes among individuals and for any particular individual at different times for the same visual stimulus. Pupil size is influenced by emotions, such as fear or elation. Thus, for a given luminous stimulus, some uncertainty is associated with an individual's pupil size until it is measured. The typical range in pupil diameter for young people is from 3 mm for high retinal illuminances to 8 mm for low retinal illuminances [13]. This change in pupil size in response to retinal illumination can only account for a 1.2 log unit change in sensitivity to light. Older people tend to have smaller pupils than young people under comparable conditions. See 2.6.3.3 Pupil Size Limits.

2.4.1.2 Photochemical Change: Pigment Bleaching

The retinal photoreceptors contain four photopigments. When light is absorbed, the pigment breaks down into an unstable aldehyde of vitamin A and a protein (opsin) and gives off energy that generates electrical signals that are relayed to the brain and interpreted as light. In the dark, the pigment is regenerated and is again available to absorb light. The sensitivity of the eye to light is largely a function of the percentage of unbleached pigment. Under conditions of steady retinal irradiance, the concentration of photopigment is in equilibrium; when the retinal irradiance is changed, pigment is either bleached or regenerated to reestablish equilibrium. Photochemical adaptation is thus determined by the rates at which pigment is bleached and regenerated. At a steady adaptation state, the rate of bleaching equals the rate of regeneration. Because the time required to accomplish the photochemical reactions is on the order of minutes, changes in the sensitivity often lag behind the stimulus changes. The cone system adapts much more rapidly than does the rod system; even after exposure to high irradiances, the cones achieve their maximum sensitivity in 10 to 12 min, while the rods require 60 min (or longer) to achieve their maximum sensitivity [14]. Altogether, photochemical change accounts for between 5 and 7 log units of sensitivity change.

2.4.1.3 Neural Change: Synaptic Interaction

This is a fast change (less than 200 ms) in sensitivity produced by synaptic interactions in the visual system [15]. Neural processes account for virtually all the transitory changes in sensitivity of the eye where cone photopigment bleaching has not yet taken place (discussed below), in other words, at luminance values commonly encountered in electrically lighted environments, below approximately 600 cd/m^2. The facts that neural adaptation is fast, is operative at moderate light levels, and is effective over a luminance range of 2 to 4 log units explain why it is possible to look around most lit interiors without being conscious of being misadapted.

2.4.1.4 Temporal Effects

Exactly how long it takes to adapt to a change in retinal illumination depends on the magnitude of the change, the extent to which it involves different photoreceptors, and the direction of the change. For changes in retinal illumination of approximately 2 to 3 log units, neural adaptation is sufficient, so adaptation is in less than a second. For larger changes, photochemical adaptation is necessary. If the change in retinal illumination lies completely within the range of operation of the cone photoreceptors, a few minutes is sufficient for adaptation to occur. If the change in retinal illumination covers from cone

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photoreceptor operation to rod photoreceptor operation, tens of minutes can be required. As for the direction of change, once the photochemical processes are involved, changes to a higher retinal illumination can be achieved much more rapidly than changes to a lower retinal illuminance. When the visual system is not completely adapted to the prevailing retinal illumination, its capabilities are limited [16]. This state of changing adaptation is called transient adaptation. Transient adaptation is unlikely to be noticeable in interiors in normal conditions but can be significant where sudden changes from high to low retinal illumination occur, such as on entering a long road tunnel on a sunny day or in the event of a power failure in a windowless building.

2.4.2 Photopic Vision

This operating state of the visual system occurs at luminances higher than approximately 10 cd/m^2. For these luminances, the visual response is dominated by the cone photoreceptors. This means that color is perceived and fine detail can be resolved in the fovea. The visual system in this state of adaptation exhibits a spectral sensitivity to monochromatic optical radiation that is defined by the Standard Photopic Luminous Efficiency Function of Wavelength of the CIE. See 5.4.2 Photopic Luminous Efficiency.

2.4.3 Mesopic Vision

This operating state of the visual system is intermediate between the photopic and scotopic states. In the mesopic state both cones and rod photoreceptors are active. Luminances below approximately 10 cd/m^2 and above approximately 0.001 cd/m^2 produce this state of adaptation. As luminance declines through the mesopic region, the fovea, which contains only cone photoreceptors, slowly declines in absolute sensitivity without significant change in spectral sensitivity [17], until foveal vision fails altogether as the scotopic state is reached. In the periphery, the rod photoreceptors gradually come to dominate the cone photoreceptors, resulting in gradual deterioration in color vision and resolution and a shift in spectral sensitivity to shorter wavelengths. The standard methods of brightness matching cannot provide a single sensitivity function for mesopic adaptation [18] [19] [20] [21], but using reaction times and other methods appears to yield a consistent system of photometry using a range of mesopic functions. [22] [23] [24] [25]

2.4.4 Scotopic Vision

This operating state of the visual system occurs at luminances less than approximately 0.001 cd/m^2. For these luminances only the large receptive fields consisting of rod photoreceptors respond to stimulation. The fovea of the retina is inoperative since the receptive fields there are small and receive input from only a few photoreceptors. There is no perception of color, and what resolution of detail there is occurs in the periphery within a few degrees of the fovea. The visual system in this state of adaptation exhibits a spectral sensitivity to monochromatic optical radiation that is defined by the Standard Scotopic Luminous Efficiency Function of Wavelength of the CIE. See 5.4.3 Scotopic Luminous Efficiency.

Table 2.1 Gives a summary of these three adaptation states, the various conditions of the visual system that accompany them, and typical lighting conditions that produce them.

2.5 Color Vision

Color vision provides a rich dimension to our visual sense and gives rise to important and very complex perceptions. Color perception is described in 6 | COLOR; only the neural and anatomical basis for these perceptions is discussed here.

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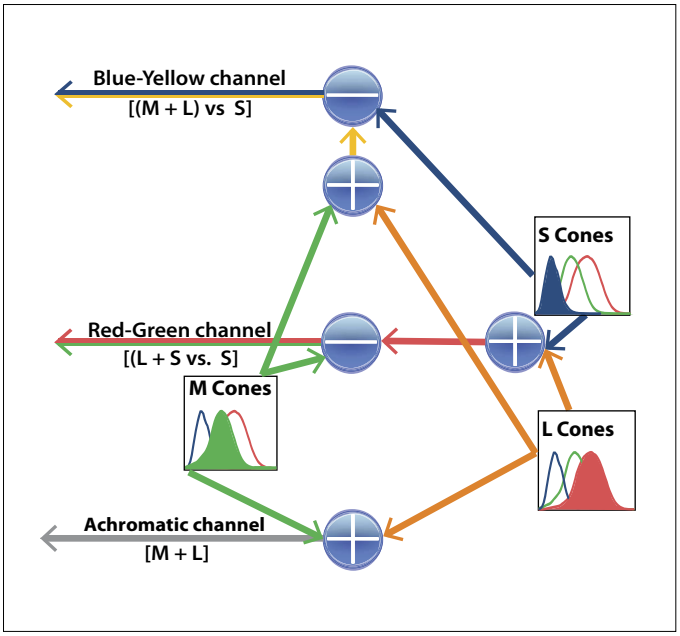


Figure 2.11 | Apparent Circuitry for Color Vision
Apparent circuitry that produces the red/green, yellow/blue, and luminance channels of visual information. The circles with + or – indicate whether the cone signals are thought to be added or subtracted.

2.5.1 Chromatic Receptive Field Opponency

Though color discrimination arises from the different spectral sensitivities of the three cone photoreceptors [25], signals from these cones do not directly produce color vision. Cone signals form chromatic receptive fields (see 2.3.4 Receptive Fields) which are circular center and concentric annular surround collections of photoreceptors circuited to a ganglion cell. The center/surround contributions are opposite, each being either excitatory or inhibitory. The receptive fields involving cones are circuited such that some center/surround pairs respond to (loosely stated) yellow and blue light, other center/surround pairs to red and green light. Thus, the center/surround opponency of these receptive fields is either yellow/blue or red/green. This is the basis for the two chromatic channels of visual information. The third channel carries luminance information. Input from the three cone photoreceptors is apparently processed as shown in Figure 2.11 to produce these three channels.

Although the achromatic channel carries luminance information, the perception of brightness has been shown to depend on all three channels [25b].

2.5.2 Color Vision Deficiencies

Most human visual systems have three cone photopigments that operate as shown in Figure 2.4. In this case the person is a trichromat (having three colors) and said to be "color normal." But approximately 8% of males and 0.2% of females have some form of abnormal color vision. Abnormal color vision occurs because of abnormal photoreceptor photopigments. The reason for the preponderance of males is that abnormal color vision is due to a genetic difference on the X-chromosome. Males have only one X-chromosome, but females have two, and for a female to have abnormal color vision, both X-chromosomes must have the same abnormal gene. Table 2.2 Lists the different types of abnormal color vision, their causes, and their prevalence.

2.5.2.1 Congenital Color Vision Deficiencies

In a small number of cases, one of the three types of cone photopigments is missing and the person is said to be a dichromate. More commonly, the photopigments in the long or middle wavelength cones is abnormal and color confusion can result.

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Table 2.1 | Vision Adaptation States

Luminance (cd/m^2)	Log(L)	Representative Luminances [a]	State of the Visual System				
			Adaptation	Photoreceptors' State	Young Adult Pupil Size (mm)	Log Retinal Illuminance (Tr)	
						Photopic	Scotopic
0.000001	-6.0		Scotopic	Rod threshold	7.9	-4.30	-3.90
0.000003	-5.5				7.8	-3.90	-3.49
0.00001	-5.0				7.7	-3.42	-3.01
0.00003	-4.5	Darkest night sky, zenith			7.6	-2.92	-2.51
0.0001	-4.0	Moonless overcast night sky			7.5	-2.40	-2.00
0.0003	-3.5				7.3	-1.89	-1.50
0.001	-3.0	Moonless clear night sky	Mesopic	Cone threshold	7.0	-1.40	-1.01
0.003	-2.5				6.6	-0.94	-0.55
0.01	-2.0	Night sky horizon with full moon			6.1	-0.50	-0.10
0.03	-1.5				5.6	-0.08	0.32
0.1	-1.0				5.0	0.32	0.72
0.3	-0.5				4.4	0.71	1.12
1	0.0	Horizon, clear sky just after sunset			3.9	1.10	1.50
3	0.5				3.5	1.49	1.89
10	1.0	Horizon, overcast sky at sunset	Photopic	Rods begin saturation	3.1	1.88	2.28
31	1.5	LCD computer display, low			2.7	2.28	2.68
100	2.0	LCD computer diplay, medium gray			2.5	2.70	3.10
310	2.5	LCD computer display, max			2.3	3.13	3.52
1000	3.0	Scattered clouds			2.2	3.57	3.97
3100	3.5	Complete overcast daytime sky			2.1	4.03	4.43
10,000	4.0	T8 fluorescent lamp, candle flame			2.1	4.50	4.90
31,000	4.5	T5 HO fluorescent lamp			2.1	4.98	5.39
100,000	5.0	Acetyline burner flame			2.1	5.47	5.89
310,000	5.5	Blackbody at 1950 K			2.1	5.98	6.39
1,000,000	6.0				2.0	6.50	6.90
3,100,000	6.5	Tungsten lamp filament			2.0	7.05	7.40
10,000,000	7.0	Sun at the horizon		Damage	2.0	7.63	7.91
31,000,000	7.5	Metal halide arc tube			2.0	8.27	8.40
100,000,000	8.0	Sun at midafternoon			2.0	8.50	8.90

a. These are objects, natural or manmade, that typically present the luminances indicated.

b. Illuminance that produces the lumiance, assuming a diffuse surface of the indicated reflectance. Values are rounded to 1 part in 10.

c. These are typical outdoor conditions that produce the indicated outdoor illuminance or surface luminance.

d. These are typical indoor conditions that produce the indicated indoor illuminance.

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Corresponding Illuminance [b]				Corresponding Representative Illumination	
Outdoor (mean ρ=0.10)		Indoor (mean ρ=0.85)			
lux	footcandles	lux	footcandles	Outdoor Conditions [c]	Indoor Conditions [d]
0.000031	0.000003	0.000004	0.0000003		
0.0001	0.00001	0.00001	0.000001		
0.00031	0.00003	0.00004	0.000003	starlight through clouds	
0.001	0.0001	0.0001	0.00001	starlight, no natural sky glow	
0.0031	0.0003	0.0004	0.00003		
0.01	0.001	0.001	0.0001	starlight and natural sky glow	
0.031	0.003	0.004	0.0003		
0.1	0.01	0.01	0.001		
0.31	0.03	0.04	0.003	quarter moon	
1	0.1	0.1	0.01	full moon	
3.1	0.3	0.4	0.03	deep twilight	
10	1	1	0.1	twilight, local roadways	emergency lighting (min)
31	3	4	0.3	major roadway	performance aisle lighting
99	9	12	1	roadways	emergency lighting (avg)
310	30	40	3	dark overcast day	some club lounges
990	90	120	11		some lobbies, stairs, dining
3100	300	400	30	overcast day	some offices
9900	900	1200	110	just after dawn, clear sky	demanding reading tasks
31000	3000	4000	300	skylight	demanding industrial tasks
99000	9000	12000	1100	sun up 25° from horizon	some dental procedures
310000	30000	40000	3000	full sunlight	some surgical procedures
990000	90000	120000	11000		some surgical procedures
3100000	300000	400000	30000		
9900000	900000	1200000	110000		
31000000	3000000	4000000	300000		
99000000	9000000	12000000	1100000		
310000000	30000000	40000000	3000000		
990000000	90000000	120000000	11000000		
3100000000	300000000	400000000	30000000		

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Table 2.2 | Types of Color Deficiency

Name	Type	Cause	Consequences	Prevalence
Dichromacies	• **Protanopia**	Missing L-cone pigment	Confuses 520-700 nm; has a neutral point	M:1.0 % F:0.02%
	• **Deuteranopia**	Missing M-cone pigment	Confuses 530-700 nm; has a neutral point	M:1.1 % F:0.1%
	• **Tritanopia**	Missing S-cone pigment	Confuses 445-480 nm; has a neutral point	Very rare
Anomalus Trichromacies	• **Protanomaly**	Abnormal L-cone pigment	Abnormal matches; poor discrimination	M: 1.0% F:0.02%
	• **Deuteranomaly**	Abnormal M-cone pigment	Abnormal matches; poor discrimination	M: 4.9% F:0.04%
Monochromacies	• **Rod Monochromacy**	Only rods in the retina	No color vision	Very rare
	• **Cone Monochromacy**	Only cones in the retina	No hue discrimination at photopic adaptation	Very rare

2.5.2.2 Acquired Color Vision Deficiencies

Some color vision deficiencies are acquired, in that they appear after birth and exhibit change over time. These deficiencies are variously due to cone dystrophies, optic neuritis, age-related macular degeneration, retinal lesions, and glaucoma.

2.6 Consequences for Lighting Design

2.6.1 Lighting to Aid Vision

In a very broad way, the characteristics of the visual system establish the criteria for good lighting design. In most cases, the visual system processes chromatic, achromatic, spatial, and temporal information in complicated ways to give final perceptions of light and color. But in certain applications some aspects of the visual system define the principal goal of, and sometimes the constraint on, a lighting system. An example is the importance of transient adaptation to tunnel lighting.

Just as importantly, the anomalous or aging characteristics of the visual system provide guidance for good lighting. These include color vision deficiencies, various effects of the aging eye, and the implications of the circadian entrainment mechanism. In some of these cases, lighting criteria need to be adjusted.

2.6.2 Color Vision Deficiencies

For most activities, abnormal color vision causes few problems, either because the exact identification of color is unnecessary or because there are other cues by which the necessary information can be obtained (for example, relative position of lit signal in traffic signals). Abnormal color vision does become a problem when color is the sole or dominant means used to identify objects, for example, in some forms of electrical wiring. People with abnormal color vision may have difficulty with such activities. Where self-luminous colors are used as signals, colored lights should be restricted to those that can be distinguished by people with the more common forms of color abnormality. The CIE has recently recommended areas on the CIE 1931 Chromaticity Diagram within which red, green, yellow, blue, and white signal lights should lie. See 6 | COLOR. These areas are designed so that the red signal will be named as red and the green as green, even by dichromats, who are missing either a long or middle-wavelength photoreceptor pigment [31]. It should be noted that for people with the most common form of abnormal color vision, the anomalous trichromats, the ability to discriminate colors shows wide individual differences. Some anomalous trichromats are barely distinguishable from people with normal color vision, whereas others resemble dichromats in their ability to discriminate colors. Figure 2.12 shows lines along which color confusion is apt to take place in individuals with various forms of color vision deficiencies.

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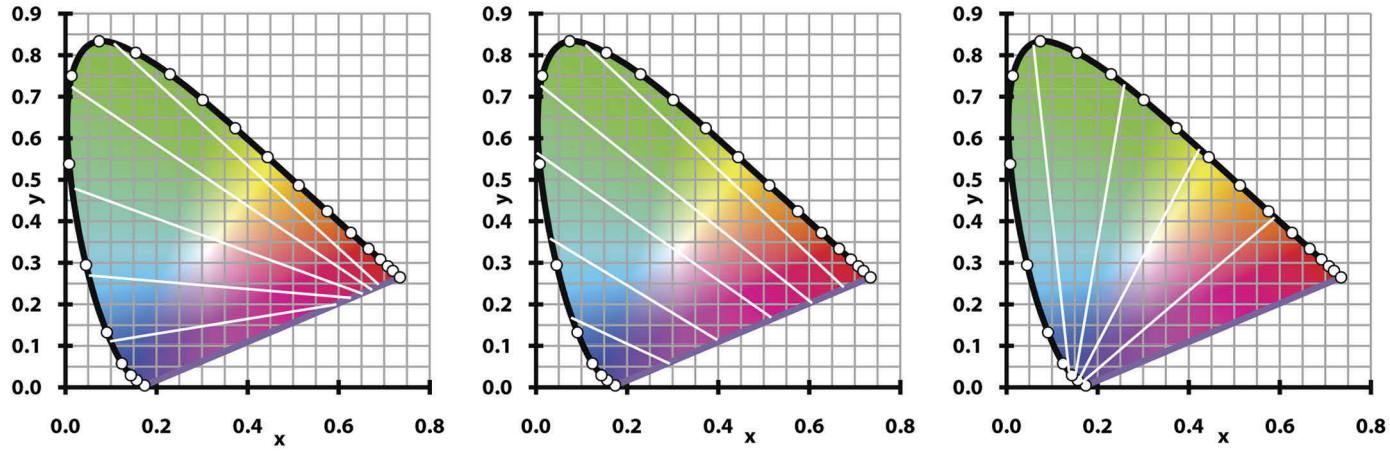


Figure 2.12 | Lines of Color Confusion for Different Types of Color Vision Deficiencies
Lines of color confusion, shown in white, on the CIE chromaticity diagram for individuals with (from left to right) anomalous or missing long, middle, and short wavelength cones or cone photopigments.

2.6.3 Effects of Age

As the visual system ages, a number of changes in its structure and capabilities occur [13]. These include loss of focusing power, reduction in lens transparency, lens yellowing, and decrease in maximum pupil size [26] [27].

2.6.3.1 Presbyopia

Accommodative function decreases rapidly with age, so that by age 45 most people can no longer focus at near-working distances (approximately 40 cm) and might need optical assistance. This is known as presbyopia. By age 60, there is very little accommodative ability remaining in most of the population, which leaves them with a fixed-focus optical system. Figure 2.13 shows this decrease. This lack of focusing ability is compensated somewhat by the physiologically smaller pupils in the elderly (senile myosis) which increases the depth of field of the eye. However, the smaller pupils in turn require increased task luminance to maintain the same retinal illuminance as when the pupils were larger.

2.6.3.2 Lens Yellowing, Clouding, and Fluorescence

The lens of the eye becomes yellow with advancing age, reducing the short wavelength radiation reaching the retina. Advancing age often brings lens clouding, called cataract, caused by chemical changes within the eye. This decrease in transparency causes a decrease in vision, which if sufficiently advanced is treated by surgical removal of the lens. In both cases these problems are slow to develop and their effect on vision gradual [28].

The quality of the retinal image can also be reduced by light generation within the eye, caused by fluorescence in the lens. This phenomenon occurs primarily in the elderly and is produced by absorption of short wavelength visible and ultraviolet radiation in the lens which is then re-emitted at longer wavelengths to which the visual system is more sensitive [29].

2.6.3.3 Pupil Size Limits

Advancing age brings a reduction in the maximum pupil size the iris can provide. This is senile myosis. Figure 2.14 shows the reduction in maximum pupil size with age [13]. The effect is particularly evident when dark-adapted. Based on pupil size alone, the 60 year-old iris of a dark-adapted observer admits less than one-half the light of that of a 20 year-old.

2.6.3.4 Decreased Retinal Illumination and Increased Scattering

As the visual system ages, the amount of light reaching the retina is reduced, more of the light entering the eye is scattered, and the spectrum of the light reaching the retina is altered by preferential absorption of the short visible wavelengths. The rate at which these changes occur accelerates after age 60. This change in lens transmittance with age is

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a strong function of wavelength; short wavelengths are affected far more than long ones [13]. Figure 2.15 shows this effect.

2.6.3.5 Cell Loss

In addition to these changes in the optical characteristics of the eye, deterioration in the neurological components of the visual system also occurs in later life [18] The consequences of these changes with age are reduced visual acuity, reduced contrast sensitivity, reduced color discrimination, increased time taken to adapt to large and sudden changes in luminance, and increased sensitivity to glare.[18,32,33]

2.6.3.6 Increased Prevalence of Retinal Disease

In addition to the effects described above, advancing age also increases the likelihood of retinal disease and the accompanying impairment of vision. The most common types are macular degeneration, diabetic retinopathy, glaucoma, hypertensive retinopathy, and retinitis pigmentosa, including night blindness and tunnel vision.

2.6.4 Partial Sight

Partial sight is a state of vision that falls between normal vision and total blindness. While some people are born with partial sight, the majority of people with partial sight are elderly. Among the partially sighted, 20% became partially sighted between birth and 40 years, 21% between 41 and 60 years and 59% after 60 years of age [26]. Surveys in the United States and the United Kingdom suggest that the proportion of the total population who are classified as partially sighted are in the range 0.5 to 1% [31, 32]. The three most common causes of partial sight are cataract, macular degeneration, and glaucoma [33]

2.6.4.1 Cataract

This is an opacity developing in the lens. The effect of cataract is to absorb and scatter more of the light passing through the lens. This increased absorption and scattering occurring in the lens results in reduced visual acuity and reduced contrast sensitivity over the entire visual field because the scattered light degrades the contrast of the retinal image. This is known as disability glare, which occurs when light is scattered in the eye. The extent to which more light can help a person with cataract depends on the balance between absorption and scattering. More light will help overcome the increased absorption but if scattering is high, the consequent deterioration in the luminance contrast of the retinal image will reduce visual capabilities. The use of dark backgrounds against which objects are to be seen will also help [34, 35].

2.6.4.2 Macular Degeneration

This occurs when the macular photoreceptors and neurons become inoperative due to bleeding or atrophy. The fovea is at the center of the macula lutea, and any loss of vision implies a serious reduction in visual acuity, color vision, and contrast sensitivity at high spatial frequencies. Typically, these changes make reading difficult, if not impossible. However, peripheral vision is largely unaffected so wayfinding is unchanged. Providing more light, usually by way of a task light, will help people in the early stage of deterioration, but as it progresses additional light is less effective. Increasing the visual size of the retinal image by magnification or by getting closer is helpful at all stages, because this can increase the size of the retinal image sufficiently to reach parts of the retina beyond the macula.

2.6.4.3 Glaucoma

Glaucoma is due to an increase in intraocular pressure that damages the retina and the anterior optic nerve. Glaucoma is shown by a progressive narrowing of the visual field, which continues until complete blindness occurs or the intraocular pressure is reduced. As glaucoma develops, in addition to a reduction in visual field size, poor night vision, slowed transient adaptation, and increased sensitivity to glare occur, all due to the destruction of peripheral photoreceptors and neurons. However, the resolution of detail seen on axis is unaffected until the final stage. Lighting has limited value in helping people in the early stages of glaucoma, because where damage has occurred, the retina has been destroyed. However,

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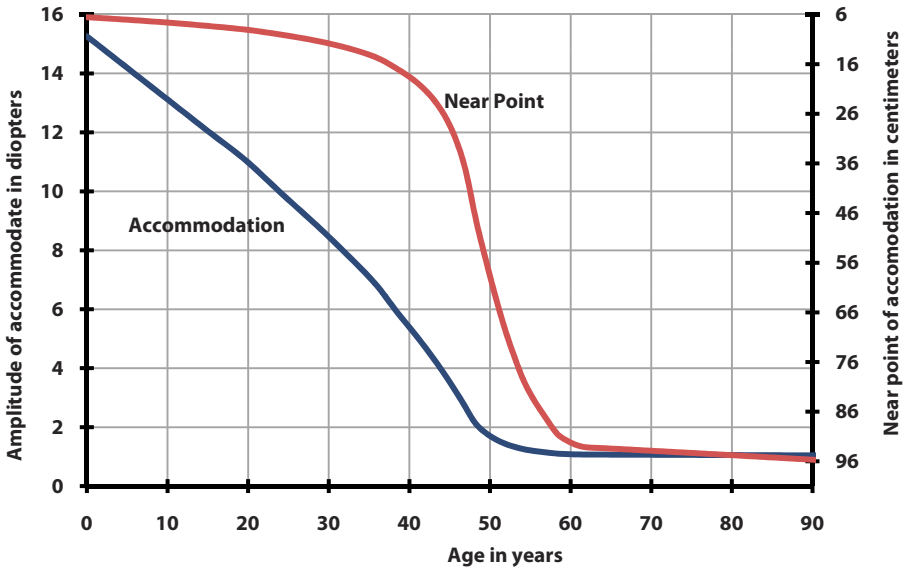


Figure 2.13 | Reduction in Change in Focusing Power with Advancing Age
Reduction in change in focusing power (amplitude of accommodation) with advancing age. The near point indicates the smallest distance at which a sharp image of an object can be obtained. The three curves indicate the range of individual differences.

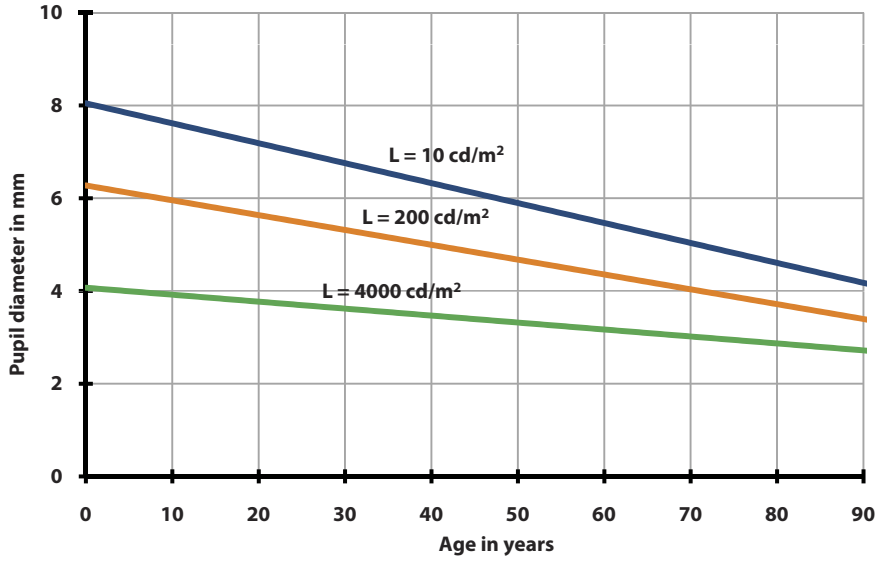


Figure 2.14 | Pupil Diameter as a Function of Age for Three Adaptation Luminances
These are maximum pupil diameters and so indicate in a general way how much optical radiation can get into the eye. The effect of age is particularly pronounced at low luminances.

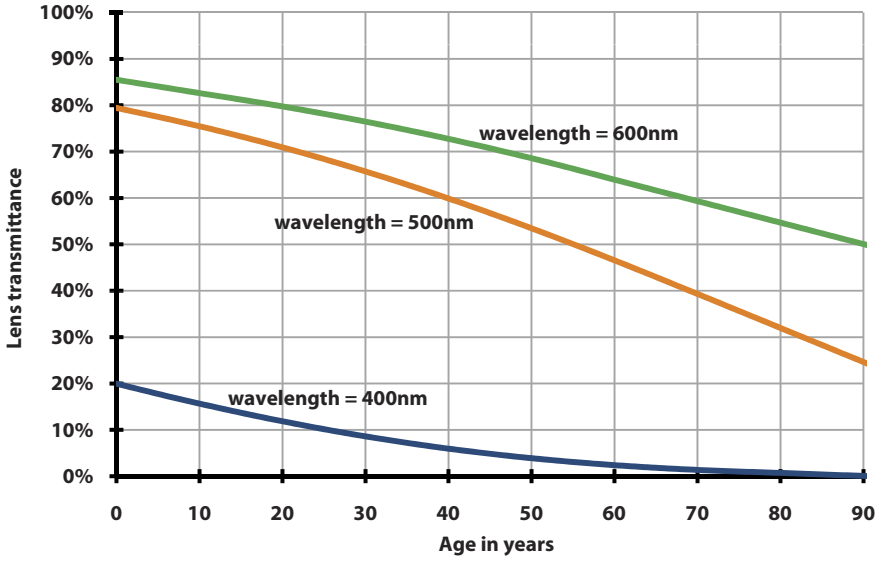


Figure 2.15 | Lens Transmittance as a Function of Age and Wavelength of Optical Radiation
The gradual change in spectral transmittance of the lens is characterized as "yellowing".

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consideration should be given to providing enough light for exterior lighting at night to enable the fovea to operate. Such lighting will be helpful only if glare is controlled.

2.6.4.4 Retinopathy

Retinopathy is non-inflammatory damage to the retina. The most common age-related causes are diabetes and hypertension.

2.6.4.5 Lighting for the Partially-Sighted

While the benefits of additional light depend on the specific cause of partial sight, there is one approach that is generally useful for all those with partial sight. This is to simplify the visual environment and to make its salient details more visible. Details can be made more visible by increasing their size, luminance contrast, and color difference.

2.6.5 Circadian Effects

Light entrains the circadian rhythm and there are several lighting factors that are important to this entraining mechanism. Exposure to light before or after sleep affects this rhythm: exposure to light after waking advances the circadian rhythm (delays sleep), while exposure before sleeping delays the circadian rhythm [36, 37]. The length of exposure and consistency are directly correlated with the size of the delay or advance effect [36] [37]. The effect is more pronounced at low light levels and with short wavelength optical radiation [38].

2.7 References

[1] Hubel DH. 1988. Eye, brain, and vision. Scientific American Library. 240 p.

[2] He S, Dong W, Deng Q, Weng S, Sun W. 2003. Seeing more clearly: Recent advances in understanding retinal circuitry. Science. 302(5633):408-411.

[3] Baehr EK, Fogg LF. 1999. Intermittent bright light and exercise to entrain human circadian rhythms to night work. American Journal of Physiology-Regulatory Integrative and Comparative Physiology 277(6): R1598-R1604.

[4] Leibowitz, HW, Owen DA. 1975. Anomalous myopias and the intermediate dark focus of accommodation. Science 189(4203):646–648.

[5] Vos JJ, Boogaard J. 1963. Contribution of the cornea to entoptic scatter. J Opt Soc Am. 53(7):869–873

[6] Boynton RM, Clarke FJJ. 1964. Sources of entoptic scatter in the human eye. J Opt Soc Am. 54(1):110–119.

[6] Wyszecki G, Stiles WS. 1982. Color science: Concepts and methods, quantitative data and formulae. 2nd ed. NewYork: John Wiley & Sons.

[8] Vos JJ. 1963. Contribution of the fundus oculi to entoptic scatter. J Opt Soc Am. 53(12):1449–1451.

[9] Said FS, Weale RA. 1959. The variation with age of the spectral transmissivity of the living human crystalline lens. Gerontologia 3(4):213–231.

[10] Coren S, Girgus JS. 1972. Density of human lens pigmentation: In vivo measures over an extended age range [Letter]. Vision Res. 12(2):343–346.

[11] Ingling CR Jr, Tsou HB. 1977. Orthogonal combinations of three visual channels. Vision Res. 17(9):1075– 1082.

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[12] Bouma H. 1965. Receptive systems mediating certain light reactions of the pupil of the human eye. Philips Research Report Supplements, no. 5. Eindhoven, Netherlands: Philips Research Laboratories.

[13] Weale RA. 1992. The senescence of human vision. New York: Oxford University Press.

[14] Hecht S, Mandelbaum J. 1939. The relation between vitamin A and dark adaptation. JAMA 112(19):1910–1916.

[15] Dowling JA. 1967. The site of visual adaptation. Science 155(3760):273–279.

[16] Boynton RM, Miller N D. 1963. Visual performance under conditions of transient adaptation. Illum Eng. 58(8): 541–550

[17] He Y, Rea M, Bierman A, Bullough J. 1997. Evaluating light source efficacy under mesopic conditions using reaction times. J Illum Eng Soc. 26(1):125–138.

[18] Commission Internationale de l'Éclairage. 1989. Mesopic Photometry: History, special problems and practical solutions. CIE no. 81. Vienna: Bureau Central de la CIE.

[19] Kaiser PK, Wyszecki G. 1978. Additivity failures in heterochromatic brightness matching. Color Res Appl. 3(4): 177–182.

[20] Wagner G, Boynton RM. 1972. Comparison of four methods of heterochromatic photometry. J Opt Soc Am. 62(12):1508–1515.

[21] Guth SL, Lodge HR. 1973. Heterochromatic additivity, foveal spectral sensitivity, and a new color model. J Opt Soc Am. 63(4):450–462.

[22] He Y, Bierman A, Rea MS. 1998. A system of mesopic photometry. Light Res Tech. 30(4):175–181.

[23] LRC mesopic. Rea, M. S., J. D. Bullough, J. P. Freyssinier-Nova and A. Bierman. 2004. A proposed unified system of photometry. Lighting Research and Technology 36(2): 85-111.

[24] MOVE mesopic. Goodman, T., A. Forbes, H. Walkey, M. Eloholma, L. Halonen, J. Alferdinck, A. Freiding, P. Bodrogi, G. Várady, and A. Szalmas. 2007. Mesopic visual efficiency IV: A model with relevance to nighttime driving and other applications. Lighting Research and Technology 39(4): 365-392.

[24b] [IES] Illuminating Engineering Society. 2006. Spectral effects of lighting on visual performance at mesopic light levels. New York. IES. 14p.

[25] Kaiser PK, and Boynton RM. 1996. Human color vision. Washington: Optical Society of America.

[25b] Fotios FA. 1998. Chromatic effect on apparent brightness in interior spaces III: Chromatic brightness model. Light Res Tech. 30(3):107-110.

[26] Sekuler R, Kline D, Dismukes K, eds. 1982. Aging and human visual function. Modern Aging Research, 2. NewYork: Alan R. Liss, Inc.

[27] Blackwell OM., Blackwell HR. 1971. Visual performance data for 156 normal observers of various ages. J Illum Eng Soc. 1(1):3–13.

[28] Wolf E, Gardiner JS. 1965. Studies on the scatter of light in the dioptric media of the eye as a basis of visual glare. Arch Ophthalmol. 74(3):338–345.

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[29] Weale RA. 1985. Human lenticular fluorescence and transmissivity, and their effects on vision. Exp Eye Res. 41(4): 457–473.

[30] Winn B, Whitaker D, Elliott DB, Phillips NJ. 1994. Factors affecting light-adapted pupil size in normal Human subjects. Investigative Ophthal & Visual Sci. 35(3):1132-1137.

[31] Cullinan TR. 1977. The epidemiology of visual disabilities studies of visually disabled people in the community. Canterbury: University of Kent.

[32] Sorensen S, Brunnstrom G. 1995. Quality of light and quality of life: An intervention study among older people. Light Res Tech. 27(2):113–118.

[33] Kahn HA. 1973. Statistics on blindness in the model reporting area 1969–1970. Department of

[34] Commission Internationale de l'Éclairage. 1997. Low vision: Lighting needs for the partially sighted. CIE Publication no. 123. Vienna: Bureau Central de la CIE.

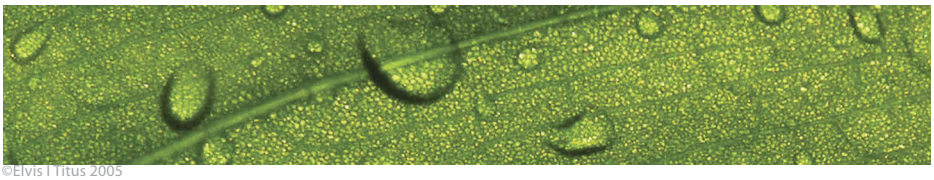
[35] Sicurella VJ. 1977. Color contrast as an aid for visually impaired persons. JVIB 71(6):252–257.

[36] Warman VL, Dijk DJ. 2003. Phase advancing human circadian rhythms with short wavelength light. Neuroscience Letters 342(1-2): 37-40.

[37] Duffy JF, Kronauer RE. 1996. Phase-shifting human circadian rhythms: Influence of sleep timing, social contact and light exposure. J Physiol. 495(1): 289-297.

[38] Gorman MR, Kendall M. Scotopic illumination enhances entrainment of circadian rhythms to lengthening Light : Dark cycles. J Biological Rhythms 20(1): 38-48

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3 | PHOTOBIOLOGY AND NONVISUAL EFFECTS OF OPTICAL RADIATION

Lethargics are to be laid in the light and exposed to the rays of the sun, for the disease is gloom and sunlight the cure.

Aretaeus of Cappadocia, 100 AD. Celebrated Greek physician

Optical radiation is a critical component for the growth and regulation of most organisms. Photosynthesis in plants and the generation of Vitamin D in humans are examples of long-known and well understood ways in which optical radiation is essential to the proper functioning of biological systems. In these two examples, the tissue of leaf and skin is the receptive entity and the site of the photobiological mechanism. Optical radiation has long been used in medicine to treat and prevent disease. All of these are examples of the nonvisual effects of optical radiation; that is, none involve the visual system. But relatively recent discoveries have made clear the very complex way in which optical radiation entering the eye not only initiates vision, but also governs daily rhythms in animals and humans. This link between optical radiation, endocrine systems, sleep cycles, and mood make it clear that the design of lighting systems will begin to account for these important effects. This chapter provides information about these developments and photobiology as they relate to the built environment.

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3.1 Overview

Humans, animals, and plants have complex physiological responses to the daily and seasonal variations in solar radiation under which they evolved. Photobiology is the study of these responses to optical radiation in the ultraviolet (UV), visible, and infrared (IR) portions of the electromagnetic spectrum. Photobiological responses result from chemical and physical changes produced by the absorption of radiation by specific molecules in the living organism. The absorbed radiation produces heat and excited states in these molecules, which can lead to photophysical and photochemical reactions of biological consequence. See 1.4.1 Atomic Structure and Optical Radiation. The distinguishing feature of photochemical reactions is that the activation energy is provided by the absorption of photons, which cause reactions to occur at physiologically low temperatures. Photobiological responses are generated in the following steps:

1. Optical radiation is incident on an organism.
2. Optical radiation is selectively absorbed.
3. Two kinds of changed are produced by this absorption: Photochemical change and Photophysical change.
4. The photochemical or photophysical change initiates a photobiological response.

For applied lighting, the optical radiation of interest can be divided into three components: UV, 100 to 400 nm; visible, 400 nm to 780 nm, IR, 780 to 1 mm. The UV region is further subdivided by the Commission Internationale de l'Eclairage (CIE) into near (UV-A, 315 to 400 nm), middle (UV-B, 280 to 315 nm) and far (UV-C, 100 to 280 nm)

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UV bands [1]. The IR region is further subdivided into three subregions: IR-A (near-IR, 780 to 1400 nm), IR-B (middle-IR, 1400 to 3000 nm), and IR-C (far-IR, 3000 nm to 1 mm) bands. Visible radiation occupies the wavelength region bounded by UV and IR, falling between approximately 400 and 750 nm. These boundaries are not sharp.

The subjects of this chapter are the nonvisual responses to optical radiation in the UV, near-IR, and IR ranges in humans, the use of optical radiation in the treatment of certain human diseases, and its germicidal use.

Table 3.1 summarizes some of the effects of optical radiation as a function of wavelength and indicates that UV bands, in particular, induce such adverse effects as actinic erythema (reddening of the skin), photokeratitis (an inflammation of the cornea, also commonly known as "flash blindness" or "welder's burn"), and photosensitized skin damage, as well as some beneficial effects, as in phototherapy and the daily synchronization of the body's circadian rhythm. Shorter wavelength optical radiation has more energy and can be more biologically active. See 1.1.3 Einstein's Photons.

Table 3.1 | Effects of Optical Radiation

Effect	Locat or Process	Ultraviolet (100 nm - 400 nm)	Visible and near-IR (380 nm - 1400 nm)	IR (over 1400 nm)
Deleterious	**Skin**	Erythema (delayed)	Burns	Burns
		Carcinogensis	Erythema (immediate)	Erythema (immediate)
		Aging		
		Drug photosensitivity		
		Melanogensis		
		Melanoma (postulated)		
	Eye	Photoconjunctivitis		
	Cornea	Photokeratitis		Burns and shocks
	Lens	Cataracts (immediate and delayed)	Near-IR cataracts	IR cataracts
		Coloration		
		Sclerosis		
	Retina	Retinal Changes	Thermal lesion	
			Shock lesion	
			Photochemical lesion	
			Macular degeneration (postulated)	
Beneficial	**Phototherapy**	Psoriasis	Retinal detachment	
		Herpes simplex	Diabetic retinopathy	
		Dentistry	Hyperbilirubinemia	
		Treatment of vitiligo, eczyma, and	Glaucoma	
		Photochemotherapy	Removal of port wine birth marks and tattoos	
			Surgery	
			Seasonal Affective Disorder	
			Jet lag	
	Non-theraputic	Vitamin D production	Biological rhythms	Radiant heating
		Protective pigmentation	Hormonal activity	
			Behavior	
			Circadian rhythm set	

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3.2 Nonvisual Response to Optical Radiation

Much like the dual functions of audition and balance long associated with the ear, the mammalian eye has dual roles in detecting optical radiation for both image-formation (vision) and for other circadian, neuroendocrine, and neurobehavioral responses. Since the effects of optical radiation can be profound for human health and well-being it is increasingly important for lighting designers to understand the direct biological influences of optical radiation, and in particular the human response to light/dark cycles.

This section describes the retinal mechanisms involved when optical radiation signals are converted into neural signals for body functions other than vision. Optical radiation reaching the retina regulates physiology and behavior, both directly and indirectly. This includes acute effects such as suppressing pineal melatonin production, elevating morning cortisol production, increasing subjective alertness, enhancing psychomotor performance, changing brain activation patterns to a more alert state, elevating heart rate, increasing core body temperature, activating pupil constriction, and even stimulating circadian clock gene expression.

Perhaps the most important and long-term effect of optical radiation is its ability to reset the internal circadian body clock and synchronize it to local time. Circadian rhythms are daily rhythms that repeat approximately every 24 hours and are driven by an endogenous clock. Nearly all behavioral and physiological parameters exhibit circadian rhythms and thus circadian clock synchronization with the daily light dark pattern is paramount to the body's efficient and appropriate functioning. IES TM-18-08 [2] provides a more detailed review.

3.2.1 Ganglion Photoreceptors

Melanopsin is the fifth opsin-based photopigment from the mammalian eye and mediates the non-visual response [3][4]. Melanopsin shares structural similarities with all known photopigments. Following the discovery of melanopsin, a new class of photoreceptor was discovered in the rodent retina: the intrinsically photosensitive retinal ganglion cells (ipRGCs) [5]. These photoreceptors contain melanopsin and are principally, though not exclusively, responsible for the body's neuroendocrine response to optical radiation. [6] [7]

In contrast to the rods and cones, the ipRGCs are located in the retinal ganglion cell layer, depolarize in response to optical radiation, exhibit a much slower response to an optical radiation stimulus, and have a peak spectral response in the spectral region near 480 nm. See 2.1.3.1 Photoreceptors. Furthermore, the ipRGCs appear to function as independent photoreceptors to the extent that they respond to optical radiation even when they are physically or chemically isolated from other neurons [8]. However, their function may be influenced by interactions with the other interconnected photoreceptors in the retina.

The ipRGCs have sparsely branching dendrites (branched fibers that carry signals towards the cell body of a neuron) that are up to several hundred microns long, and most terminate in the inner plexiform layer (IPL). These ipRGCs comprise only 1-3 percent of all rodent retinal ganglion cells; however, because melanopsin is found throughout the dendrites, cell body, and axons, these cells form a diffuse photosensitive net that covers virtually the entire retina. Although ipRGCs respond to optical radiation stimuli very differently to the rods and cones, there is growing evidence that they receive input from rod and cone pathways, more specifically, the ipRGCs receive synaptic input from bipolar and amacrine cells. [9] [10]

The ipRGC exists in both human and non-human primates. They comprise approximately 0.2 percent to 0.8 percent of all ganglion cells present in the non-human primate retina. In the human retina, ipRGCs exist as an extended dendritic tree and form a pan-retinal network [11].

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3.2.2 Action Spectra

Recent analytical action spectra have characterized the spectral sensitivity of a range of the physiological responses that are consistent with the short-wavelength sensitivity of these newly characterized sensory cells. Action spectra for examined neuroendocrine, circadian, and ocular responses in humans, monkeys, and rodents all showed similar sensitivity to short-wavelength visible (blue) radiation. Predominantly, these action spectra show peak sensitivities in the short-wavelength region of the visible spectrum, with calculated λ_{max} indicating peak photosensitivity of 459 nm to 484 nm [24] [25].

Research suggests that this photoreceptor system is involved in ocular-mediated circadian, neuroendocrine, and neurobehavioral phototransduction. Although full analytic action spectra have yet to be developed, research work has confirmed that shorter wavelength polychromatic and monochromatic optical radiation is more potent in humans than exposure to other wavelengths of optical radiation for evoking the same criterion responses for circadian phase shifts, enhancing subjective and objective correlates of alertness, and increasing heart rate and temperature [12] [13] [14] [15]. Additionally, it has been shown that circadian system response to polychromatic optical radiation is not linearly additive [16].

3.2.3 Circadian Entrainment

The circadian pacemaker is a cluster of neurons named the suprachiasmic nucleus (SCN) of the anterior hypothalamus and is the site of the body's internal pacemaker. Optical radiation information is captured by retinal photoreceptors, converted into neural signals and conveyed directly to the SCN via a dedicated neural pathway: the retionhypothalamic tract RHT [17]. The 24-hour light-dark cycle resets the internal clock on a daily basis; in turn this clock signals a wide range of brain areas, resetting clock-controlled physiology and behavior. Figure 3.1 shows the neural pathway.

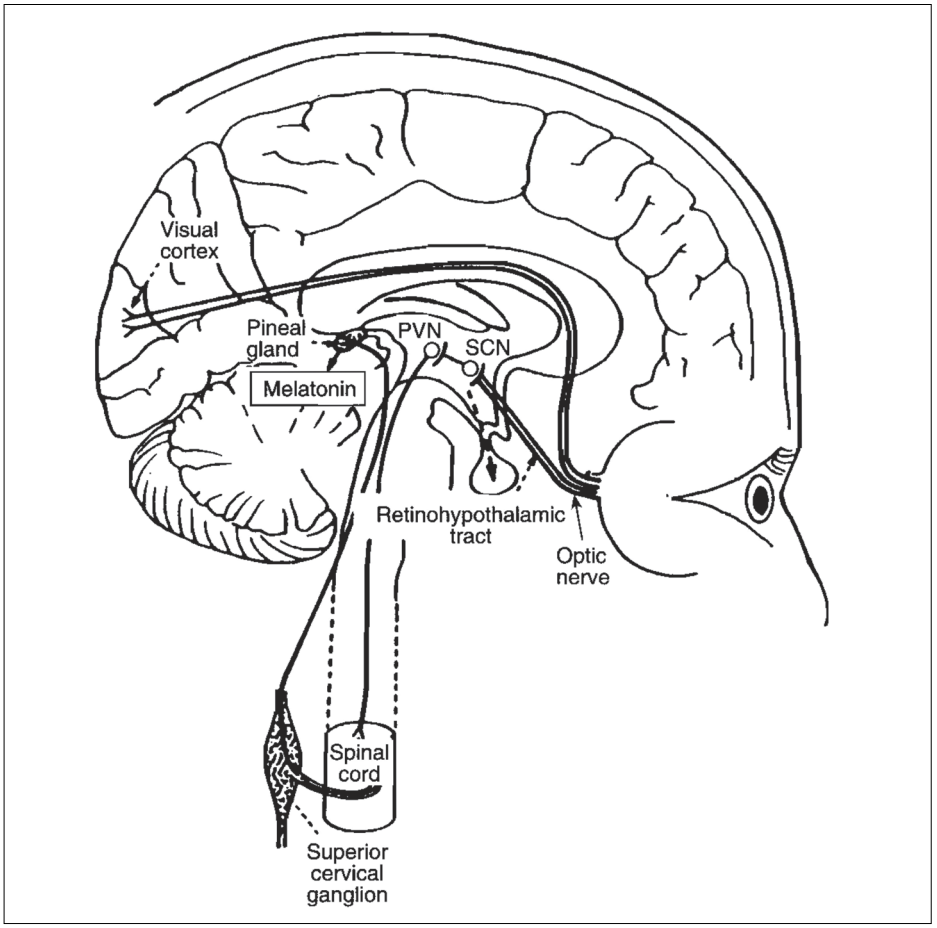


Figure 3.1 | Neutral Pathway of the Circadian Pacemaker
Simplified illustration of the pathway from the retina to the suprachiasmic nucleo (SCN) of the hypothalamic "clock" and its long multisynaptic projection to the pineal glad.

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The circadian pacemaker does not run at exactly 24 hours [18]. Environmental time cues must be able to reset this internal clock to ensure that physiology and behavior are appropriately synchronized with the outside world. The major environmental time cue that is able to reset (phase-shift) these rhythms is the 24-hour light-dark cycle. The ipRGCs are the central photoreceptors mediating circadian, neuroendocrine, and neurobehavioral responses.

In mammals, a wide variety of physiological and behavioral events exhibit circadian rhythmicity ranging from the obvious sleep-wake cycle to more covert changes in hormone levels, core body temperature, blood pressure, and gene expression. Perhaps the most pertinent circadian rhythms for the purpose of applied research are those which can be used as markers of the phase (timing) of the clock and hence reveal the impact of optical radiation stimuli on the clock.

The SCN drives the circadian rhythm in pineal melatonin production (that is, high melatonin levels at night and low melatonin levels during the day) via a multisynaptic pathway that projects to the paraventricular nucleus of the hypothalamus (PVN) and the superior cervical ganglion (SCG) [19]. Core body temperature (CBT) and the pineal hormone melatonin are the most commonly used phase markers of this rhythm. Melatonin is used more often since it is not subject to as many masking influences as it can be measured non-invasively.

3.2.4 Lighting's Effect on Circadian Rhythm

For synchronization with the environment (entrainment) to occur, the circadian clock's sensitivity to the resetting stimulus must change periodically. This allows phase shifts having different direction and magnitude, depending on the characteristics of the stimulus. Multiple optical radiation characteristics (that is: quantity, spectrum, timing, duration, pattern, and prior optical radiation exposure) all affect the magnitude of the phase-resetting response. [20]

3.2.4.1 Quantity of Broad Spectrum White Light

Laboratory work to determine the sensitivity threshold of the circadian system has demonstrated that the human circadian pacemaker phase shifts in response to relatively low levels of a broadband spectrum white light source (approximately 100 lux [10 fc] at the cornea) [21]. In fact, dose-response curves for a single 6.5-hour exposure of 9,500 lux (950 fc) of a white light source (4100 K fluorescent lamp) during the biological night, centered 3.5 hours before minimum core body temperature, show an S-shaped function. Figure 3.2 shows this relationship. This indicates that the phase-delay resetting response saturates at ~600-1000 lux (~60-100 fc) at the cornea, with ~100 lux (~10 fc) at the cornea generating about 50 percent of the maximum resetting response. Threshold levels of optical radiation required to impact the circadian clock outside of laboratory conditions are still unknown. [22] [23]

3.2.4.2 Spectrum

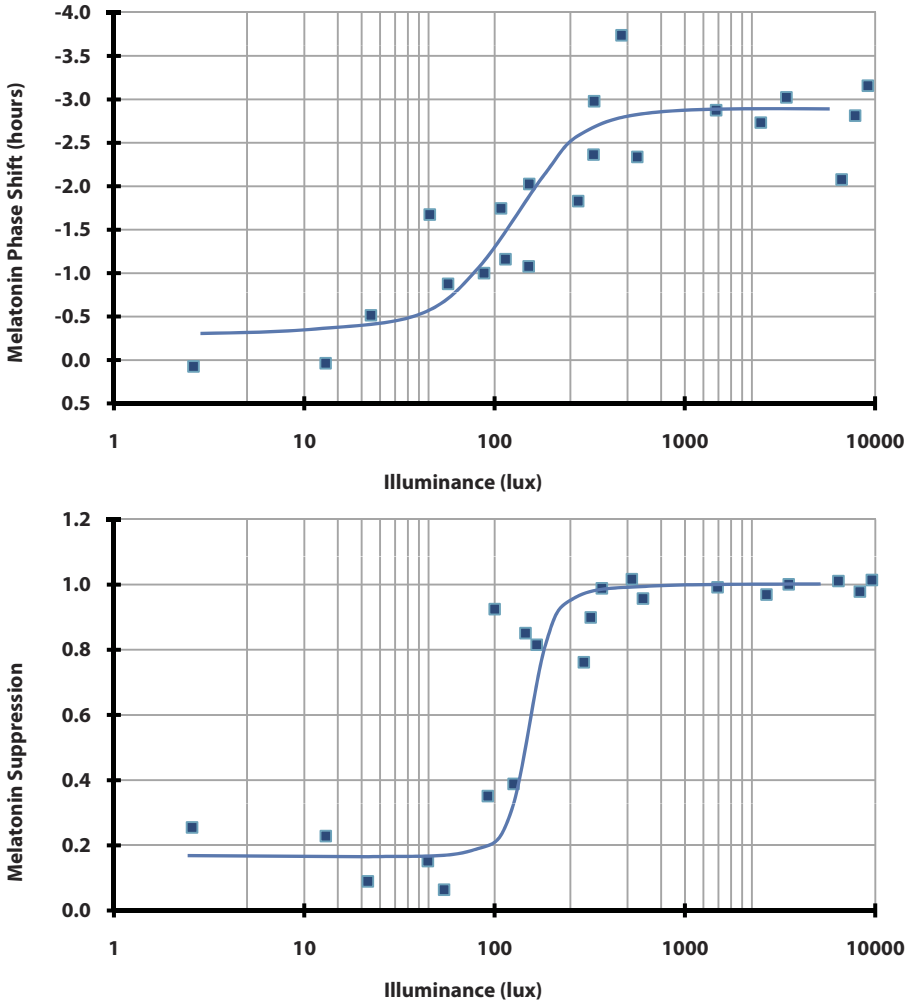
It is now widely accepted that circadian phototransduction sensitivity peaks in the short wavelength portion of the visible spectrum, and that multiple photopigments have the capacity to participate [24][25][26][7]. The wavelength regions where normal humans exhibit maximum non-visual sensitivity should also be considered when designing architectural lighting. Similarly, the wavelength sensitivity of different species will determine the optimum environmental lighting for these animals.

3.2.4.3 Timing

Crucial in determining the direction and magnitude of circadian phase-resetting effects is the timing of any optical radiation exposure. Exposure at one time of day can shift the circadian pacemaker timing earlier (i.e., advance the clock phase); exposure at another time of day can shift the pacemaker timing later (that is, delay the clock phase).

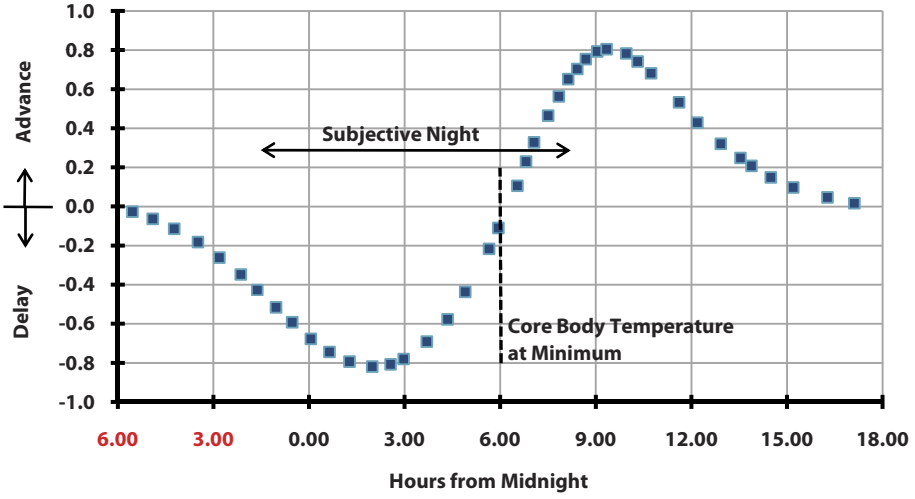
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Figure 3.2 | Melatonin Phase Shift and Suppression
Melatonin phase shift (top) and suppression (bottom) as a function of illuminance for a single 6.5-hour exposure of white light at the cornea from a 4100K fluorescent lamp, during biological night. Data is centered around a point 3.5 hours before body temperature reached minimum. Data from [21].



The change in direction and magnitude of the phase shift as a function of time of exposure to optical radiation can be plotted as a Phase Response Curve (PRC). A diagram representing the human PRC to optical radiation for someone living under normal light-dark conditions is shown in Figure 3.3. The phase shifting effects of optical radiation (vertical axis) to either a later time (phase delay, negative value) or earlier time (phase advance, positive value) are plotted against the time of day of exposure (horizontal axis).

Figure 3.3 | Phase Response
Circadian phase response of the pacemaker to time of exposure to optical radiation.



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An eight-hour sleep episode is superimposed from 0:00-8:00 hours. Under normal conditions, optical radiation exposure between 18:00-6:00 hours (before the minimum core body temperature is reached) causes a pacemaker phase delay, with a maximum delay at about 2:00 am. Optical radiation delivered between 6:00-18:00 hours (after the minimum core body temperature is reached) causes the clock to advance, with a maximum advance occurring after exposure in the morning (~9:00 hours) [27]. It is important to note that minimum core body temperature occurs at different times in different individuals and that light should be applied with respect to this minimum.

Optical radiation exposure has a maximum effect shifting the pacemaker when it occurs during the biological night. This is when humans are usually asleep and therefore normally encounter minimum light. Exposure is less effective during the biological day.

3.2.4.4 Duration

The phase-shifting effects of optical radiation are also dependent on the duration and pattern of optical radiation exposure, and vary exponentially with duration. A daily three-hour exposure to 5000 lux (500 fc) at the cornea was as effective as a six-hour exposure for adaptation to an experimental night shift. The PRC for a one-hour exposure to 10,000 lux (1000 fc) from a polychromatic light source at the cornea has approximately 45 percent of the PRC amplitude for a 6.7-hour exposure to the same optical radiation [28].

3.2.4.5 Spatial Distribution

Unlike the visual system, non-visual photoreception does not require precise spatial resolution of optical radiation because it is concerned with changes in ambient irradiance. The distribution and number of ipRGCs generating these non-visual responses support this hypothesis. Non-visual receptors consist of a small number of the total retinal ganglion cells, spread nearly uniform across the retina in a net-like distribution. These cells also have very large dendritic fields that are photosensitive, which further assists broad (but relatively insensitive) optical radiation detection [29].

3.2.4.6 Adaptation

The human circadian system's sensitivity to optical radiation appears to be determined by optical radiation exposure over the immediately preceding hours (and possibly the days), and so non-visual phototransduction appears to exhibit adaptation. Photic history (from the preceding days and weeks) also influences human sensitivity to optical radiation at night as measured by melatonin suppression. The higher the exposure to optical radiation during the day (for example, one week of exposure for four hours/day to outdoor light), the lower the human circadian system's sensitivity becomes to optical radiation at night. [30]

3.3 Effects of Optical Radiation on the Eye

Three elements are involved in optical radiation damage to various components of the eye: the accessibility of a given wavelength to the tissue in question, the absorbance of that wavelength, and the ability of the tissue to deal with the insult that the absorption of energy represents.

Retinal and other ocular effects of optical radiation can be increased or decreased in severity by the presence of internally generated or externally supplied photoactive compounds. Psoralens, hematoporphyrin derivatives, and other phototherapeutic agents can enhance the damaging effects of various wavelengths on the eye and other tissues. In contrast, vitamin E can act as a quencher of excited-states in related species and has been hypothesized to increase the threshold for light-induced damage. Many new pharmaceutical agents can increase the potential for phototoxic effects.

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3.3.1 UV Effects

Table 3.2 shows how much energy in each of several wavelength bands in the UV are absorbed by the various components of the eye. For wavelengths less than 320 nm, nearly all of the radiation is absorbed by the cornea. Between 320 and 400 nm, much of the UV radiation is absorbed by the lens; the proportion is dependent on age. See 2.6.3 Effects of Age. The optical media of the human eye, until early adulthood, transmit a small percentage of UV radiation to the retina, resulting in a theoretical visual response for wavelengths as short as 300 nm.

3.3.1.1 UV Effects on the Cornea

Photokeratitis is a painful but not necessarily deleterious inflammation of the epithelial (outermost) layer of the cornea. The period of latency between exposure and the onset of symptoms varies from 2 to 8 hours, depending on the amount of radiation received. For moderate exposures, the effects are more frightening than serious. The symptoms include inflammation of the conjunctiva accompanied by a reddening of the surrounding skin and eyelids. There is a sensation of sand in the eyes, tearing, sensitivity to light, and twitching of the eyelids. Recovery is rapid and usually complete within 48 hours except for severe cases. The action spectrum, similar to that for skin erythema, peaks at 270 to 280 nm.

3.3.1.2 UV Effects on the Lens

The lens shows a number of changes with aging, including a yellowing coloration, an increasing proportion of insoluble proteins, sclerosis with loss of accommodation, and cataract. There is a growing body of evidence, mostly epidemiological, to implicate UV radiation in these changes. For example, cataract extractions are significantly more frequent in India than in Western Europe. Part of the difference may be due to diet and genetic factors, but most authorities believe that exposure to sunlight plays an important role. While many of the early epidemiological studies of cataract have been inconclusive, more recent attempts have shown statistical significance in the relationship between cortical lens opacities and lifelong UV-B exposure in persons living and working in high levels of solar energy. Suggestions have been made that UV-A also may have a role in cataract formation. There are arguments that UV exposure might not be a significant causal factor for cataracts. Until these issues are resolved, the conservative approach is to minimize unnecessary UV exposure of the eyes. [31] [32]

3.3.1.3 UV Effects on the Retina

Retinal effects of UV radiation are difficult to categorize because they depend on the individual filtering capabilities of the preretinal ocular media. In adults, the crystalline lens, which typically absorbs wavelengths below about 400 nm, effectively shields the retina from UV radiation. Studies have shown, however, that a small percentage of UV radiation can reach the retina in human adults up to 30 years of age. Removal of the lens in cataract surgery renders the retina more susceptible to damage from wavelengths down to 300 nm. If a UV-blocking intraocular lens (IOL) is surgically implanted, however, then the UV absorption is restored. UV shielding is also available for rigid gas-permeable (RGP) and hydrogel varieties of contact lenses.

Table 3.2 | UV Precent Absobtion by Components of the Eye

Wavelength (nm)	Cornea	Aqueous Humour	Lens	Vitreous Humour
< 290 nm	100	0	0	0
300 nm	92	6	2	0
320 nm	45	16	36	1
340 nm	37	14	48	1
360 nm	34	12	52	2

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3.3.2 Visible and Near-IR Effects

Retinal injury resulting in a loss of vision (scotoma) following observation of the sun has been described throughout history. The incidence of chorioretinal injuries from fabricated light sources is extremely small and is no doubt far less than the incidence of eclipse blindness. Until recently, chorioretinal burns resulting from industrial operations were rare occurrences. This is still largely accurate, since the normal aversion to high-brightness light sources (the blink reflex and movement of the eyes away from the source) provides adequate protection unless the exposure is hazardous within the duration of the blink reflex. The use of lasers has meant a great increase in the use of high-intensity, high-radiance sources that have output parameters significantly different from those encountered in the past and may present serious chorioretinal burn hazards.

In addition to lasers, one may encounter the following sources of continuous optical radiation in industry: compact arc lamps (as in solar simulators), tungsten-halogen lamps, gas and vapor discharge tubes, electric welding units, and sources of pulsed optical radiation, such as flash lamps and exploding wires. The intensities of these sources may be of concern if adequate protective measures are not taken. Extreme IR irradiances have been linked to corneal, lenticular, and retinal damage; although the ocular structures can adequately dissipate the heat from low-power diffuse IR exposures, the same amount of energy delivered in pulses to very small areas of tissue can cause damage. Coherent light generated by Neodymium yttrium aluminum garnet (Nd:YAG) and argon lasers can penetrate to intraocular structures. Light from krypton, HeNe, and ruby lasers can reach the retina. Such sources have been used therapeutically in retinal photocoagulation procedures.

To place chorioretinal injury data in perspective, Table 3.3 shows the retinal irradiance for many light sources. It is reemphasized that several orders of magnitude in radiance or luminance exist between sources that cause chorioretinal burns and those levels to which individuals are continuously exposed. The retinal irradiances shown in Table 3.3 are only approximate and assume minimal pupil sizes and some squinting for the very high luminance sources.

Most standards regarding Maximum Permissible Exposure (MPE) are derived from animal and human experiments, and modeling biological systems [33]. The primary data are usually for narrow band sources such as lasers, and account for wavelength and duration. MPE values for broadband sources are derived from integrating across wavelengths.

As discussed in 2.2.4 | Retinal irradiation, the retina is vulnerable to radiation effects between 400 and 1400 nm. Between these wavelengths the retina is by far the most sensitive tissue of the body. Optical radiation travels through multiple layers of neural cells in the retina before encountering the photoreceptors. See 2.1.1.6 Retina. Just behind

Table 3.3 | Retinal Irradiance vs. Image Size for Different Light Sources

Source	Absorbed Retinal Irradiance (W/cm^2)	Approximate Retinal Image of the Source (mm)
Interior Lighting	10^{-8} - 10^{-7}	10
Outdoor Daylight	10^{-6} - 10^{-4}	1 - 10
Candle	10^{-5}	0.05
T-8 Fluorescent Lamp	10^{-4}	0.2 - 1
Frosted Incandescent Lamp	10^{-4}	0.2
Pyrotechnic Flare	10^{-3} - 10^{-4}	0.05
Tungsten Filament	10^{-2} - 10^{-1}	0.025
Sun	10^{-1} - 1	0.1
Welding Arc	1 - 10^{+1}	0.02
Laser (1 mW)	10^{+2} - 10^{+3}	0.01

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the photoreceptors is a single layer of heavily pigmented cells, the pigment epithelium, which absorbs a large portion of the light passing through the neural retina. The pigment epithelium acts like a dark curtain to absorb and prevent backscatter from those photons that are not absorbed in the outer segments of the rods and cones. The neural retina itself is almost transparent to light. Most of the optical radiation that reaches the retina is converted to heat by the pigment epithelium and the choroid. Sufficiently large quantities of light can generate sufficient heat to damage the retina.

Research in recent decades has demonstrated that for radiant energy between 400 and 1400 nm, there are at least three different mechanisms leading to retinal damage. These are:

1. Thermal damage from pulse durations extending from microseconds to seconds. Except for minor variations in transmittance through the ocular media and variations of absorbance in the pigmented epithelium and choroid, thermal damage is not wavelength dependent.

2. Photochemical damage from exposure to short wavelengths in the visible spectrum for time durations and power densities on the retina that preclude thermal effects. Photochemical damage is wavelength dependent.

3. Mechanical (shock-wave) damage from picosecond and nanosecond pulses of lasers.

In terms of exposure time and wavelength there is no abrupt transition from one type of damage to the other. A number of researchers have shown that long-term exposure to light can cause retinal damage in some animals. For example, when rats and mice are subjected to cool white fluorescent lighting for extended periods of time (weeks to months), they become blind. Histological examination reveals that the photoreceptors in the retinae of these animals have degenerated. Although rodent retinal photoreceptors can be damaged with long exposures to relatively low levels of white light, such damage in primates has been demonstrated only with the eyes dilated and at a continuous exposure of 10,800 lux for 12 hours. Exposure of the undilated monkey eye at that illuminance for 12 hours per day for 4 weeks did not produce photoreceptor damage. [34]

3.3.3 IR Effects

Very little IR radiation of wavelengths longer than 1400 nm reaches the retina, but such radiation can produce ocular effects leading to corneal and lenticular damage. Cataracts from exposure to IR radiation have been reported in the literature for a long time, but there are few and no recent data to substantiate the clinical observations. It is now believed that IR radiation is absorbed by the pigmented iris and converted to heat that is conducted to the lens, rather than by direct absorption of radiation in the lens. IR cataractogenesis has been reported to occur among glassblowers, steel puddlers, and others who undergo long-term occupational exposure to IR radiation. Present industrial safety practices have virtually eliminated this effect.

3.4 Effects of Optical Radiation on the Skin

Acuity is the ability to resolve fine details and is ultimately limited by diffraction, aberrations, and the photoreceptor density of the retina. Several different kinds of acuity are recognized and involve various levels of visibility, from detection to recognition. See 4.2.7 Threshold and Suprathreshold Visibility.

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3.4.1 Properties of the Skin

The reflectance of skin for wavelengths shorter than 300 nm is low, regardless of skin color; however, from 300 to 750 nm the reflectance is dependent on skin pigmentation. The transmission of UV radiation through the skin depends on wavelength, skin color (melanin content), and skin thickness. In general, transmission increases with increasing wavelength from 280 to 1200 nm. Typically, for those of European descent, the transmittance through the top layer of skin (stratum corneum) is 35% at 300 nm and 60% at 400 nm. In persons of African descent, the transmittance of the stratum corneum is about 20% at 300 nm and 40% at 400 nm. Transmission decreases with increasing melanin content of the skin and with increasing skin thickness. Typical data are shown in Fig 3.4

Figure 3.4 Skin spectral transmittance for two individuals: (a) heavily pigmented skin, and (b) lightly pigmented skin. Solid line shows the spectral transmittance of just the top layer of the epidermis, the stratum corneum. The dashed line shows the spectral transmittance for the entire epidermis.

While skin color is the genetically determined result of a number of factors, the primary factor is melanin. Melanin protects against UV damage by reducing transmission through absorption and scattering. Its quantity, granule size, and distribution all affect skin color. The immediate tanning that occurs with exposure to UV-A radiation and extending into the visible region is the darkening of existing melanin. Delayed tanning results from UV stimulation of the melanin-producing cells (the melanocytes) to produce additional melanin. Pigmentation from this process begins immediately at the subcellular level. Fading requires months, as melanin is lost during the normal shedding process.

3.4.2 Erythema

The delayed reddening (actinic erythema) of the skin caused by exposure to UV radiation is a widely observed phenomenon. The spectral efficiency of this process, particularly for sunlight radiation between 290 and 320 nm, has been well studied. The reported erythema action spectrum for wavelengths shorter than 290 nm varies considerably among observers because of differences in the degree of erythema taken as the endpoint criterion and differences in the time of observation after irradiation. In the past, no single

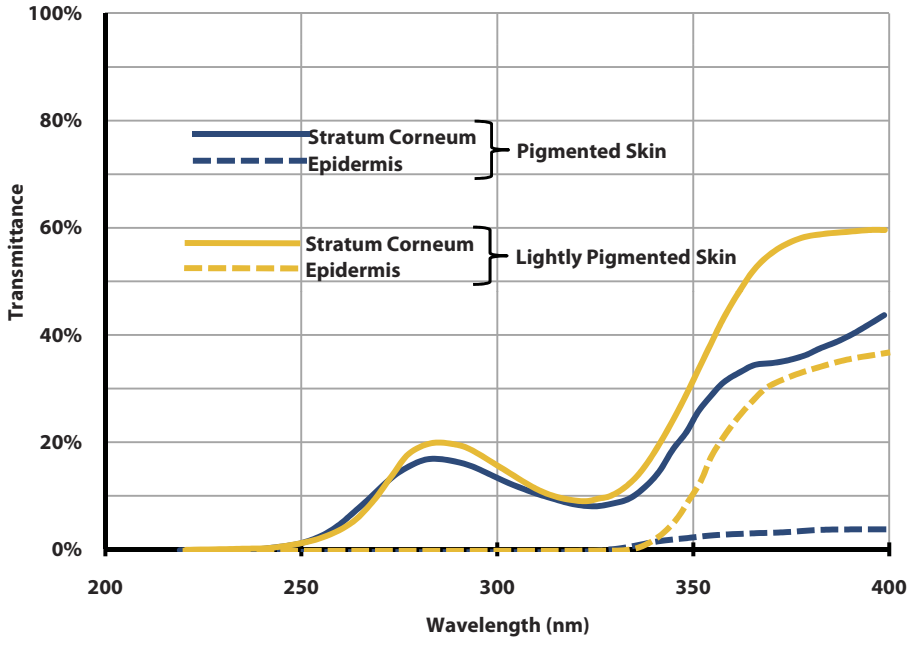


Figure 3.4 | Skin Transmittance
Skin spectral transmittance for two individuals: (a) heavily pigmented skin, and (b) lightly pigmented skin. Solid line shows the spectral transmittance of just the top layer of the epidermis, the stratum corneum. The dashed line shows the spectral transmittance for the entire epidermis.

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erythemal action spectrum had been universally adopted. In 1993, a reference erythemal spectrum was proposed by the CIE, and it should supplant the various functions used in the past [35]. Erythema is a component of skin inflammation and results from increased blood volume in superficial cutaneous vessels. Affected skin can therefore be warm and tender.

Approximately 25 mJ/cm^2 of energy at the most effective wavelength (297 nm) causes a barely perceptible reddening in fair-skinned Caucasians. This amount of effective energy can be experienced during a 12-min exposure under overhead sun in the tropics where the stratospheric ozone layer is thinner. When the sun is 20° from its zenith and the ozone layer thickness is greater, an exposure of 20 min is typically required for the same degree of reddening.

Exposure to UV radiation (particularly at high irradiance levels) can cause immediate erythema. Fading can occur a few minutes after irradiation ceases, and can reappear after 1 to 3 hours. The greater the dose, the faster the reappearance, and the longer the persistence of erythema.

If the erythema is severe, skin peeling (desquamation) can begin approximately 4 days after exposure. This rapid sloughing off of the top skin layer results from the increased proliferation of skin cells during recovery after UV damage. Desquamation carries away some of the melanin granules stimulated by the UV radiation.

Photoprotection, in its common usage, refers to the protection against the detrimental effects of optical radiation afforded by sunscreens topically applied to the skin. These sunscreens reduce the effect of UV exposure primarily by absorption, but also by reflection in some cases. Some sunscreens are effective and relatively resistant to being washed away by sweating or swimming.

3.4.3 Vitamin D Production

UV radiation plays an important role in the production of vitamin D in the skin. Vitamin D production begins with UV-B irradiance on the skin, transforming Cholesterol-containing body oils into pre-Vitamin D. These are absorbed by the body, transformed into Vitamin D and eventually appear in the blood and distributed to organs.

The action spectrum for this effect has been determined directly in human skin, with a peak of effectiveness near 297 nm. Melanin content in the skin, sunscreen use, and aging decrease the capacity of the skin to produce vitamin D. Furthermore, such environmental factors as changes in latitude, season, and time of day also greatly influence the cutaneous production of vitamin D. Increased exposure to sunlight results in an increased production of vitamin D, which can be detected in the blood. Most of the vitamin D requirement (upwards of 90%) for children and adults comes from casual exposure to sunlight. Elderly or infirm persons who consequently might not be exposed to normal environmental levels of UV radiation depend on dietary sources and supplements for their vitamin D requirement [36].

This vitamin is essential for normal intestinal absorption of calcium and phosphorus from the diet and for the normal mineralization of bone. Vitamin D deficiency causes a deficiency of calcium and phosphorus in the bones (such that they bend, fracture, or become painful) and causes such bone-softening diseases as rickets in children and osteomalacia in adults. Vitamin D poisoning, on the other hand, leads to excessive absorption of calcium and phosphorus from the diet and consequently a toxic effect on the skeleton. There is also a resultant increase in the blood calcium concentration and a precipitation of calcium phosphate deposits in vital organs, causing permanent damage or even death. Vitamin D poisoning also causes increased excretion of calcium in the urine, which can produce kidney stones or bladder stones. Mild cases of vitamin D poisoning lead only to increased urinary calcium excretion.

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3.4.4 Immune System Response and Skin Cancer

Photoimmunology is the study of nonionizing radiation, predominantly in the UV portion of the spectrum, on the immune system. The photoimmunologic effects of UV radiation are selective: only a few immune responses are affected. The alterations studied in greatest detail are the induction of susceptibility to UV-induced neoplasia and systemic and local suppression of contact hypersensitivity. Most observations have been made in experimental animal systems, although some photoimmunologic effects have been observed in humans.

UV radiation can affect immunity systematically. For example, exposure of the skin to UV at one place on the body can reduce the sensitivity to UV at unexposed sites. This probably occurs through the release of mediators from the skin at the exposure site, which in turn results in the formation of antigen-specific T suppressor lymphocytes (white blood cells); such cells have been found in the spleens of animals.

The three varieties of skin cancer are basal cell, squamous cell, and malignant melanoma. The frequency of occurrence is in the order stated, basal cell cancer being the most common. The prevalence of basal cell carcinoma varies inversely with latitude. The prevalence of both basal and squamous cell cancer correlates positively with solar UV exposure, but there is some evidence that UV exposure after age 10 might not contribute to basal cell cancer. Basal and squamous cell cancers often are cured if treated promptly. Melanomas are considerably rarer, have a poorer cure rate, and show a poorer correlation with UV exposure. Whether commonly used electric light sources provide enough UV radiation to increase carcinogenic risk is not certain. The unfiltered, quartz envelope halogen lamps can emit enough UV radiation to induce actinic erythema in people who work under them for extended periods at high illuminances. Quartz halogen luminaires commonly include glass filters to reduce UV emissions. The Commission Internationale de l'Eclairage (CIE) concludes that there is insufficient evidence to support the hypothesis that common fluorescent lamps can cause malignant melanoma [37].

3.5 Phototherapy

Optical radiation has been used therapeutically in a wide variety of applications, including dermatology, photochemistry, psychiatry, and oncology. A variety of diseases have been treated with visible or UV energy, alone or in combination with sensitizing drugs. Some forms of treatment, such as photochemotherapy, are established and have been practiced for decades, while others, such as low-level laser therapy, remain experimental.

3.5.1 Seasonal Affective Disorder (SAD)

Seasonal Affective Disorder (SAD) has been formally described in the scientific literature and included in the latest edition of the American Psychiatric Association's (APA) diagnostic manual, DSM-IV-TR [38]. Independent studies in the United States and Europe suggest that winter depression is a widespread syndrome. A study of the frequency of SAD manifestation on the east coast of the United States estimated that SAD occurs in less than 2% of the population in Florida, but in New Hampshire nearly 10% of the population show symptoms during fall and winter. From this study, it has been projected that as many as 10 million Americans have SAD and possibly an additional 25 million are susceptibility to a milder, subclinical form of SAD.

People affected with this malady experience a dramatic decrease in their physical energy and stamina during the fall and winter months. As days become shorter, persons with SAD often find it increasingly difficult to meet the routine demands at work and at home. In addition to this general decrease in energy, SAD sufferers experience emotional

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depression, feelings of hopelessness, and despair. Other symptoms of winter depression or SAD can include increased sleepiness and need for sleep, increased appetite (particularly for sweets and other carbohydrates), and a general desire to withdraw from society. Fortunately, daily light therapy has been found to effectively reduce symptoms in many patients.

Considerable research has been directed at determining the optimum illuminance, exposure, and time of day for the light treatment of winter depression. Most studies using light boxes indicate that illuminances from 2,500 to 10,000 lx produce strong therapeutic results in treating SAD. In determining the best dosage of light, the intensity and exposure duration must be considered together. The strongest therapeutic responses have been documented with a 2,500-lx exposure over 2 to 4 h and with a 10,000-lx exposure over 30 min.

Current evidence supports the hypothesis that light therapy works by way of an ocular pathway as opposed to a dermal or transdermal mechanism. Several studies have investigated the action spectrum for SAD light therapy. Ultimately, a thoroughly defined action spectrum can both guide the development of light treatment devices and yield important information about the photosensory mechanism responsible for the beneficial effects of light therapy. Current research clearly shows that SAD symptoms can be reduced by lamps that emit little or no UV. Hence, UV radiation does not appear to be necessary for eliciting positive therapeutic results.

Most of the clinical trials treating winter depression have employed white light emitted by commercially available lamps. The white light used for treating SAD can be provided by a range of lamp types, including incandescent and fluorescent. But short wavelength optical radiation from LEDs has been shown to be more effective in SAD treatment than long wavelength optical radiation. [39][40]

3.5.2 Skin Disease

UV radiation is used for the treatment of various skin diseases such as psoriasis and eczema. The most effective wavelengths appear to be in the UV-B portion of the spectrum. Patients are usually given a small, whole-body exposure to a dose of radiation three to five times a week. The dose is just below that which produced erythema. Usually twenty to forty such treatments are required to clear the skin. Maintenance treatments are then necessary at weekly intervals to control the condition until remission occurs. Various sources of radiation have been used, but at this time fluorescent and metal halide lamps are preferred. Adverse effects from this treatment are uncommon except for the short-term problem of erythema. Photoaging of the skin and presumably skin cancer are potential long-term problems, although the degree of risk of the latter effect has not been evaluated fully.

Photochemotherapy is defined as the combination of optical radiation and a drug to bring about a beneficial effect. Usually, in the doses used, neither the drug alone nor the radiation alone has any significant biologic activity; it is only the combination of drug and radiation that is therapeutic. PUVA (psoralen and UV-A) is a term used to describe oral administration of psoralen and subsequent exposure to UV-A. PUVA has proven to be effective in treating psoriasis, vitiligo, certain forms of severe eczema, a malignant disorder called mycosis fungoides, and a growing list of other skin disorders.

Psoralens are naturally occurring chemicals, some of which can be photoactivated by UV-A. In living cell systems, absorption of energy from photons within the 320- to 400-nm waveband (with a broad peak at 340 to 360 nm) results in the transient inhibition of DNA synthesis. When certain psoralens are delivered to the skin either by direct application or by oral route, subsequent exposure to UV-A can result in redness and tanning,

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which are delayed in onset, occurring hours to days after exposure. The redness, or skin inflammation, from PUVA can be severe and is the limiting factor during treatment.

Because skin diseases can be treated at PUVA dose exposures that are less than those causing severe redness, careful dosimetry permits safe treatments. Pigmentation resulting from PUVA appears histologically and morphologically similar to true melanogenesis (delayed tanning).

The sun can be used as a PUVA radiation source but carries the disadvantage of unpredictable and varying UV irradiance and spectral distribution at the earth's surface. In tanned or pigmented patients, long exposure times can be required. For example, the exposure duration for both front and back of the body can be two to three times that needed for a single total-body treatment in a photochemotherapy system. Some patients, however, are willing to tolerate the heat and boredom of sun exposure in order to have the advantage of home treatment. Intense sun, clear skies, metering devices, careful instruction, and intelligent, cooperative, and motivated patients are required to make sun PUVA therapy a reasonable alternative to hospital or office treatment.

Exposure to high irradiances of UV-A for prolonged periods of time can cause cataract and skin cancer in laboratory animals. These effects are enhanced by psoralens. The exposures used in these studies are much greater than therapeutic exposures. Observations in animal systems indicate that the extent of skin cancer induction varies with dose and route of psoralen administration and UV exposure. Both basal cell and squamous cell carcinomas have been observed in patients treated with PUVA. The incidence of these tumors is highest in patients with a prior history of exposure to ionizing radiation or a previous cutaneous carcinoma. These findings suggest that the potential risk of PUVA-related cutaneous carcinogenesis should be carefully weighed against the potential benefit of this therapy. Special care must be taken in treating patients with prior histories of cutaneous carcinoma or exposure to ionizing radiation.

It seems wise to limit the use of psoralen photochemotherapy to those with significant skin disease and to use adequate UV-A eye protection during the course of therapy. After ingesting psoralens, patients should protect their eyes for at least the remainder of that day. Physicians must be aware of these theoretical concerns and must carefully observe patients for signs of accelerated actinic damage. Glasses that are opaque to UV-A decrease total UV-A exposure to the lens and should be worn on treatment days.

3.5.3 Hyperbilirubinemia

Hyperbilirubinemia in neonates is more commonly known as jaundice of the newborn. It is estimated that 60% of all infants born in the United States develop jaundice during the first week of life and that about 7 to 10% of neonates have hyperbilirubinemia of sufficient severity to require medical attention.

Jaundice is the symptom and not the disease. It results from the accumulation of a yellow pigment, bilirubin, as a result of the infant's inability to rid itself of bilirubin as rapidly as it is produced. Bilirubin is derived principally from the degradation of hemoglobin. At normal concentrations, bilirubin is transported in the blood and excreted in the urine. Infants with hyperbilirubinemia lack the ability to excrete bilirubin in the normal manner.

In neonates, increased amounts of bilirubin circulate in the blood. This is a result of normal red corpuscle degradation coupled with the functional immaturity of the neonatal liver. Peak levels of bilirubin typically occur in healthy full-term neonates between the second and fifth day of life. By the seventh day of life, they typically decrease to normal adult levels. In the case of premature infants, peak bilirubin levels build up more slowly, and then slowly decline to adult levels over a period of up to four weeks.

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As the plasma concentration of bilirubin increases, there is a danger of allowing free bilirubin to circulate, penetrate the blood-brain barrier, and accumulate in the brain, thus producing bilirubin encephalopathy and irreversible damage from toxic injury to the brain. Phototherapy can be used to prevent the dangerous rise in plasma bilirubin.

Typically, phototherapy is administered with one of three types of systems: a conventional or overhead system of fluorescent lamps, an overhead tungsten-halogen spotlight, or a fiber optic pad. The light sources may be filtered to maximize radiation in the short visible wavelength region and to minimize unnecessary UV and IR radiation.

Overhead systems may be portable or incorporated into incubators, radiant warmers, or bassinets. They typically are mounted 25 to 50 cm from the infant, depending on the intensity required. Because of the blue appearance of the illumination from these systems, changes in infant skin color can be difficult to detect. Blue illumination also may contribute to irritation or nausea in some caregivers. The American Academy of Pediatrics (AAP) recommends radiation in the blue-green range: 430-490 nm in overhead phototherapy systems [41]. Phototherapy should be carried out only under the supervision of a suitably trained clinician.

3.6 Germicidal UV Radiation

Electromagnetic radiation in the wavelength range between 180 and 700 nm is capable of killing many species of bacteria, molds, yeasts, and viruses. The germicidal effectiveness of the different wavelength regions can vary by several orders of magnitude, but wavelengths shorter than 300 nm are generally the most effective for bactericidal purposes.

3.6.1 Action spectra

The bacterium most widely used for the study of bactericidal effects is Escherichia coli. Studies have shown the most effective wavelength range to be between 220 and 300 nm, corresponding to the peak of photic absorption by bacterial deoxyribonucleic acid (DNA). The absorption of the UV radiation by the DNA molecule produces mutations or cell death. The relative effectiveness of different wavelengths of radiation in killing a common strain of E. coli is shown in Table 3.4

Table 3.4 | Approximate Germicidal Efficiency of UV Optical Radiation at Various Mercury Emission Lines

Wavelength (nm)	Germicidal Efficiency
235.3	0.35
244.6	0.58
248.2	0.7
253.7	0.85
257.6	0.94
265.0	1
265.4	0.99
267.5	0.98
270.0	0.95
275.3	0.81
280.4	0.68
285.7	0.55
289.4	0.46
292.5	0.38
296.7	0.27
302.2	0.13
313.0	0.01

3.6.2 Sources

The most practical method of generating germicidal radiation is by passage of an electric discharge through low-pressure mercury vapor enclosed in a special glass tube that transmits shortwave UV radiation. Approximately 95% of the energy from such a device is radiated at 253.7 nm, which is very close to the wavelength corresponding to the greatest lethal effectiveness. These lamps come in various sizes and shapes including linear and compact sources.

Hot-cathode germicidal lamps are similar in physical dimensions and electrical characteristics to the standard fluorescent lamps. While both types of lamps operate on the same auxiliaries, germicidal lamps contain no phosphor and the envelope is made of a UV-transmitting glass. Quartz envelopes are used for some germicidal lamps. Slimline germicidal lamps are instant-start lamps capable of operating at several current densities within their design range, 120 to 420 mA, depending on the ballast with which they are used. Cold-cathode germicidal lamps are instant-start lamps with a cylindrical cathode. They are made in many sizes and operate from a transformer.

The life of the hot-cathode and slimline germicidal lamps is governed by the electrode life and frequency of starts. (Their effective life is sometimes limited by the transmission of the bulb, particularly when operated at low temperatures.) The electrodes of cold-cathode

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lamps are not affected by the number of starts, and their useful life is determined entirely by the transmission of the bulb. All types of germicidal lamps experience a decrement in UV emission as the total hours of operation increase. Lamps should be checked periodically for UV output to ensure that their germicidal effectiveness is maintained.

The majority of germicidal lamps operate most efficiently in still air at room temperature. For lamp efficiency measurements, UV output is standardized at an ambient temperature of 25°C. Temperatures either higher or lower than this decrease the output of the lamp.

Slimline germicidal lamps operated at currents ranging from 300 to 420 mA and certain preheat germicidal lamps operated at 600 mA are designed exceptions to this general rule. At these high current loadings, the lamp temperature is above the normal value for optimum operation; therefore, cooling of the bulb does not have the same adverse effect as with other lamps. These lamps are well suited for use in air conditioning ducts.

In addition to emissions at 253.7 nm, some germicidal lamps generate a controlled amount of 184.9-nm radiation, which produces ozone. Since ozone is highly toxic, its environmental concentrations have been limited by an Occupational Safety and Health Administration (OSHA) regulatory mandate to 0.1 parts per million (ppm), or 0.2 mg/m^3 [42]. Care should be taken when choosing germicidal lamps to meet the requirements of these regulations.

3.6.3 Effectiveness

The effectiveness of germicidal radiation is dependent on many parameters, including the specific susceptibility of the organism, the wavelength of radiation emitted, the radiant flux, and the time of exposure. [43] Germicidal effectiveness is proportional to the product of irradiance and time (from 1 μs to several h). A nonlinear relationship exists between UV exposure and germicidal efficacy. For example, if a certain UV exposure kills 90% of a bacterial population, doubling the exposure time or irradiance can kill only 90% of the residual 10%, for an overall germicidal efficacy of 99%. Likewise, a 50% decrease in irradiance or exposure time decreases germicidal efficacy only from 99% to 90%. Humidity can reduce the effectiveness of germicidal UV radiation.

3.6.4 Application Considerations

With the resurgence of multiple-drug-resistant forms of airborne disease (for example, Mycobacterium tuberculosis), new attention is being given to using UV air-mixing systems to prevent transmission. These systems can provide cost-effective controls in strategically placed areas and possibly in the whole building.

In occupied rooms, irradiation by an direct application luminaire germicidal lamp should be confined to the area above the heads of occupants. The ceiling of the room to be disinfected should be higher than 2.9 m (9.5 ft), and occupants should not remain in the room for more than 8 h. If either of the above conditions does not meet the requirements of the workspace, louvered equipment should be used to avoid localized high concentrations of flux that may be directed onto room occupants. Louvered luminaires using compact sources and electronic ballasts can provide energy efficient wall-, corner-, and pendant-mounted upper-room options. Some of these luminaires meet OSHA and NIOSH limits for rooms with 2.9 m ceilings for surface-mounted units and pendant units at a height of at least 3 m. [44] [45] [46][47]. An average irradiation of 20 to 25 μW/cm^2 is effective for slow circulation of upper air and maintains freedom from respiratory disease organisms comparable to outdoor air. Equipment performance is an additional consideration [51].

Upper-air disinfection, as practiced in such areas as hospitals, schools, clinics, jails, shelters, transportation systems, and offices, can be effective in providing relatively bacteria-free air at the breathing level of room occupants. Personnel movement, body heat, and

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winter heating methods create convection currents through a room sufficient to mix upper and lower room air. All surfaces irradiated by UV germicidal radiation (including ceilings and upper walls) should have a UV reflectance below 5% (characteristic of most oil and some waterbase paints). "White coat" plaster or gypsum-product surfaced wallboard and acoustical tile can have higher germicidal reflectances and should always be painted with a less reflective substance. Unpainted white plaster walls and ceilings can limit safe exposure to only 2 to 3 h even with louvered luminaires. These precautions are especially important in hospital infant wards because children are more sensitive to UV radiation than adults. Other considerations include safety and equipment performance.

In operating rooms where prolonged surgery is performed, UV sources are mounted above doorways to disinfect air entering through the doorways. Face and skin protection are required for anyone passing through these doorways.

It is possible to provide a sufficiently high level of UV radiation to kill 90 to 99% of most bacteria within very short exposure times at usual duct air velocities. Duct installations are especially valuable where central air heating and ventilating systems recirculate air through all of the otherwise isolated areas of a building. Slimline germicidal lamps, especially designed for cool, high-velocity ducts, commonly are installed inside access doors in the sides of ducts, either along or across the duct axis. Where possible, the best placement for lamps is across the duct to secure longer travel of the energy before absorption by the duct walls and to promote turbulence to offset the variation in UV radiation levels throughout the duct. Lamps should be cleaned periodically because dust buildup lowers UV emission.

3.6.5 Precautions

Exposure to germicidal UV radiation can produce eye injury and skin erythema and has produced skin cancer in laboratory animals [48][49][50]. The American Conference of Government and Industrial Hygienists (ACGIH) limit for exposure of the unprotected skin or eyes to radiation at 253.7 nm is 6 mJ/cm^2 within an 8-h period. For example, this conservative limitation would be 0.2 μW/cm^2 for an 8-h continuous exposure, 0.4 μW/cm^2 for a 4-h continuous exposure, and 10 μW/cm^2 for a 10-min continuous exposure. The maximum exposure time is only 1 min for 100 μW/cm^2. Some common G30T8 unshielded germicidal lamps can deliver this irradiance at a distance of 0.75 m.

Based on the potential for producing threshold keratitis, the National Institute of Occupational Safety and Health (NIOSH) has proposed that half of the intensity-time relationship established by ACGIH above be used as a safe industrial exposure for the eye. Eye protection is essential for all who are exposed to the direct or reflected radiation from lamps emitting UV radiation, especially those germicidal lamps emitting UV-C radiation. Ordinary window or plate glass or goggles that shield the eyes from wavelengths shorter than 340 nm are usually sufficient protection. However, if the radiation is intense or is viewed for some time, special goggles should be used. Failure to wear proper eye protection can result in temporary but painful inflammations of the conjunctiva, cornea, and iris; photophobia; blepharospasm; and ciliary neuralgia. Skin protection, achieved by wearing clothing and gloves that are opaque to germicidal radiation, is advised if the UV radiant intensity is high or if the exposure duration is long. Accidental overexposure can be avoided by education of maintenance workers. Warning signs in appropriate languages should be posted.

3.7 Lighting Safety Criteria

Human exposure limits for nonionizing optical radiation are consensus values. The Threshold Limit Values (TLVs) of the American Conference of Governmental Industrial Hygienists (ACGIH) normally are used in the United States and are widely accepted internationally. These TLVs are reviewed and updated annually to represent the best current

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scientific consensus for exposure safety. It is explicitly stated that these TLVs "represent conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects." Because they are presented as specific values, concern might arise if an exposure exceeds one of these values. The ACGIH explicitly addresses this concern by stating that the TLVs are guidelines, not specific breakpoints between safe and dangerous exposures.

The TLVs are the basis for the ANSI/IESNA RP-27.1-05 recommended practice [52].This document covers optical radiation of lamps and lamp systems between 200 nm and 3000 nm except for lasers and light-emitting diodes used in optical fiber communications. It expands upon and details methods for applying TLV criteria, which are applied to specific exposure situations and can be described as follows:

1. UV actinic effects of photokeratitis and photocon-junctivitis of the eye, and erythema (sunburn) of the skin. A spectral weighting function from 200 to 400 nm is used to collectively represent the potential hazard of radiation with respect to these effects.

2. UV cataractogenesis. Until the possibility of an increased risk of cataracts owing to long-term exposure is resolved, ocular exposure to radiation between 320 and 400 nm should be limited as a precaution.

3. Retinal photochemical injury ("blue-light" hazard). The retinal image of a source with high levels of energy primarily between 400 and 500 nm can produce photochemical injury of the retina. Radiation between 400 and 700 nm is spectrally weighted by a function to establish the potential for injury.

4. Retinal thermal energy. Viewing a high-radiance source can elevate retinal temperature. The radiant power between 400 and 1400 nm is spectrally weighted by a function related to ocular transmit-tance and retinal absorbance. Because retinal heat transfer depends on the image area, this criterion includes the angular size and shape of the source. This type of injury is dominant over retinal photochemical injury for exposures less than 10 s.

5. IR cataractogenesis. Chronic exposure to high levels of irradiance between 770 and 3000 nm can increase the risk of certain types of cataracts.

6. Skin thermal injury. Cellular injury occurs if skin temperature reaches approximately 45°C. Because this temperature is associated with intolerable pain, injurious exposure tends to be self-limited by discomfort for extended exposure times, and this criterion is applied only to short duration exposure to radiation between 400 and 3000 nm.

ANSI/IESNA RP-27.3 [53] extends these criteria to develop risk group classification for lamps. Lamps are divided into four groups each associated with a degree of potential hazard. The absolute degree of risk or safety cannot be determined for most lamps independent of their specific use in an application. This recommended practice defines exposure conditions, including time and distance, based on the philosophy of the risk groups. Using the characteristics of a lamp, the resulting exposures are evaluated in accordance with the criteria of ANSI/IESNA RP-27.1 to determine the risk group classification for the lamp. The system places a lamp in a single risk group based on the likelihood and seriousness of the potential risk. Specific lamp labeling and informational requirements are specified for each risk group.

The four risk groups and the philosophical basis for each of them are as follows:

1. Exempt group: The lamp does not pose any photobiological hazard within the limits specified in ANSI/IESNA RP-27.3.

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2. Risk group 1 (low risk): The lamp does not pose any photobiological hazard due to normal behavioral limitations on exposure.

3. Risk group 2 (moderate risk): The lamp does not pose any photobiological hazard due to the aversion response to very bright sources or due to thermal discomfort.

4. Risk group 3 (high risk): The lamp may pose a photobiological hazard even for momentary or brief exposures.

Owing to concern about eye safety and products that incorporate laser-type emitting devices, including certain light-emitting diodes, the International Electrotechnical Commission (IEC) and European Committee for Electrotechnical Standardization (CENELEC) have developed standards to minimize risks of eye injury from use of products containing LEDs. These standards include MPE levels and required testing methods for products using LEDs, as well as eye safety labeling recommendations based on the amount and type of emission produced by these products, just as with other light sources.

3.8 References

[1] [CIE] Commission Internationale de l'Eclairage. 1999. CIE collection in photobiology and photochemistry. CIE no. 133-99. Vienna: Bureau Central de la CIE.

[2] [IES] Illuminating Engineering Society. 2008. IES TM-18-08. An overview of the impact of optical radiation on visual, circadian, neuroendocrine, and neurobehavioral responses. New York. IES.

[3] Provencio, I. 1998. Melanopsin: An opsin in melanophores, brain, and eye. The Proceedings of the National Academy of Sciences Online (US). 95(1):340-5.

[4] Provencio, I. 2000. A novel human opsin in the inner retina. Journal of Neuroscience. 20(2): 600-5

[5] Berson, D M, Dunn, FA, Takao M.2002. Phototransduction by retinal ganglion cells that set the circadian clock. Science. 295(5557):1070-3

[6] Rea, M. 2005. A model of phototransduction by the human circadian system. Brain Res Rev. 50(2):213-28.

[7] Hattar, S. 2003. Melanopsin and rod-cone photoreceptive systems account for all major accessory visual functions in mice. Nature, 424(6944): 76-81.

[8] Berson D M. 2003. Strange vision: ganglion cells as circadian photoreceptors. In: Trends in Neurosciences. 26(6): 314-20.

[9] Provencio I, Rollag MD, Castrucci AM. 2002. Photoreceptive net in the mammalian retina. This mesh of cells may explain how some blind mice can still tell day from night. Nature. 415(6871): 493.

[10] Belenky, MA. 2003. Melanopsin retinal ganglion cells receive bipolar and amacrine cell synapses. J Comparative Neurology. 460(3): 380-93.

[11] Hattar, S. 2002. Melanopsin-containing retinal ganglion cells: architecture, projections, and intrinsic photosensitivity. Science. 295(5557): 1065-70.

[12] Warman VL. 2003. Phase advancing human circadian rhythms with short wavelength light. Neuroscience Letters. 342(1-2): 37-40.

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[13] Lockley SW, Brainard GC, Czeisler CA. 2003. High sensitivity of the human circadian melatonin rhythm to resetting by short wavelength light. J Clinical Endocrinology & Metabolism. 88(9): 4502-5.

[14] Belenky, MA. 2003. Melanopsin retinal ganglion cells receive bipolar and amacrine cell synapses. The Journal of Comparative Neurology. 460(3):380-93.

[15] Hannibal, J.2004. Melanopsin is expressed in PACAP-containing retinal ganglion cells of the human retinohypothalamic tract. Investigative Ophthalmology & Visual Science. 45(11): 4202-9.

[16] Figueiro MG, Bierman A, Rea MS. 2008. Retianl mechanisms determine the subadditive respnse to polychromatic light by the human circandian sytem. Neurosci Lett. 438(2):242-245.

[17] Moore RY, Speh JC, Card JP. 1995. The retinohypothalamic tract originates from a distinct subset of retinal ganglion cells. The Journal of Comparative Neurology. 352(3): 351-66.

[18] Czeisler, CA. 1999. Stability, precision, and near-24-hour period of the human circadian pacemaker. Science. 284(5423): 2177-81.

[19] Klein DC, Moore RY, Reppert SM. 1991. Suprachiasmatic Nucleus: The Mind's Clock. New York, NY: Oxford University Press. 230p.

[20] Rea MS, Figueiro MG, Bullough JD. 2002. Circadian photobiology: An emerging framwork for lighting practice and research. Light Res Tech. 34(3):177-187.

[21] Zeitzer, JM. 2000. Sensitivity of the human circadian pacemaker to nocturnal light: mela-tonin phase resetting and suppression. The Journal of Physiology. 526(Pt 3): 695-702.

[22] Boivin DB. 1996. Dose-response relationships for resetting of human circadian clock by light. Nature. 379(6565): 540-2.

[23] Cajochen C. 2000. Dose-response relationship for light intensity and ocular and electro-encephalographic correlates of human alertness. Behavioral Brain Research.115(1): 75-83.

[24] Brainard, GC.2001. Action spectrum for melatonin regulation in humans: evidence for a novel circadian photoreceptor. J Neuroscience. 21(16): 6405-12.

[25] Thapan, K, Arendt J, Skene DJ. 2001. An action spectrum for melatonin suppression: evidence for a novel non-rod, non-cone pho-toreceptor system in humans. J Physiology. 535(Pt 1): p261-7.

[26] Warman VL. 2003. Phase advancing human circadian rhythms with short wavelength light. Neuroscience Letters. 342(1-2):37-40.

[27] Khalsa SB. 2003. A phase response curve to single bright light pulses in human subjects. The Journal of Physiology. 549(Pt 3): 945-52.

[28] Lockley S, Gooley JJ, Kronauer RE, Czeisler CA. 2006. Phase Response Curve to single one-hour pulses of 10,000 lux bright white light in humans. In: 10th meeting of the Society for Research in Biological Rhythms (SRBR). Sansestin, Fla.

[29] Ruger M.2005. Nasal versus temporal illumination of the human retina: effects on core body temperature, melatonin, and circadian phase. J Biological Rhythms. 20(1): 60-70.

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[30] Wong KY, Dunn FA, Berson DM. 2005. Photoreceptor adaptation in intrinsically photosensitive retinal ganglion cells. Neuron. 48(6):1001-10.

[21] Taylor HR, West SK, Rosenthal FS, Munoz B, Newland HS, Abbey H, Emmett EA. 1988. Effect of ultraviolet radiation on cataract formation. New Engl. J. Med. 319(22): 1429-1433.

[32] Parisi AV, Green A, Kimlin MG. 2001. Diffuse Solar UV Radiation and Implications for Preventing Human Eye Damage. Photochemistry and Photobiology 73(2):135-139.

[33] Delori FC, Webb RH, Sliney DH. 2007. Maximum permissible exposures for ocular safety (ANSI 2000), with emphasis on ophthalmic devices. JOSA A. 24(5):1250-1265.

[34] Sykes SM, Robinson WG, Waxier M, Kuwabara T. 1981. Damage to the monkey retina by broad-spectrum fluorescent light. Invest. Ophthalmol. Vis. Sci. 20(4):425-34.

[35] [CIE] Commission Internationale de l'Eclairage. 1993. Reference action spectra for ultraviolet induced erythemal and pigmentation of different human skin types. CIE no 103/3. Vienna: Bureau Central de la CIE.

[36] Webb AR, Kline L, Holik MF. 1988. Influence of season and latitude on the cutaneous synthesis of vitamin D3: Exposure to winter sunlight in Boston and Edmonton will not promote vitamin D3 synthesis in human skin. J. Clin. Endocrinol. Metab. 67(2):373-378.

[37] Muel B, Cersarini J-P, Elwood JM. 1988. Malignant melanoma and fluorescent lighting. CIE Journal 7(l):29-32.

[38] American Psychiatric Association. 2000. Diagnostic and statistical manual of mental disorders. 4 ed. Washington: American Psychiatric Association.

[39] Golden RN, Gaynes BN, Ekstrom RD, Hamer RM, Jacobsen FM, Suppes T, Wisner KL, Nemeroff CB. 2005. The efficacy of light therapy in the treatment of mood disorders: a review and meta-analysis of the evidence. Am J Psychiatry. 162:656–662.

[40] Glickman G, Byrne B, Pineda C, Hauck W, Brainard G. 2006. Light Therapy for Seasonal Affective Disorder with Blue Narrow-Band Light-Emitting Diodes (LEDs). Biological Psychiatry. 59(6):502-50.

[41] [AAP] American Academy of Pediatrics. Subcommittee on Hyperbilirubinemia. 2004. Management of Hyperbilirubinemia in the newborn infant 35 or more weeks of gestation. Pediatrics. 114(1):297-316.

[42] US Dept of Labor. Occupational Safety and Health Administration. 1910.1000 TABLE Z-1.

[43] Miller SL. 2002. Efficacy of ultraviolet irraditation in controlling the spread of tuberculosis. Report: Centers for Disease Control and Prevention. 200-97-2602.

[44] Dumyahn T, First M. 1999. Characterization of ultraviolet upper room air disinfection devices. Am Indus Hygiene Assoc J. 60:219-227.

[45] [CIE] Commission Internationale de l'Eclairage. 2003. Ultraviolet air disinfection. CIE no 155:2003. Vienna: Bureau Central de la CIE. 85p.

[46] [NIOSH] National Institute for Occupational Safety and Health. 2009. Environmental control for tuberculosis: basic upper-room ultraviolet germicidal irradiation guidelines for healthcare settings. NIOSH Publication 2009-105. Washington, DC. 87 p.

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[47] [ASHRAE] American Society of Heating, Refrigeration, and Airconditioning Engineers. 2008. ASHRAE Handbook. Ch 16: Ultraviolet lamp systems. Atlanta, GA.

[48] [CIE] Commission Internationale de l'Eclairage. 2010. UlV-C photocarcinogenesis risks from germicidal lamps. CIE no 187:2010. Vienna: Bureau Central de la CIE. 23p.

[49] Nardell EA, Bucher SJ, Brickner PW, Wang C, Vincent RL, Becan-McBride K. 2008. Safety of upper-room ultraviolet germicidal air disinfection for room occupants: Results from the Tuberculosis Ultraviolet Shelter Study. Public Health Rep 123(1): 52-60.

[50] First MW, Weker RA, Yasui S, Nardell EA. 2005. Monitoring human exposures to upper-room germicidal ultraviolet irradiation. J Occup Environ. 2:285-92.

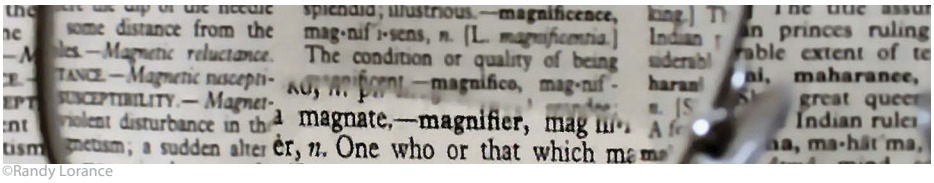
[51] First, MW, Banahan K, and T.S. Dumyahn. 2007. Performance of ultraviolet light germicidal irradiation lamps and luminaires in long-term service. Leukos 3(3):181-188.

[52] [IES] Illuminating Engineering Society. 2005. ANSI/IESNA RP-27.1-05. Photobiological Safety for Lamps and Lamp Systems-General Requirement. New York. IES.

[53] [IES] Illuminating Engineering Society. 2007. ANSI/IESNA RP-27.3-07. Photobiological Safety for Lamps and Lamp Systems-Risk Group Classificaiton. New York. IES.

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4 | PERCEPTIONS AND PERFORMANCE

The way the world looks to us is a remarkable achievement that calls for an explanation.
Irvin Rock, 20th Century Experimental Psychologist

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Lighting is one of the components of the built environment that produces our visual perceptions and provides for our visual performance. Acting in concert with the geometry of architecture, lighting helps establish how we perceive, assess, and react to an environment. Lighting also renders text and objects visible and so determines, in part, how well we can perform visual work; whether reading a book, operating a lathe, or driving a car. What we perceive and how well we perform is very often in the hands of the lighting designer.

Perceptions are, in some sense, part of our self-awareness. Though we may not know precisely why a space appears small, dim, and restful, we recognize it for being so and, when asked, will describe it as such. Yet for all their nearness to the surface, perceptions are difficult to quantify and so precise, analytic ways to predict them have yet to be found. Nevertheless, lighting design can be informed by a knowledge of the factors that affect perceptions and the general principles that govern them.

Though we constantly do visual work, we usually have a very imperfect idea of how well or poorly we do. In that sense, visual performance is below the surface. Nevertheless, performance, if defined with sufficient care and detail, can be measured. Assessments of experience, combined with such measurements, produce recommendations that can guide the analytic aspects of lighting and can become recommendations.

In the case of both perception and performance, psychophysics is the method of study and so this chapter begins with a description of that science. From that follow the principles and examples of perception and the recommendations established by the needs of visual performance.

4.1 Psychophysics: Studying Perceptions and Performance

Psychophysics is a subdiscipline of psychology that analyzes perceptual processes by studying the relationships between physical stimuli and a human response, the response being given by either the report of a perception or the performance of a task. Psychophysics is the source for much of the information about visual perceptions and performance that is used in lighting design. In psychophysical experiments, the properties of stimuli are varied along one or more physical dimensions and the resulting change in a subject's experience or behavior is noted. Subsequent analysis of these data is used to test hypotheses about relationships between stimuli and perceptions, and to evaluate the reliability and limits of models of vision or perception built from these hypotheses [1] [2]. Modern lighting design and illuminating engineering are guided by these models.

Models of vision and visual perception can be no more reliable or applicable than the relationships found by psychophysics from which these models are built. The reliability and utility of relationships between physical stimuli and visual perceptions can vary considerably, from weak and unreliable or of limited utility, to robust and of great generality. This variability arises because human visual and perceptual mechanisms are so formidably

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complex that it is usually impossible to establish an unbroken link between cause and effect, with a full understanding of the precise mechanisms involved. That is, usually only the input (the stimuli) and the output (the perceptual response) are known. Without a detailed understanding of the mechanisms involved, careful inference and repeated testing and analysis are required to develop reliable and robust relationships. These qualities are revealed by the characteristics of psychophysical relationships. Boyce gives a useful, practical overview of these issues, from which the following is derived [34].

4.1.1 Characteristics of Useful Psychophysical Relationships

Psychophysical experiments involve dependent or output variables which are the perceptions or behaviors that are being studied, and independent or input variables which are the physical stimuli being varied to see their effect. Important characteristics of useful psychophysical relationships are: statistical significance, effect size, reliability, cause, and specificity.

4.1.1.1 Statistical Significance

This assesses whether a relationship between the dependent and independent variables is due to chance. By convention, if statistical analysis shows less than a 5 percent probability of chance cause, the relationship is assumed to be real. Lower percentages that the result is due to chance give more confidence that the relationship is real.

4.1.1.2 Size of the Effect

Effect size characterizes how much of the observed variance or change in the dependent variable is explained by changes in the independent variable. One suggestion [3] for behavioral and psychophysical work is that large effects explain at least 25 percent of the observed variance, medium effects explain at least 9 percent, and small effects explain only 1 percent or less. In some cases, the effects of multiple independent variables, acting individually or in combination, on a dependent variable are investigated. The cumulative effect size of all the independent variables might be large, though their individual effect sizes are small.

4.1.1.3 Reliability

This is determined by whether the relationship is supported by data that comes from replicating experiments. Repeated experiments or experiments using different procedures and subjects can not only verify the relationship but also help define its limits of applicability.

4.1.1.4 Cause

Cause is the physical, neural, physiological or psychological mechanism that is known to link the change in dependent variable with change in the independent variable. Cause may be multifactorial. A knowledge of cause helps identify conditions where the relationship does and does not apply.

Specificity identifies the range of conditions under which a relationship holds. Validity of a relationship over a wide range of conditions makes it of great value, but usually requires either a knowledge of the cause of the effect or a very extensive program of experiments. Even with highly specific conditions, individual differences between subjects introduces uncertainty in the relationship. See 4.11.1 Research Results.

4.1.2 Characteristics of Weak Psychophysical Relationships

Some relationships established from experimental data can be weak or of very limited utility because of the nature of the experiments that produced the data. In some cases the variables used in the experiment are vague and difficult to measure. Examples are discomfort glare and mood. Assessing these as dependent variables often involves questionnaires, but these have proven to be difficult to design and use in ways that yield reliable and statistically defensible data [5] [6] [7]. Subjects' responses to vague or ambiguous questions render the resulting data difficult to interpret and use. Careful experimental design

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that minimizes bias by employing counterbalancing and null condition tests goes a long way toward producing reliable and statistically defensible data [8] [9].

Remote relationships are those derived from studies in which dependent and independent variables are widely separated in time or space. Separation in time is exemplified by long-term studies of the exposure to optical radiation [10]. It can be very difficult to eliminate the influence of other independent variables in such studies. Separation in space—real or metaphorical—is exemplified by studies in which the independent variable affects the dependent variable by very indirect means. This is the case, for example, in studies attempting to relate productivity or task performance to aspects of lighting quality other than task visibility. Such studies have not revealed statistically significant effects.

Diluted relationships are those in which there are a large number of intervening variables between the dependent and independent variables. Examples of studies that can yield very diluted relationships are those searching for links between daylighting and student performance [3]. In these cases, it can be very difficult to eliminate the effect of the intervening variables, such as indoor air quality and noise, and then assess the effect of only the independent variables of interest, such as daylighting.

4.1.3 Psychophysics and Lighting

The relationships established by psychophysics are used in lighting design and illuminating engineering in several ways:

- Establish lighting design criteria,
- Provide lighting design guidance,
- Serve as the basis for analysis tools,
- Help avoid poor lighting, and
- Guide lighting equipment design

Design criteria can be obtained from relationships that are particularly reliable, robust, and specific. An example of this is the relationship between visual task performance and factors of task contrast, size, and background luminance. But even in this case, experience, judgment, and consensus are usually necessary to establish lighting design criteria.

Though less robust relationships usually cannot serve as bases for design criteria, they may still be useful as a guide for lighting design. An example is the relationship between impressions of spaciousness and surface luminance distribution in an interior space: lighting the walls or peripheral surfaces increases the impression of spaciousness.

Relationships that can be cast into quantitative models can serve as the basis for lighting analysis computer software, permitting a systematic comparison between proposed lighting designs. Even though criteria might not be able to be established with these relationships, they can be used to rank order proposed lighting designs by some measure of quality. Examples are the quantitative models of discomfort glare.

Psychophysical relationships can help the designer avoid poor or inappropriate lighting. Examples include avoiding the inappropriate positioning of lighting equipment that would produce discomfort glare, or failing to establish a sufficient luminance ratio for an architectural element that is to be highlighted.

Lighting equipment design can be guided, in part, by psychophysical relationships. Examples include managing the brightness magnitude and pattern in reflectors, producing intensity distributions appropriate for accent lighting, and the design of equipment to produce a wash of light on a wall having the appearance of uniformity.

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4.2 Basic Parameters

Knowledge of the visual system and the psychophysical experimentation that yields an understanding of its operation reveals certain quantities that are fundamental to a description of visual perceptions and performance. For example, the visibility of a target depends on its size and how different its luminance and color are from its surrounding. Thus, if target visibility is to guide lighting design, the parameters that determine it (size and luminance difference, for example) must be defined unambiguously.

Considering the range of aspects of visual perceptions and performance important to lighting, these fundamental quantities are: luminance, the amount of light entering the eye and falling on the retina, the size of a visual task, a visual task's luminance and chromatic contrast, spatial frequency, and flicker. Changes in these fundamental quantities affect threshold and suprathreshold performance.

Luminance, L, is the light-emitting power of a surface in a particular direction, per unit area, expressed in units of luminous intensity per unit area; usually in cd/m^2. It is described and defined in detail in 5.5.2.3 Luminance. The other factors are discussed here.

4.2.1 Light Entering the Eye

The amount of light entering the eye is determined by pupil size and the luminances of the object being viewed. Measured in trolands, this amount of light is determined by

$$e_t = L\, A_p \tag{4.1}$$

Where:

L = object luminance in cd/m^2,
A_p = pupil area in mm^2

4.2.2 Retinal Illuminance

The amount of light reaching the retina is the amount entering the eye reduced by the ocular transmittance of cornea, lens, and humors, and accounting for the offset from the line of sight and the distance from retina to pupil. But more important than the amount of light is the density of light on the retina. That is, the retinal illuminance in lumens per square meter. See 5.6.1 Illuminance. Retinal illuminance is defined using trolands in the following function:

$$E_r = e_t\, \tau\, \frac{\cos(\theta)}{k^2} \tag{4.2}$$

Where:

E_r = retinal illuminance in lm/m^2
e_t = amount of light entering the eye in trolands.
τ = ocular transmittance
θ = angular displacement of object from the line of sight
k = constant with value of 15

It should be noted that the amount of light entering the eye, e_t, measured in trolands, is often referred to as retinal illumination. This is misleading because it does not take into account the transmittance of the ocular media or the pupil-retina distance, and therefore does not represent the luminous flux density on the retina.

4.2.3 Visual Size

The relevant size of a target is an angular measure and depends on the physical dimensions, d, of the object itself; the angle of inclination, θ, of the target from normal to the

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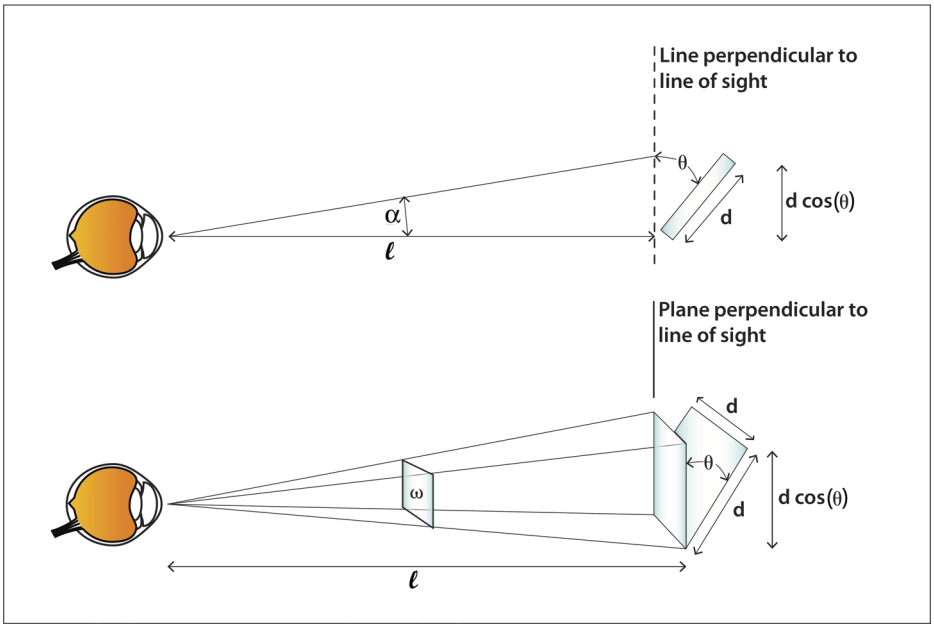


Figure 4.1 | Parameters Defining Plane and Solid Angle Calculations
The plain angle of a visual object is its angular extent in a prescribed plane from a particular viewing point; that is, its apparent size in one dimension. The solid angle is a visual object's spatial extent from a particular viewing point; that is, its apparent size in two dimensions. Both plane and solid angles are a function of the actual physical extent of the object, its distance from the viewing point, and its orientation with respect to the viewing point.

line of sight; and the distance from the viewer, ℓ. See Figure 4.1. In the context of vision, size always means visual size and is expressed as either the plane angle subtended or the solid angle subtended.

4.2.3.1 Visual Angle

Size can be measured as a plane angle, α, that describes the extent of an object in one dimension, as shown in Figure 4.1. The visual angle, α, of an object can be calculated by the following equation:

$$\alpha = 2\tan^{-1}\left(\frac{d\cos(\theta)}{2\ell}\right) \approx \frac{d\cos(\theta)}{\ell} \qquad (4.3)$$

Where:

d = single-dimensional extent of the object
cos(θ) = cosine of the angle of inclination to view
ℓ = distance from eye to object

The approximate expression in Equation 4.3 holds within 5% if $d\cos(\theta)/\ell < 0.4$.

4.2.3.2 Solid Angle

In some cases, the extent to which a target covers the retina is required. Solid angle can be used to do this. Solid angle, signified by ω, defines the spatial extent of an object and describes its extent in two dimensions, as shown in Figure 4.1. If the object is a simple planar area, its solid angle can be approximated by the equation:

$$\omega \approx \frac{A\cos(\theta)}{\ell^2} \qquad (4.4)$$

Where:

A = physical area of the object
cos(θ) = angle of inclination to view
ℓ = distance from eye to object

See 5.7.1 Solid Angle for a more complete description of solid angle.

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4.2.4 Luminance Contrast

A target will be visible only if it differs from its immediate background in luminance or color. If it differs in luminance from the immediate background, the target (for example, a black letter on this page) has a luminance contrast. Luminance contrast is defined in several ways:

$$C = \left| \frac{L_t - L_b}{L_b} \right| \tag{4.5}$$

Where

L_t = luminance of the target
L_b = luminance of the background

This equation results in luminance contrasts that range between 0 and 1 for targets that are darker than their backgrounds, and between 0 and infinity for targets that are brighter than their backgrounds. This equation is used most often in the former case, where the background is brighter than the target (for example, the white paper surrounding the black letters on this page).

$$C = \frac{L_g - L_l}{L_l} \tag{4.6}$$

Where:

L_g = greater luminance
L_l = lesser luminance

This equation results in contrasts greater than 0 for all objects, whether brighter or darker than their backgrounds. It is especially applicable in a situation like a two-part pattern in which neither of the areas on the two sides of the border can be identified as target or background.

$$C = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} \tag{4.7}$$

Where

L_{min} = minimum luminance
L_{max} = maximum luminance

The quantity defined by this equation is often called contrast, or Michelson contrast, but is more properly called modulation. It gives a value between 0 and 1 for all objects. It applies to periodic patterns, such as gratings, which have one maximum and one minimum in each cycle. Because there are several different definitions of luminance contrast and different definitions have different ranges of possible values, it is important to know which definition is being used when the contrast of a target is specified. When a target and its background are both diffuse reflectors and uniformly illuminated, the luminance contrast is not affected by changing the illuminance, so the luminance contrast can be calculated from the reflectances. However, if either the object or the background are directional reflectors (for example glossy paper and/or glossy ink), luminance must be used to calculate contrast. It should be noted that for calculating luminance contrast, it does not matter how the luminance is achieved. It makes no difference whether the luminance is produced by reflection from a surface, such as print; from a self-luminous source, such as a VDT screen; or by some combination, such as a display on a VDT screen with a reflected image of room wall or luminaire superimposed.

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4.2.5 Chromatic Contrast

Color is another difference that can differentiate a target from its immediate background and make it visible. This difference is chromatic contrast. Unlike the single dimension of luminance as a stimulus, color is multidimensional and so the precise specification of chromatic contrast is more difficult than luminance contrast. The simplest case involves discriminating among monochromatic lights. The visual system varies in its ability to discriminate among wavelengths. There are regions of maximum wavelength discrimination in the middle of the visible spectrum but discrimination falls off rapidly at the spectral extremes [11]. Likewise, the ability to discriminate hue from white is wavelength dependent. Monochromatic colors from the ends of the visible spectrum are more easily discriminated from white because they are more saturated than colors in the middle of the spectrum [12].

The ability to discriminate nonspectral colors is also related to their chromaticities [13]. Generally, color discrimination is best in the fovea and decreases toward the periphery. However, color discrimination for very small fields (20 min of arc or less) presented to the fovea is poor because there are very few short-wavelength S-cones in the center of the fovea. The ability to discriminate between colors can be estimated in terms of distances in a uniform 3-D chromaticity space. See 6.2.1 Chromaticity Diagrams.

4.2.6 Veiling Reflections

Veiling reflections are luminous reflections from specular or semi-matte surfaces that physically change the contrast of the visual task and therefore change the stimulus presented to the visual system. Two factors determine the nature and magnitude of veiling reflections: the specularity of the material of the target, and the geometry between the observer, the target, and any sources of high luminance. Veiling reflections occur only if the task has a specular reflection component. The positions where veiling reflections occur are those where the incident ray corresponding to the reflected ray that reaches the observer's eye from the target comes from a source of high luminance. This means that the strength and magnitude of such reflections can vary dramatically within a single lighting installation [14].

The effect of veiling reflections on contrast may be quantified by adding the luminance of the veiling reflection to the appropriate components in one of the luminance contrast formulas.

4.2.7 Threshold and Suprathreshold Visibility

Threshold is that condition of visibility that produces visual performance just above what would be obtained by chance. That is, at or just above 50%. The type of threshold visual performance can be anything from the mere detection of a simple on-axis target, to the performance of a complex visual task involving recognition, cognition, and motor response. In each case, threshold can be applied to any of the parameters that affect performance and so it is possible to define threshold contrast, threshold luminance, threshold size, and so on. Under threshold conditions, the visual system is usually operating at the limits of its ability [14]. Simple visual detection tasks have been studied in great detail [15] and data for one particular condition are shown in Figure 4.2.

Suprathreshold is that condition of visibility above threshold where additional lighting continues to influence the speed and accuracy with which the visual information can be processed. Suprathreshold visual performance is governed principally by the following parameters: retinal illuminance, task contrast, visual size, and the characteristics of the visual system. These factors affect suprathreshold visual performance in a way that can usually be discovered only by psychophysics and often results in relatively complicated models relating performance to these factors.

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4.2.8 Spatial Frequency

A visual target in the form of repeated identical strips, sinusoidally varying in luminance across their extent, is a fundamental stimulus for the visual system. These targets are usually called gratings and are characterized by their contrast and an aspect of their size or form called spatial frequency. Spatial frequency specifies the size of a complete high-low luminance cycle in terms of plane visual angle; thus it has the units of cycles per degree. Figure 4.3 shows this arrangement. Sections 4.5.2 Spatial Contrast Sensitivity Functions and 4.8.2 Role of Spatial Vision describe the importance of this to vision and lighting.

4.3 Brightness

Brightness is the perceptual response to a source of light, with the perception being somewhere along the common sense continuum of bright-dim. Brightness is the most fundamental visual perception and is central to illuminating engineering and lighting design. Broadly, brightness is the perceptual response to luminance. Though luminance is usually the most important stimulus to brightness perceptions, size, gradient, surround luminance, adaptation, and spectral composition can have important effects on brightness. A related perception is lightness, which is the extent to which a surface appears to reflect or transmit more or less light and is a judgment made about the property of a surface.

Figure 4.2 | Frequency of Detection
A frequency of seeing function as luminance contrast in increased, the number of times a luminous disc is correctly detected, relative to the number of times is it presented, increases. By convention, a performance of 50% is threshold and the contrast that produces that condition is threshold contrast.

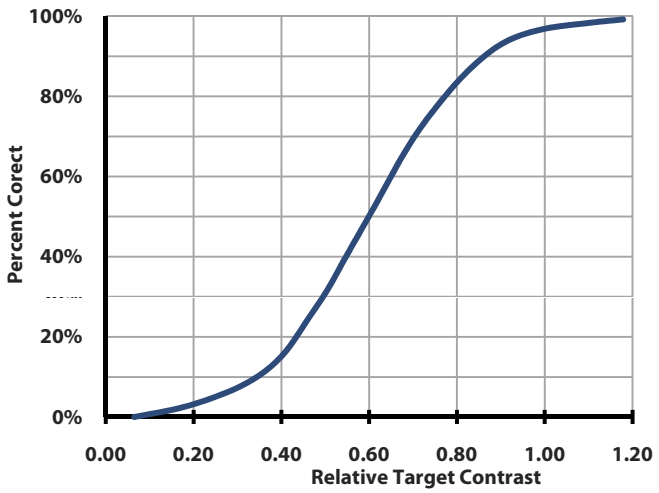
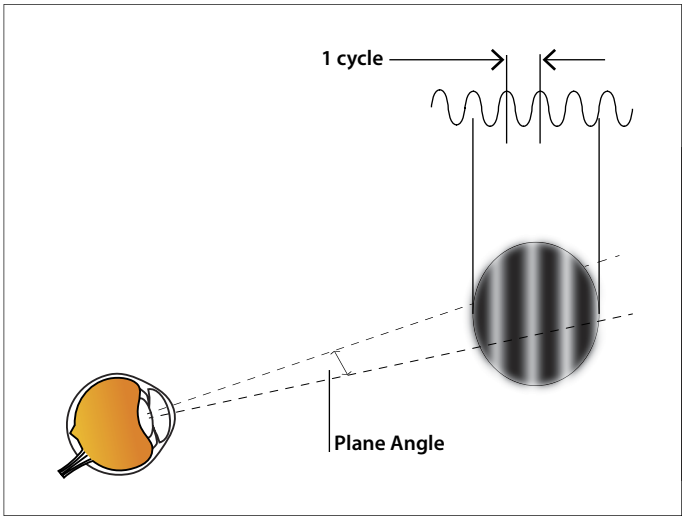


Figure 4.3 | Spatial Frequency
Spatial frequency of a sinusoidal grating target as determined from the cycles of bright and dark, and the plane angle of their extent.



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4.3.1 Brightness and Lightness Constancy

The most important aspect of brightness is its constancy. Objects of various reflectances under uniform illumination will each assume a brightness. If the uniform illumination is increased or decreased, the relative brightnesses among objects remain relatively unchanged, though there is some increase in the maximum brightness as luminance is increased. This is a result of the overall sensitivity of the visual system changing to provide the necessary adaptation and a perceptual mechanism that attempts to "center" the range of luminances within the field of view between very bright and dim.

Our judgment of the lightness of a surface involves an assessment of its surroundings and a judgment of the illumination condition. Lightness also exhibits a perceptual constancy that is part of the process of extracting meaning from what we see. Figure 4.4 shows brightness and lightness constancy.

4.3.2 Factors Affecting Brightness

Five factors usually govern the transformation or mapping of luminance as stimulus to brightness as response: object luminance, surround luminance, state of adaptation, gradient, and spectral content.

4.3.2.1 Object Luminance

In simple settings, the brightness of an object is proportional to a fractional power of its luminance. That is, the relationship between luminance and brightness is compressive and is approximated by a power law with an exponent of luminance being approximately 1/3. Figure 4.5 shows this relationship and is a useful guide assessing the perceptual effect of a luminance change.

4.3.2.2 Surround Luminance

The luminance around an object affects the object's brightness; a low luminance surround increases the brightness while a high luminance surround decreases the brightness. Figure 4.6 shows this effect.



Figure 4.4 | Demonstration of Brightness and Lightness Constancy
The brightnesses of the various locations in the image are relatively unchanged by the amount of sunlight on the building or the amount of illuminance on this page. The lightness attributed to the white siding is the same over the entire image, even though the luminance of the white siding in the deep shade of the tree is essentially the same as the luminance of the black shingles in the full light of the sun on the porch to the right.

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4.3.2.3 Adaptation

The state of adaptation and the highest luminance in the visual field affects the brightness of objects in a complex field [16]. Figure 4.7 shows the effect of adaptation luminance.

At high adaptation luminances, the curve relating object luminance to brightness is shallow: small changes in object luminance produce small changes in brightness and so there are many brightness steps or shades of gray. At low adaptation luminances the governing curve is very steep: small changes in object luminance produce large changes in brightness and so there are few brightness steps or shades of gray.

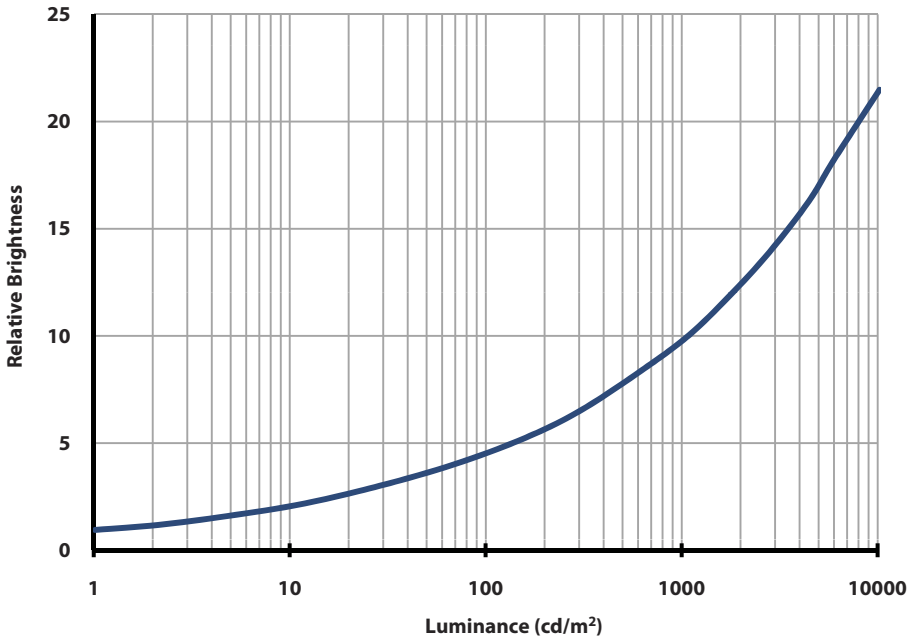


Figure 4.5 | Brightness Power Law
A Luminance-Brightness power relationship based on an exponent of 1/3.



Figure 4.6 | Surround and Brightness
Effect of surround luminance on the brightness of an object. The two small squares centered in the larger squares have the same luminance but differ in brightness due to their surround luminance. The bar across the series of patches at the bottom has the same luminance across its length, but its brightness varies since it is affected by the local surround luminance.

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4.3.2.4 Gradient

Gradient is the rate of change of luminance with visual angle. High gradients are produced by surfaces edges, abrupt changes in illumination, or changes in reflectance. High luminance gradients are usually necessary to produce noticeable brightness steps. Low luminance gradients usually suppress brightness change and give the perception of brightness uniformity. Figure 4.8 shows the effect of luminance gradient on brightness. See 4.8.2 Role of Spatial Vision in Edge Detection for additional discussion on the cause of this phenomena.

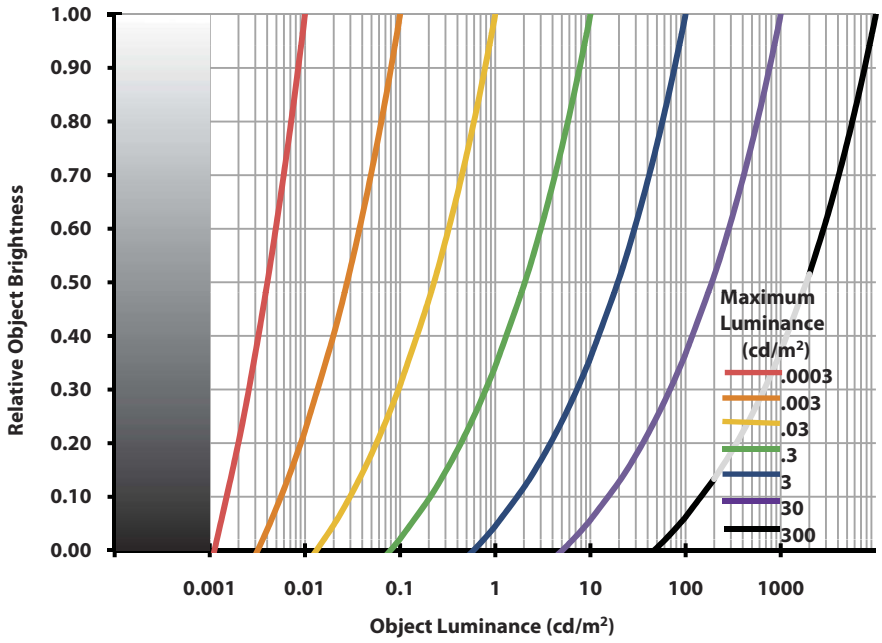


Figure 4.7 | Surround Brightness Data
Data of Bartleson and Breneman showing the effect of adaptation state on the mapping of luminance to brightness. The vertical scale is relative brightness, indicated numerically on the left and as a value range on the left. Each solid line represents the luminance-brightness mapping found for different adaptation luminances. For a given adaptation luminance, an object's relative brightness is predicted by its luminance (from the horizontal scale) and the appropriate adaptation curve.

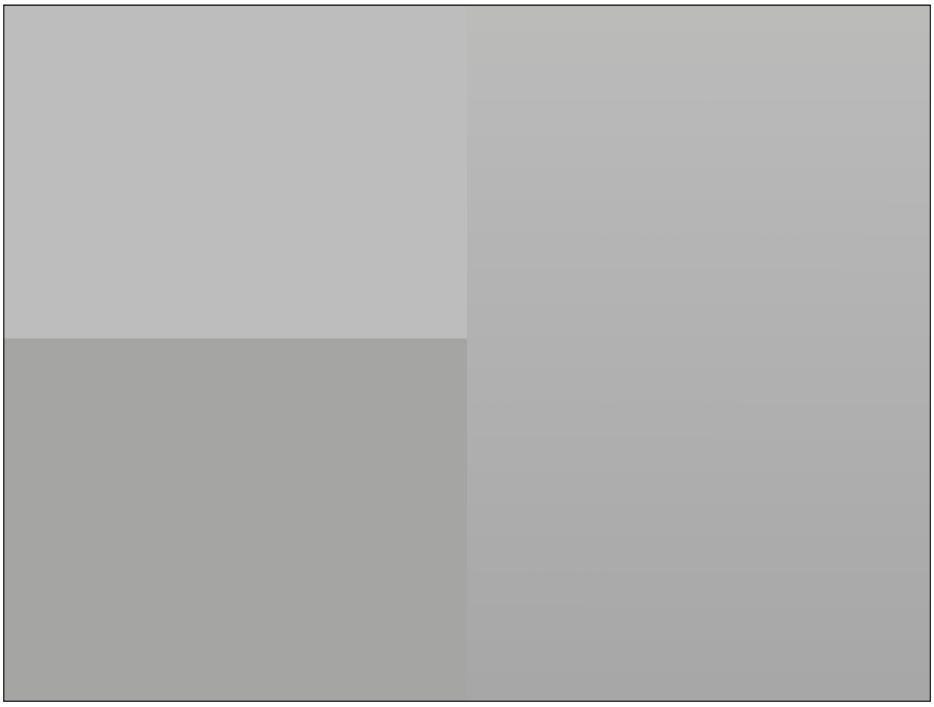


Figure 4.8 | Gradient and Brightness
The effect of gradient on brightness steps and brightness ratios. The luminance at the very top of both the left and right-hand fields is the same and greater than the luminance at the very bottom left and right. The gradient on the right is small and continuous from top to bottom. The gradient in the field on the left is zero except at the center where it is very high, essentially infinite. The high gradient in the middle of the field on the left produces a brightness step.

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4.3.3 Approximate Brightness Calculation

The simplest relationship between brightness and luminance is expressed by the power law of Stevens [17] for a single surface seen in isolation:

$$B = \alpha L^{0.33} \tag{4.8}$$

Where:

B = brightness
α = constant
L = object luminance

A more recent study [17] shows that the perceived brightness of any single surface increases with luminance according to a power law with an exponent of 0.35, but that the brightness of a number of surfaces seen simultaneously follows a power law with an exponent of approximately 0.6. These relationships can be used to estimate the relative brightness of surfaces in an interior by assuming that the brightest surface in the room has a brightness given by:

$$B_{max} = \alpha L_{max}^{0.35} \tag{4.9}$$

then another surface with luminance L will have a brightness given by:

$$B = \frac{B_{max}}{L_{max}^{0.6}} L^{0.6} \tag{4.10}$$

This simple system underestimates the brightness of highly saturated colored surfaces and overestimates the brightness of translucent surfaces. These relationships are given for guidance only.

A much more elaborate model of the brightness-luminance relationship is given by Bodmann and LaToison [19] and is described in detail in the Formulary. It has the advantage of accounting for the size of the object. Figure 4.9 shows how this model predicts brightness of an object subtending a 10° visual angle, compared to the power law of Stevens.

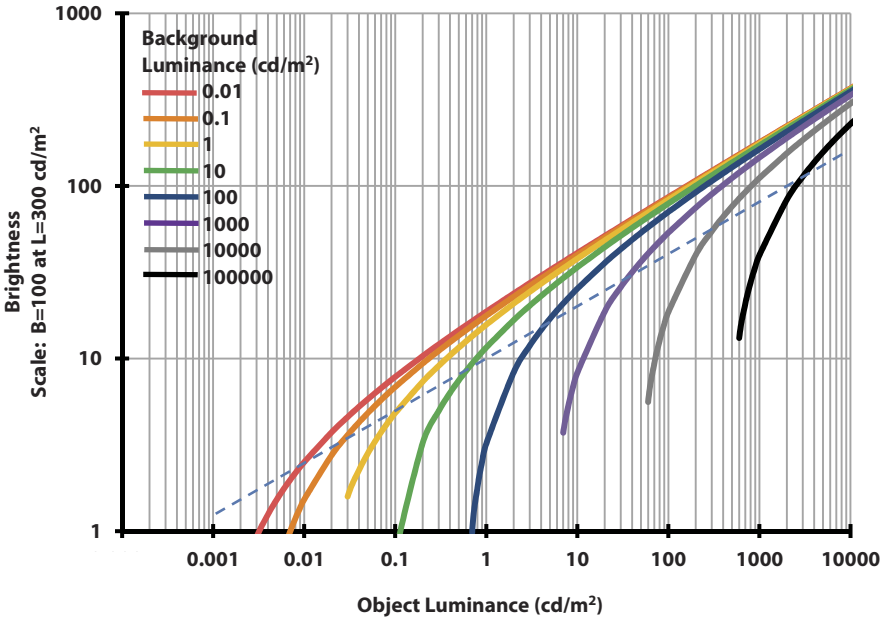


Figure 4.9 | Brightness-Luminance Mapping
Plot shows a mapping of luminance to brightness. The dashed line is the mapping of Stevens 1/3 power law and is approximately correct for lower background luminances. The Bodmann-LaToison data is plotted with solid lines. The intersection of the vertical line specified by the object luminance, and the appropriate background luminance curve, gives the brightness of the object found on the left hand vertical scale.

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4.3.4 Ratios and Perceptual Steps

Brightness increments are governed by the approximate relationship between luminance and brightness expressed by the 1/3 power law: a doubling of brightness requires an eight-fold increase in luminance. Brightness change is governed by luminance gradient. With a very high gradient, a luminance ratio as small as 1.1 is detectable and an edge or brightness discontinuity is perceived. But an area with a very low gradient will be perceived as having a single brightness, or a very smoothly changing brightness, even with a luminance ratio as large as 10 [20].

4.4 Visual Acuity

Acuity is the ability to resolve fine details and is ultimately limited by diffraction, aberrations, and the photoreceptor density of the retina. Several different kinds of acuity are recognized and involve various levels of visibility, from detection to recognition. See 4.2.7 Threshold and Suprathreshold Visibility.

4.4.1 Types of Acuity

Three kinds of visual acuity are important in lighting: resolution acuity, recognition acuity, and vernier acuity.

4.4.1.1 Resolution Acuity

The ability to detect that there are two stimuli, rather than one, in the visual field is defined as resolution acuity. It is measured in terms of the smallest angular separation between two stimuli that can still be seen as separate, such as two nighttime stars. Typically, resolution acuity is of the order of 1 minute of arc.

4.4.1.2 Recognition Acuity

The ability to correctly identify a visual target, as in differentiating between a G and a C, is defined as recognition acuity. Visual acuity testing performed using letters, as is done clinically, is a form of recognition acuity testing. Typically, recognition acuity is of the order of a few minutes of arc.

4.4.1.3 Vernier Acuity

The ability to identify a misalignment between two lines is defined as vernier acuity. Vernier acuity is typically of the order of a few seconds of arc.

Several examples of acuity test objects are shown in Figure 4.10 including the Landolt ring. Gratings and letters have also been used as acuity test objects.

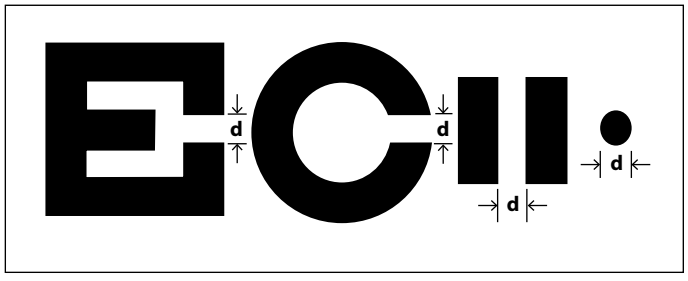


Figure 4.10 | Acuity Targets
Three resolution acuity-testing targets: E and Landolt ring with spacing separator, parallel bars, disc. In each case the critical size is shown by the dimension d. The Landolt ring is used with the gap oriented in various directions.

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4.4.2 Factors Affecting Visual Acuity

As with many other threshold tasks, visual acuity varies with refractive error, eccentricity, pupil size, retinal illuminance, size of background field, exposure duration and target motion. It also varies with luminance contrast, but by convention acuity is measured only at high luminance contrast. Refractive error, such as produced by myopia, causes blurring of the retinal image which decreases acuity. See 2.2.3 Refractive Errors. In general, acuity is finest when the target falls on the fovea and improves as the retinal illuminance increases, because of increased receptive field size and decreased pupil diameter. See 2.3.4 Receptive Fields. Figure 4.11 shows visual acuity as a function of eccentricity for three targets.

Acuity continues to improve with increasing background luminance as long as the background is large; when the background field is small, there is an optimum luminance for visual acuity, above which acuity declines [21]. This is shown in Figure 4.12. Visual acuity

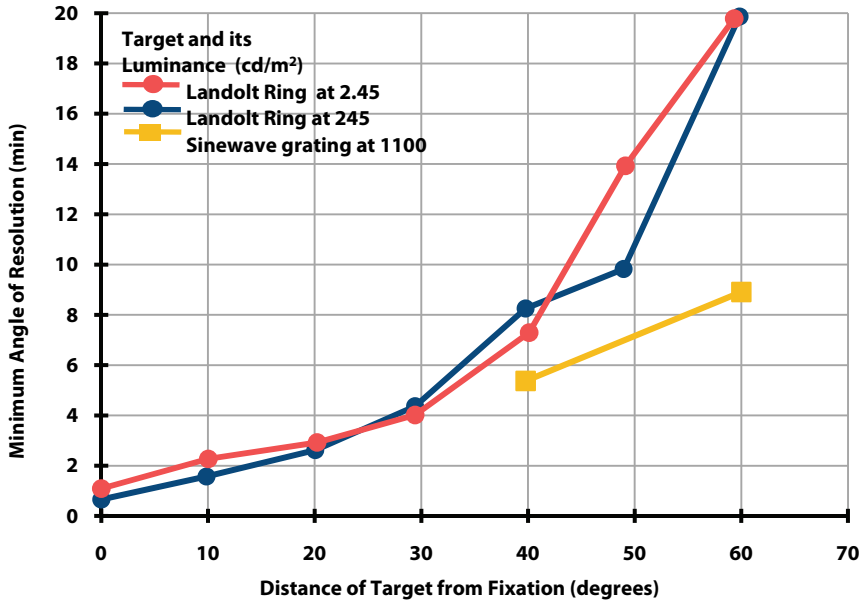


Figure 4.11 | Acuity
Minimum resolution in minutes of arc, as a function of angular separation from the fovea. Three targets were used: Landolt rings at 2.45 cd/m^2 and 245 cd/m^2 background luminances (open and filled circles, respectively), and sine wave gratings with background luminance of 1118 cd/m^2 (squares).

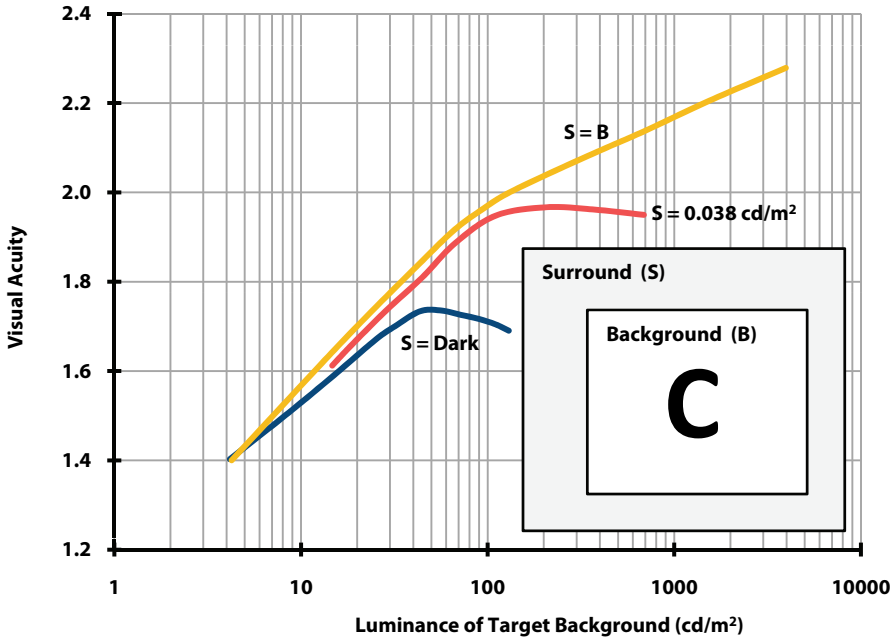


Figure 4.12 | Acuity vs Background Luminance
Visual acuity of Landolt rings for three conditions of surround luminance. B= background, S=surround.

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also increases as the exposure duration increases, up to approximately 500 ms, after which no further improvement occurs. Target movement can limit the exposure duration and the ability to keep the retinal image on the fovea. As might be expected, increasing target speed tends to reduce visual acuity. The fovea fails to have the best visual acuity under scotopic vision conditions, where the fovea is inactive and the best visual acuity is found a few degrees off the line of sight.

4.4.3 Measures and Expressions of Acuity

In psychophysics, acuity is expressed as the minimum angle of the target detail used for resolution, recognition, or vernier acuity. Lighting designers are likely to deal with clients that are more familiar with optometric expressions of visual acuity. In optometry, acuity is specified for distance vision and is expressed as a ratio of the distances at which an individual and an average observer can correctly distinguish similar letters or the orientation of closely-spaced dark bars. In the United States the distances are expressed in feet, elsewhere, meters are used. The numerator is the standard test distance: 20 ft or 6 m, which, for the eye's optical system, is essentially an infinite distance. An individual with an optometrically expressed acuity of 20/100 requires a distance of 20 ft to correctly distinguish letters or bars that an average observer can see at 100 ft. The individuals acuity is poorer than average. An acuity of 20/10 specifies an acuity better than average.

The chart developed by Hermann Snellen, consisting of specially designed block letters, has been used for nearly 150 years to test acuity. More recently, acuity charts developed by the National Eye Institute in the US are becoming common in optometric practice. The minimum angle of resolution (MAR) in arc minutes and the denominator in an optometric expression of acuity (x) is given by

$$\mathrm{MAR} = \frac{x}{20} \tag{4.11}$$

4.5 Contrast Sensitivity

Contrast sensitivity functions define the minimum contrast required for targets to be seen as function of target or viewing characteristics. The viewing conditions can be simple or complex, ranging from something as simple as the mere detection of a spot of light to something as complex as a luminous grating. In most cases determinations are usually made at threshold. It is customary to use the reciprocal of these contrasts and designate them as contrast sensitivities.

4.5.1 Threshold

The ability to detect a target against a background can be quantified by its threshold contrast. Many factors affect threshold contrast. Among the more important are target size and retinal illuminance. Figure 4.13 shows the change in contrast threshold for a 4 min arc disc displayed for 200 ms plotted against adaptation luminance, for people of two different age groups. It shows that as adaptation luminance increases, the contrast threshold decreases, rapidly at first and then more slowly [22, 23]. Targets of different sizes exposed for different times give different absolute values of contrast threshold but all follow the same trend.

4.5.2 Spatial Contrast Sensitivity Functions

Spatial contrast sensitivity functions give the relationship between contrast at threshold and spatial frequency at different adaptation luminances. Figure 4.14 shows an example. It is usually based on data collected from grating targets of different spatial frequency. Contrast sensitivity for a given spatial frequency is the reciprocal of the luminance contrast of the grating at threshold with the contrast defined by Equation 4.7. Targets

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Figure 4.13 | Threshold Contrast
Two threshold contrast sensitivity curves for a luminous disc target. Blue curve is for 20- to 30-year-olds, gold curve for 60- to 70-year-olds.

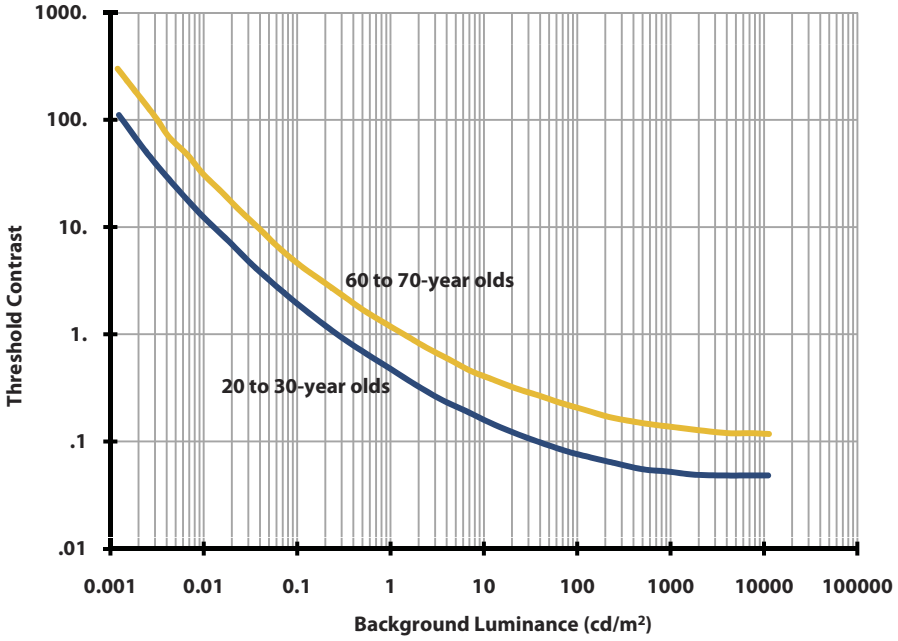
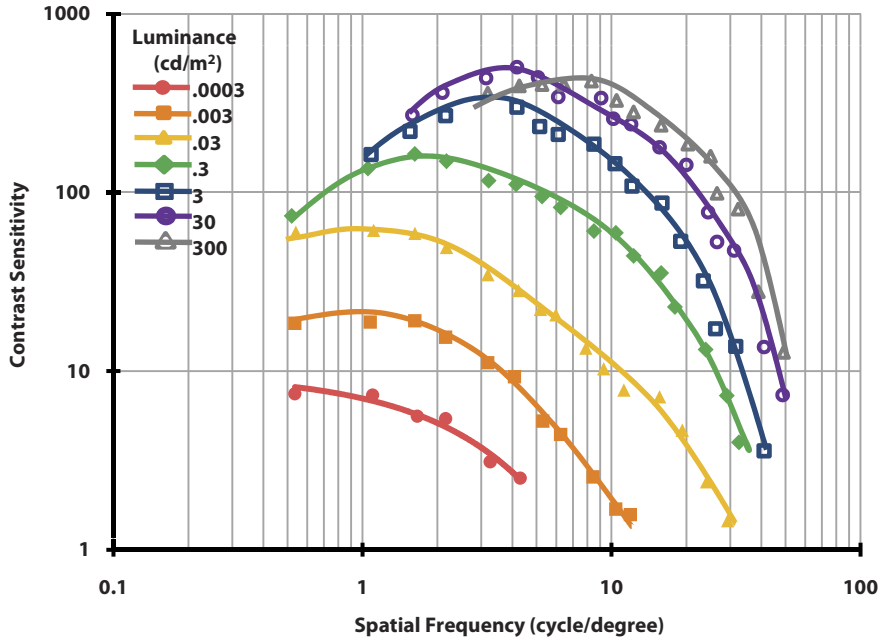


Figure 4.14 | Spatial Contrast Sensitivity
Spatial contrast sensitivity functions for foveal vision, at different target luminances. Data is from reference [25].



that have a spatial frequency and contrast sensitivity such that they lie above the contrast sensitivity function are invisible (that is, can be detected on fewer than 50% of the occasions presented) and those that lie below the contrast sensitivity function are visible (that is, can be detected on more than 50% of occasions presented). For complex targets, such as photographs of faces, that contain many different spatial frequencies, the contrast sensitivity function can be used to determine if and how the target will appear by breaking it into its spatial frequency components [24]. The target will be visible only if at least one spatial frequency component has a contrast sensitivity less than the contrast sensitivity function. Exactly how the target will appear will depend on the weighting given to each of its spatial frequency components by the contrast sensitivity function. Additionally, though the target is centered on the fovea, at low spatial frequencies the detection might occur in the annular area immediately around the fovea (parafovea) or the annular region further out (perifovea). Figure 4.15 gives a direct demonstration of contrast sensitivity as a function of spatial frequency.

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Many seemingly simple targets, such as the luminous disc target used to obtain the data shown in Figure 4.13, are actually quite complex. They have sharp edges which are represented by many spatial frequencies. See Figure 4.22 for an example of the spatial frequencies that comprise a luminous bar.

4.5.3 Factors Affecting Sensitivity

Among the most important factors that affect spatial contrast sensitivity are the adaptation luminance, the location in the visual field, and the spatial frequency of the target. As the adaptation luminance changes the operating state of the visual system from scotopic to photopic, the contrast sensitivity increases for all spatial frequencies; the spatial frequency at which the peak contrast sensitivity occurs increases, and the highest spatial frequency that can be detected increases. Location in the visual field also affects contrast sensitivity. It is reduced at all spatial frequencies with increasing eccentricity or distance from the line of sight, but the decrement is greater for high spatial frequencies. Viewing distance also affects spatial frequency: changing viewing distance to a detail of fixed size changes the angular size of the detail, and thus its spatial frequency. Detail apparent at one viewing distance can be difficult to detect or even imperceptible at another.

4.6 Flicker and Temporal Contrast Sensitivity

Just as the visual system responds to variations of luminance in space, it also responds to variations of luminance in time. Brief and repeated flashes are characterized as flicker, while on sensitivity are characterized by temporal contrast sensitivity functions.

4.6.1 Single Flashes of Light

For single brief flashes of light (less than 100 ms), any combination of luminance (L) and flash duration (t) with the same product produces the same perception. This characteristic is known as Bloch's law and is valid for t < 100 ms:

$$L \times t = \text{constant} \tag{4.12}$$

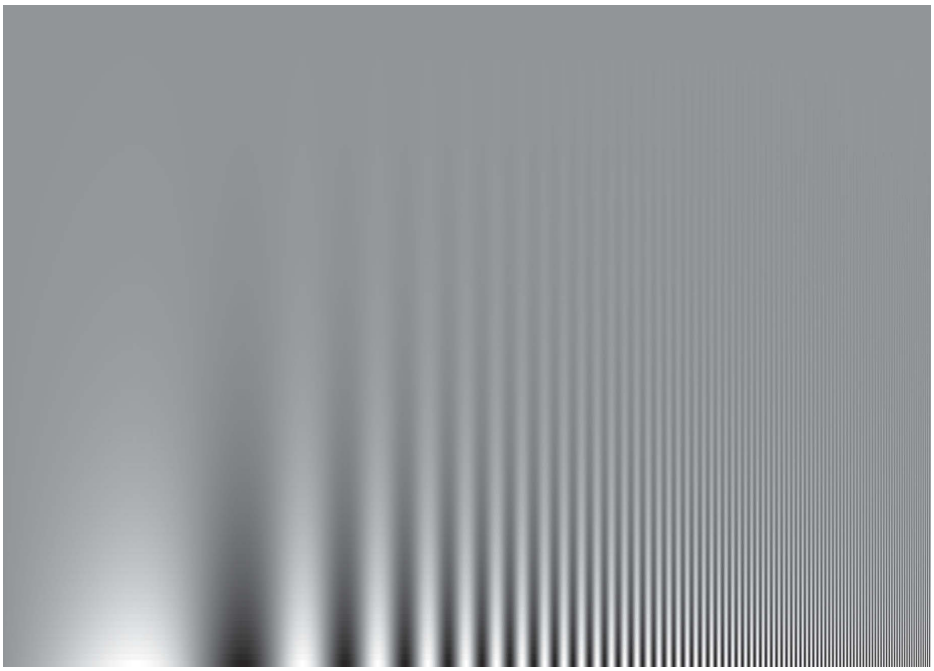


Figure 4.15 | Spatial Contrast Sensitivity Demonstration
Demonstration of the change in contrast sensitivity with spatial frequency. The contrast of the sinusoidal grating varies from 1.0 at the bottom to the 0 at the top. The spatial frequency of the grating varies from low at the left to high at the right. The contrasts at which the grating is just visible for different spatial frequencies forms an arc similar to the data plotted in Figure 4.14.

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For single brief flashes of light longer than approximately 100 to 200 ms, the perception of the flash is solely a function of luminance. Tasks more complicated than detecting brief flashes continue to show a duration sensitivity up to approximately 400 ms [26].

4.6.2 Repeated Flashes of Light

As a repetitive flashing stimulus is increased in frequency, it is eventually perceived as steady rather than as intermittent; this is the critical flicker frequency (or critical fusion frequency, CFF). The frequency at which the fusion occurs varies with stimulus size, shape, retinal location, adaptation luminance, and modulation depth. Figure 4.16 shows the relationship of CFF to adaptation luminance for centrally fixated test objects of different sizes. The CFF rarely exceeds 60 Hz even for a large visual area with 100% modulation, seen at a high adaptation luminance. This is just as well because all light sources that operate from an ac electrical supply show some fluctuation in light output.

Sensitivity to flicker differs across the retina. The fovea can follow flicker rates up to approximately 60 Hz at moderate luminances, but is relatively insensitive to low amplitude modulations. The peripheral retina, on the other hand, can detect flicker rates to approximately 15 Hz, but is very sensitive to small flicker amplitudes. This is why flicker is often detected in the peripheral field but disappears when the light is viewed directly.

4.6.3 Temporal Contrast Sensitivity Functions

Temporal contrast sensitivity is the equivalent in time of the spatial contrast sensitivity function. A luminance's variation in time is called its temporal modulation and is characterized by the amplitude and frequency of the variation. Amplitude change that can be detected by the visual system varies with frequency and is called the temporal contrast sensitivity function. Figure 4.17 shows the temporal contrast sensitivity function for different adaptation luminances [28]. This sometimes called the modulation transfer function (MTF). The vertical axis is the contrast sensitivity and the horizontal axis is the frequency of fluctuation measured in cycles per second. Figure 4.16 shows that in photopic conditions (that is, above approximately 3 cd/m^2), the visual system is most sensitive to frequencies in the range 10 to 30 Hz and that as the adaptation luminance decreases, the absolute sensitivity to flicker decreases, the frequency at which the peak sensitivity

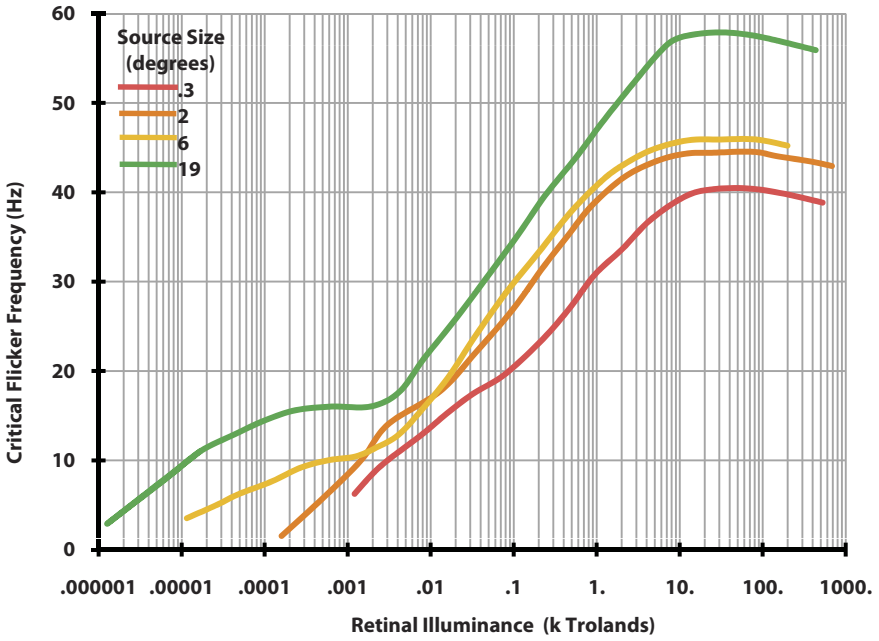


Figure 4.16 | Critical Fusion Frequency
Critical fusion frequency (CFF) as a function of source size and retinal illuminance. Data from reference [27].

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occurs decreases, and the highest frequency that can be detected decreases. These temporal modulation transfer functions, and others for different conditions, can be used to determine the likelihood that a given fluctuation in light will be perceived as flickering. For a fluctuation with a complex waveform to be seen as flicker, at least one of its frequency components must have a modulation sufficiently high that the modulation sensitivity is below the temporal MTF. Knowledge of the visual system's temporal response is most helpful when considering the detection of flashing signals and the perception of animated signs.

4.7 Visual Performance

The purpose of lighting is often to support the performance of visual tasks; visual performance being part of task performance. Task performance is, in turn, part of productivity. Most tasks have three components: visual, cognitive, and motor [29] [30]. The visual component refers to the process of extracting information relevant to the performance of the task using the sense of sight. The cognitive component is the process by which these sensory stimuli are interpreted and the appropriate action determined. The motor component is the process by which the stimuli are manipulated to extract information and the consequential actions carried out. Figure 4.18 shows one conceptual relationship between visual stimuli, visual performance, task performance, and productivity [29]. The stimuli to the visual system are determined by the task characteristics and the way the task is lighted. These stimuli and the operating state of the visual system determine visual performance.

Every task is a unique balance between visual, cognitive, and motor components and hence the effect lighting conditions have on performance can vary from task to task. This makes it impossible to generalize from the effect of lighting on the performance of one task to the effect of lighting on the performance of another. Additionally, there is no known way to always translate visual performance to task performance. The literature on this subject sometimes erroneously confuses measures of visual performance with measures of task performance. Task performance, not visual performance, is needed to assess productivity and establish cost-benefit ratios comparing one lighting system to another.

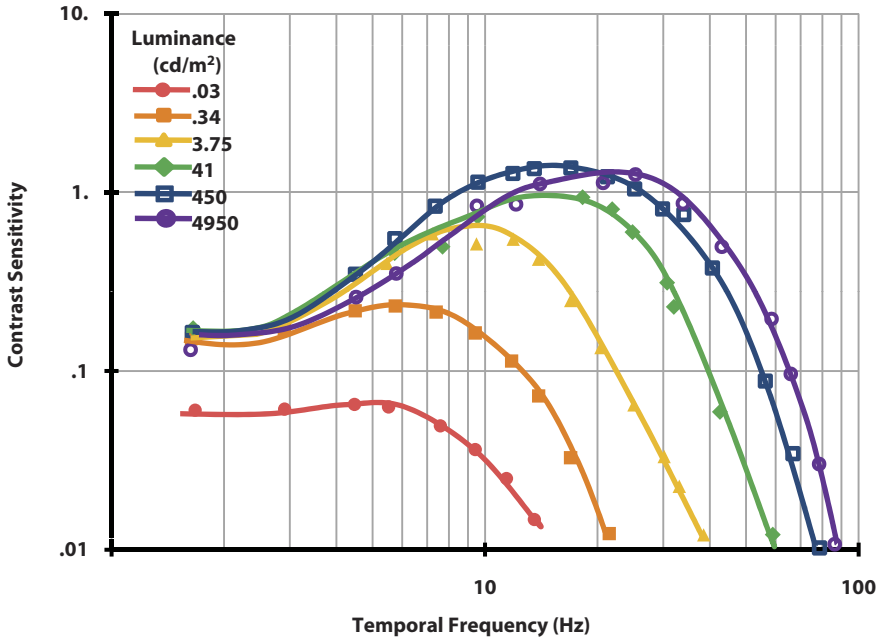


Figure 4.17 | Temporal Contrast Sensitivity
Temporal contrast sensitivity function for different adaptation luminances with a 68° field of view.

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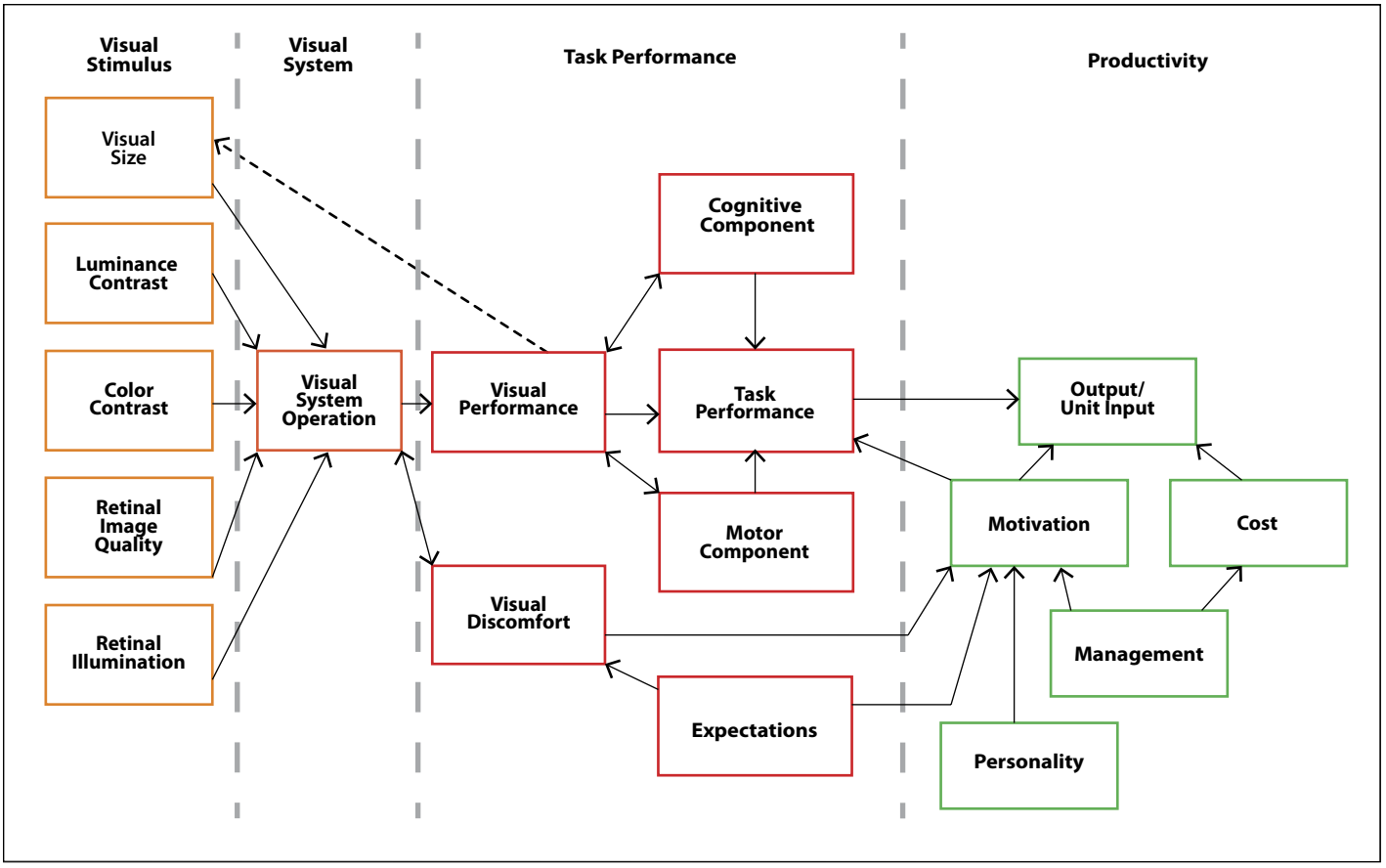


Figure 4.18 | Stimuli and the Visual System
A conceptual diagram of the relationships between the stimuli to the visual system and their effect on visual performance and ultimately productivity. The dotted line indicates a behavior that can change visual size: if performance is poor, observers move closer to the stimulus to increase its visual size. After [29].

4.7.1 Principal Factors

A wide range of psychophysical studies of suprathreshold visual performance [30–46] have revealed parameters that are important to suprathreshold visual performance: target size, target luminance contrast, and background luminance. The curves in Figure 4.19 demonstrate the effects of illuminance on detection of Landolt rings (see Figure 4.11) of different orientations and printed in different contrasts and sizes [31] [32] [33]. Performance was defined, in these studies, as an aggregate score based on speed and accuracy.

The performance data shown in Figure 4.19 provide only general trends in suprathreshold response but, importantly, trends that cannot be gleaned from knowledge of threshold vision.

4.7.1.1 Adaptation Luminance

In general, the data show that as background luminance increases, performance (measured in terms of speed and accuracy) increases rapidly at first but then at a diminishing rate until a point is reached where very large changes in background luminance are required to produce very small changes in performance.

4.7.1.2 Task Contrast and Size

These diminishing returns are more pronounced for high-contrast, large targets than for low-contrast, small targets. Also, performance for a small, low-contrast target cannot be brought to the same level as a large, high-contrast target simply by increasing illuminance. Rather, changing the size and luminance contrast of the target often have a much larger effect on suprathreshold visual performance than increasing the illuminance over any practical range.

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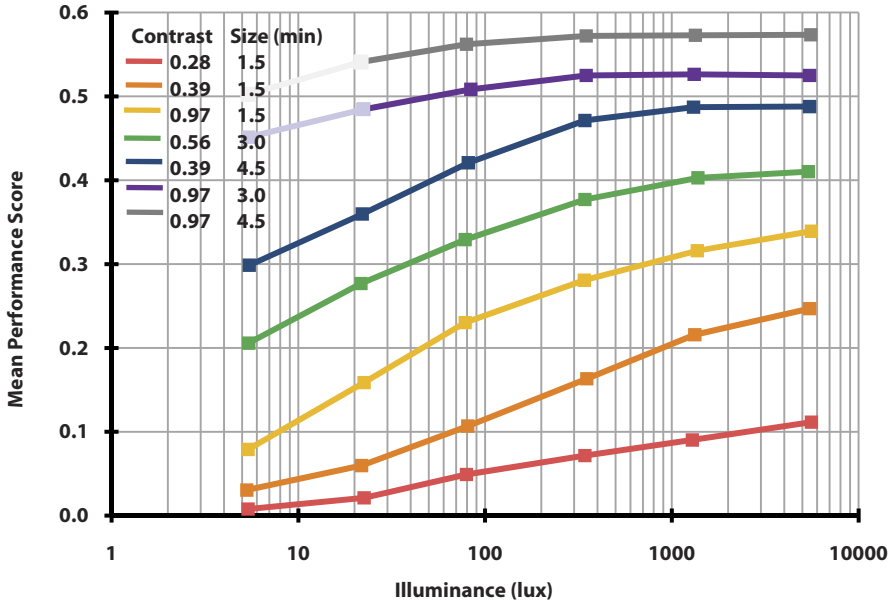


Figure 4.19 | Visual Performance Data
Mean performance scores for Weston's Landolt ring tasks of different visual size and contrast, as a function of illuminance.

4.7.1.3 Viewing Time, Search, and Task Eccentricity

In many cases, the observer knows where to look to perform a visual task as, for example, while reading. However, there is a class of tasks in which the object to be detected can appear anywhere in the visual field as with driving or industrial inspection. These tasks involve visual search. Visual search is typically undertaken through a series of eye fixations, the fixation pattern being guided either by expectations about where the target is most likely to appear or by what part of the visual scene is most important. Typically, the target is first detected in the periphery of the retina. Detection is followed by eye movements that bring the detected target onto that region of the retina most sensitive to them: for high spatial frequency targets this is the fovea, for other targets it may be off-fovea.

The speed with which a visual search task is completed depends on the size, luminance contrast, and color difference of the target; the presence of other targets in the search area; and the extent to which the target is different from the other targets. The simplest visual search task is one in which the expected target appears somewhere in an otherwise empty field, such as paint scratches on a car body. The most difficult visual search task is one in which the target is situated in a cluttered field, where the clutter is very similar to the target to be found, such as searching for a particular face in a crowd. The speed of visual search is determined by both the task characteristics and the lighting conditions. The task characteristics that hasten visual search are those that make the target stand out from its background (that is, make it visible) and make it different from surrounding clutter (that is, make it conspicuous).

To make a target recognizable, its visual size and luminance contrast must be well above the threshold values. To make a target conspicuous, it should differ from the surrounding clutter on as many perceptual dimensions as possible. These dimensions include: size, shape, color, movement, and flicker [34] [35]. Figure 4.20 shows the probability of detecting the object within one fixation pause, for 3 targets of varying size and contrast. This probability is at maximum when the target is viewed with the fovea and decreases with increasing eccentricity from the fovea. The probability distribution is assumed to be radially symmetrical about the visual axis, resulting in circular contours of equal probability of detection within one fixation pause around the fixation point. Given that the interfixation distance is related to the width of the probability curve, and that the search area is fixed, the time taken to find a target is inversely related to probability of detection.

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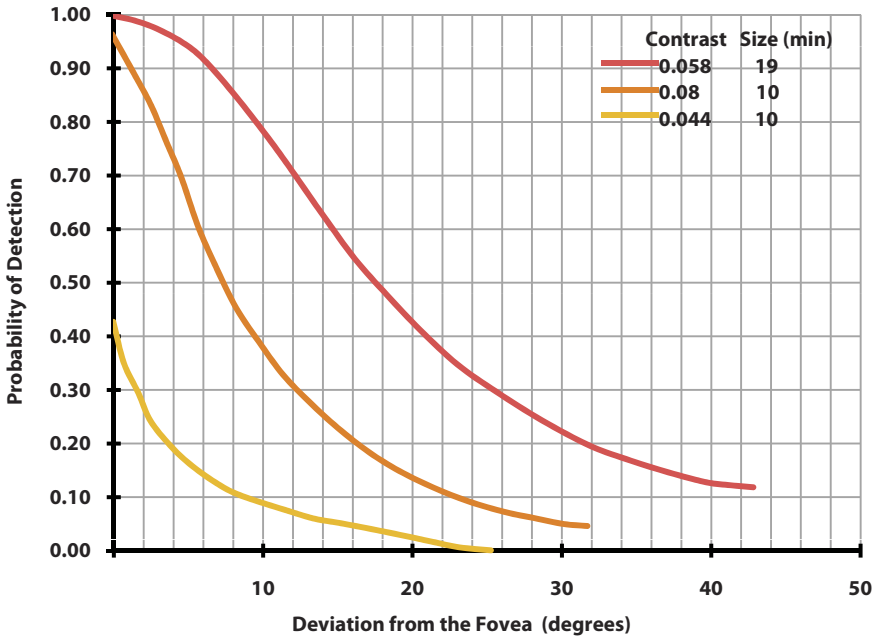


Figure 4.20 | Eccentricity and Detection
Probability of detecting a target with a single fixation pause, as a function of angular distance from the fixation visual axis. Data are for three targets. a: contrast = 0.058, size = 19 min. b: contrast=0.08, size =10 min. c: contrast = 0.044, size= 10 min. Data from [32]

For objects that appear on a uniform field, the probability curve is based on the detection of the object. For objects that appear among other similar objects, the probability curve is based on the discriminability of the object from the others surrounding it. Visual search is fastest for targets that have the widest probability curve.

4.7.2 Relative Visual Performance

It has been shown that it is not generally possible to accurately predict suprathreshold performance from threshold performance [36]. For this reason, several studies have been conducted on realistic tasks performed at suprathreshold visibility to determine how illumination affects performance [37] [38] [39] [40] [41]. This approach allowed the experimenter to assess performance for a specific task in suprathreshold conditions, but it was difficult to generalize the results with high precision to other, even superficially similar tasks because it was impossible to separate visual from nonvisual components of performance.

The Relative Visual Performance (RVP) model of visual performance is a quantitative model based on an extensive data set consisting of the changes that occur in reaction time for the detection of visual stimuli seen by the fovea [42] [43] [44] [45] [46] [47] [48] [49]. The conditions covered in the data set represent a wide range of adaptation luminances, luminance contrasts, and visual sizes. By using simple reaction time as a measure, this model attempts to minimize the nonvisual components in the task. By basing the model on the difference in reaction times from the least reaction time observed, for different combinations of adaptation luminance, luminance contrast, and visual size, the effect of any remaining nonvisual components is further minimized. Therefore, the RVP model shows the effect of adaptation luminance, luminance contrast and visual size on suprathreshold visual performance undiluted by nonvisual components. Figure 4.21 shows the form of the relative visual performance (RVP) model for four different visual task sizes, each surface being for a range of luminance contrasts and retinal illuminances. The overall shape of the relative visual performance surface has been described as a plateau and an escarpment. In essence, it shows that the visual system is capable of a high level of visual performance over a wide range of visual sizes, luminance contrasts, and retinal illuminations (the plateau) but at some point either visual size, luminance contrast, or retinal illumination become insufficient and visual performance collapses rapidly (the escarpment) towards a threshold state.

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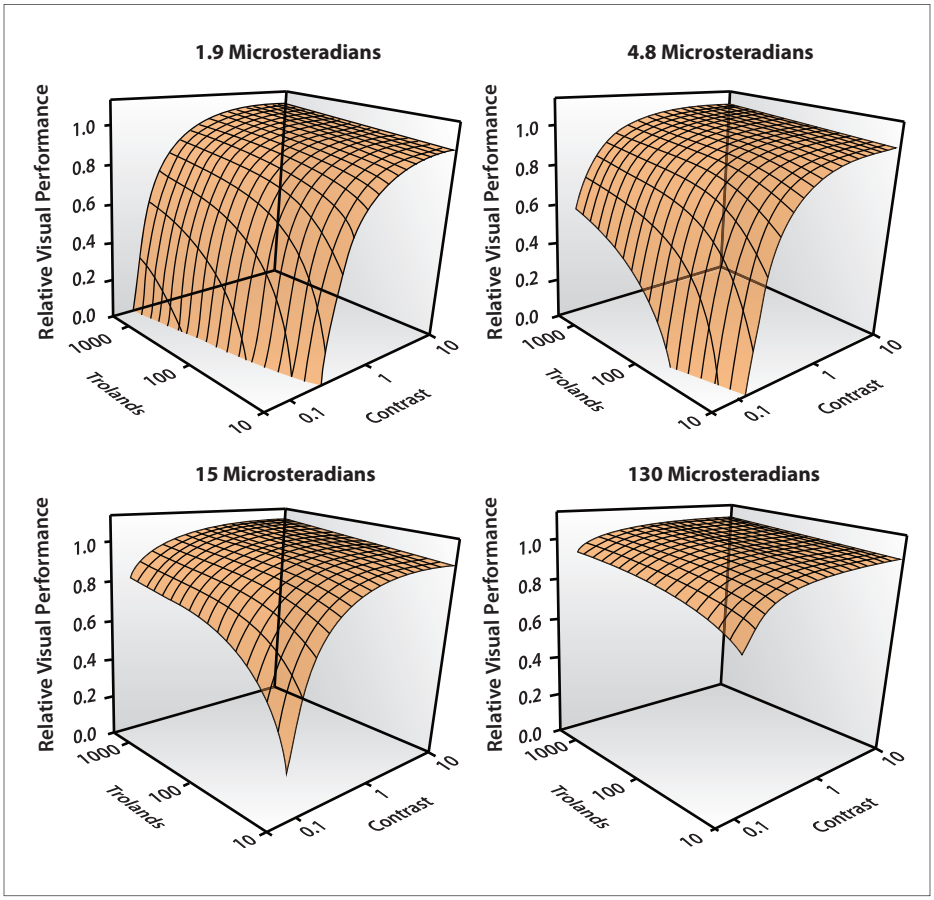


Figure 4.21 | Relative Visual Performance
Relative visual performance derived from numerical verification task performance, as a function of task contrast, retinal illuminance, and target size measured in solid angle.

The RVP model provides a quantitative means of predicting the effects of changing either task size, luminance contrast, or adaptation luminance for on-axis, suprathreshold visual performance. It is applicable to luminances in the photopic range but does not take into consideration the effect of reduced retinal image quality caused by limited accommodation, nor the effect of color differences between the target and the background. It can be only applied once a decision is made as to what constitutes the true critical size of the target. The RVP model has been validated in that it has been shown to predict the form of the change in performance produced by different lighting conditions, measured in three independent experiments, using different visual tasks [39, 40, 41,42]. It can be applied using input variables that can all be measured directly from the task. The RVP model is limited to predicting performance that can be described using speed and accuracy. More complex or cognitively based performance are not well predicted by this model.

It should also be noted that the RVP model is based on the luminance contrast presented to the observer, regardless of how that contrast is achieved. This means that both light polarization and distribution can affect visual performance for tasks that involve specularly reflecting materials, because both can change luminance contrast [20, 28]. Light distribution can produce veiling reflections that can make luminance contrast larger or smaller, depending on the specific arrangement of the materials. The change in luminance contrast can be large but it is difficult to control because it depends critically on the geometry between the source of luminance being reflected, the task, and the observer. A small change in position of any of these entities can markedly change the luminance contrast [40]. Polarization, in principle, is capable of reducing specularly reflected light, but this too is very dependent on the geometry between the source of polarized light, the reflecting surface and the observer, as well as the magnitude and nature of the polarization [53].

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4.8 Form and Depth Perceptions

4.8.1 Form and Pattern Perceptions

Signals arising from the opponency of receptive fields of various sizes capture the presence of borders or edges in a complex visual scene. These signals, and the way they are combined by the wiring of the visual system, produce neural activity in areas of the visual cortex that are tuned to respond only to luminous bars or gratings of various spatial frequencies and orientations. In this way, complex luminous patterns are broken down or decomposed into the simpler, fundamental spatial frequencies that comprise them. All scenes, however complex, can be considered constructed from these fundamental spatial frequencies [54].

This is analogous to the decomposition of a complex wave or signal into its fundamental sinusoidal components, known as Fourier Analysis [55]. Figure 4.22 gives an example of how a square wave can be considered as composed of the sum of sinusoidal waves of various frequencies and magnitudes.

Form and pattern perception arise, in part, from the operation of this spatial frequency decomposition or analysis performed by the visual system. The overall form or large-scale aspects of the perception of visual objects comes from the wide-bar or low spatial frequency information. Perception of detail of visual objects comes from the narrow-bar or high spatial frequency information.

4.8.2 Role of Spatial Vision in Edge Detection

The ability to perceive detail and detect edges rests on the contrast sensitivity at high spatial frequencies. The curves in Figure 4.14 show the border between visible and invisible spatial frequencies as a function of adaptation luminance. As shown in Figure 4.22, edges generate or are comprised of high spatial frequencies and shows why the detection of high spatial frequencies is important to vision.

Age significantly affects spatial contrast sensitivity at high spatial frequencies [56]; the sensitivity at 12 cycles per degree for most 65 year-olds is less than ½ that of most 20 year-olds.

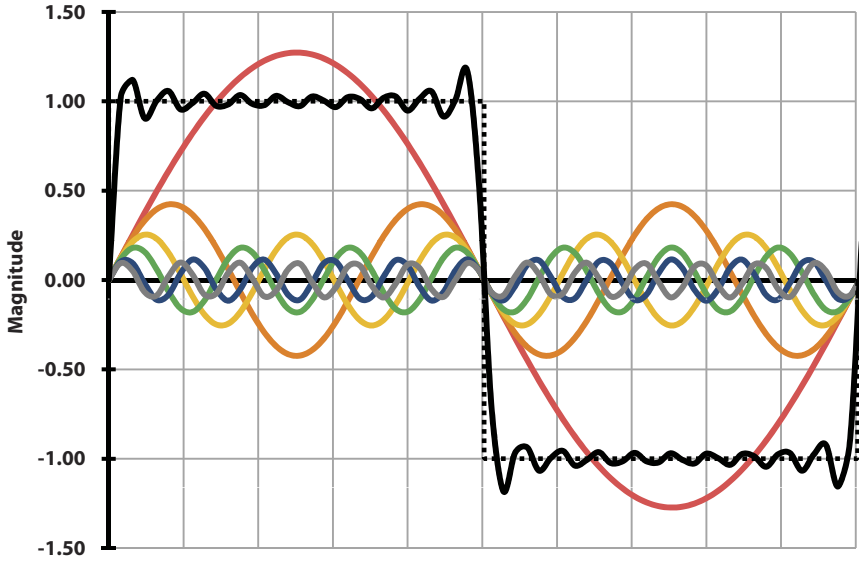


Figure 4.22 | Relative Visual Performance
Fourier representation of a square wave by the summation of several purely sinusoidal waves. If at every point along the horizontal scale, the values of the various sinusoidal waves at that point (positive and negative) are summed, the plotted result is the near-square wave. Adding high frequencies adds detail, making the wave more square.

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4.8.3 Lighting's Effect on Form and Pattern Perception

Form and pattern perception can be affected by lighting. Figure 4.14 shows the effect of lower adaptation luminances: overall lower spatial frequency sensitivity with a significant reduction is sensitivity to high spatial frequencies. Low luminance conditions can thus reduce or eliminate the perception of detail.

4.8.4 Depth Perception

Depth perception arises from oculomotor and visual cues. Oculomotor cues involve accommodation (change in focusing power of the eye) and vergence (change in eye position or angle). Visual cues involve object interposition and overlap, size, perspective, and motion parallax. Size and depth perception are closely related; the size of familiar objects often governs the perception of depth. As an object recedes, its retinal image becomes smaller, but the perception of its size remains constant. Familiarity, texture, and overlap provide cues to the object's greater distance and are unconsciously taken into account. These are principal monocular cues for depth perception. Others cues come from both eyes and provide stereopsis: the binocular ability to judge relative depth. These include retinal disparity, the slight difference in position of objects on the two retinas.

4.8.4 Lighting's Effect on Depth Perception

Luminance and color can affect depth perception. Luminance patterns and shadows can establish interposition order and depth hierarchy. Lighting can also accentuate or diminish the perception of texture on a surface and so enhance or suppress texture gradient as a depth cue. Surfaces of warm colors, especially red, are generally perceived as "near" and surfaces of cool colors are generally perceived as "distant" [57, 58, 59, 60, 61], hence warm tones seem to advance and cool tones seem to recede from the observer.

4.9 Spatial Perceptions

The magnitude and distribution of luminances in an interior can affect the perceptions of a space. In a series of studies performed in functioning interiors where work was to be done, it was found that certain subjective factors correlate with various impressions produced by the spaces [62] [63] [64] [65] [66] [67]. All studies show that brightness/dimness and uniformity/nonuniformity are two dimensions of subjective factors used by observers to evaluate the environment. A third dimension is sometimes found: overhead/peripheral in one study, simple/complex in another. The impressions correlated to these dimensions include spaciousness, preference or visual attraction, visual clarity, privacy, and relaxation. Figure 4.23 shows the relationship between the subjective factors and the impression of spaciousness from one study [56].

4.10 Glare

Glare occurs in two ways: luminance is too high or luminance ratios are too high. First, it is possible to have too much light. Too much light produces a simple photophobic response, in which the observer squints, blinks, or looks away. Too much light is common in full sunlight. The only solution to this problem is to reduce the retinal illuminance by obscuring a bright part of the visual field—by wearing a cap with a brim—or by lowering the luminance of the whole visual field—by wearing sunglasses. Second, glare occurs when the range of luminance in a visual environment is too large. Glare of this sort can have two effects: a feeling of discomfort and a reduction in visual performance.

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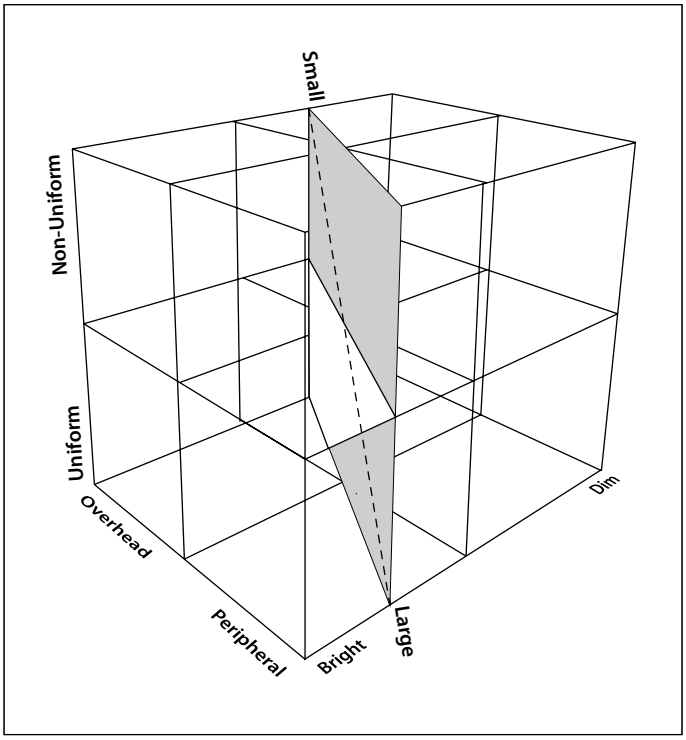


Figure 4.23 | Factors Affecting Spaciousness Perception
The impression of spaciousness related to the three dimensions of bright/dim, overhead/peripheral, and uniform/nonuniform. The impression of spaciousness moves along the line in the shaded plane as the values of the three dimensions change. Spacious is associated with bright, peripherally, uniformly lighted spaces.

4.10.1 Discomfort Glare

Discomfort glare is a sensation of annoyance or pain caused by high luminances in the field of view. The cause of discomfort glare is not well understood. Despite this lack of understanding of causal mechanism, four factors are known to participate in the perception of discomfort glare [61] [62] [63] [64] [65] [66] [67]:

1. Luminance of the glare source,
2. Size of the glare source,
3. Position of the source in the field of view, and
4. Luminance of the background

The effect of source size [64] and position [66] on discomfort glare are shown in Figures 4.24 and 4.25, respectively. Additionally, the relative glare potential of the source decreases approximately as the square-root of the background luminance. [61]

The relationships between these factors and the perception that a source is at or beyond the point of causing discomfort are well known and have been used to develop a number of empirical prediction systems in different countries.[65] [68] In North America, the empirical prediction system is the Visual Comfort Probability (VCP) system [65]. This system is based on assessments of discomfort glare for different sizes, luminances, and numbers of glare sources, their locations in the field of view, and the background luminance against which they are seen, for conditions likely to occur in interior lighting. The criterion used to measure the effect of these variables is the luminance just necessary to cause discomfort, a threshold criterion termed the borderline of comfort and discomfort (BCD).[61]

The visual comfort probability (VCP) system evaluates lighting systems in terms of the percentage of the observer population that will accept the lighting system and its environment as not being uncomfortable, using the perception of glare. See 10.9.2 Calculating Glare for a description of the computational procedure and the limits of applicability.

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While the VCP system is used in North America, the rest of the world uses somewhat different discomfort glare prediction systems. Nearly all these systems are based on a formula that implies that discomfort glare increases as the luminance and solid angle of the glare source at the eye increase and decreases as the luminance of the background and the deviation of the glare source from the line of sight increases.[68] Methods for calculating discomfort glare are described in 10.9.2 Calculating Glare.

Comparative evaluations between the different discomfort glare prediction systems for a common range of installations have shown that their predictions are well correlated and that none is significantly more accurate than the others at predicting the sense of discomfort, though each system has limitations [69] [70] [71]. All give reasonable predictions for the average discomfort of a group of people but give only poor predictions of an individual's response [72]. The CIE produced a consensus system to predict discomfort glare: the Unified Glare Rating system (UGR) [73]. The accuracy with which the UGR system can

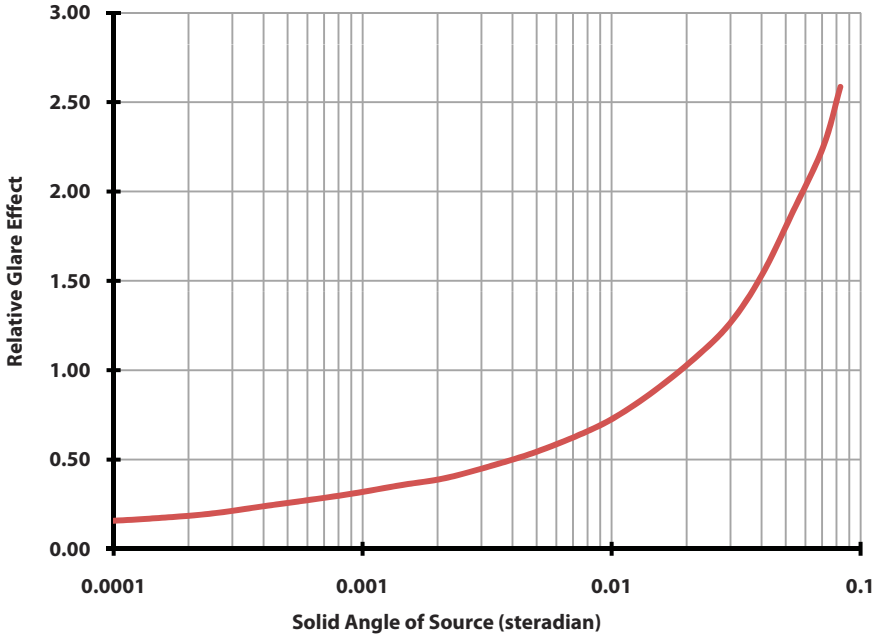


Figure 4.24 | Source Size and Discomfort Glare
The effect of source solid angle on the relative glare potential of the source.

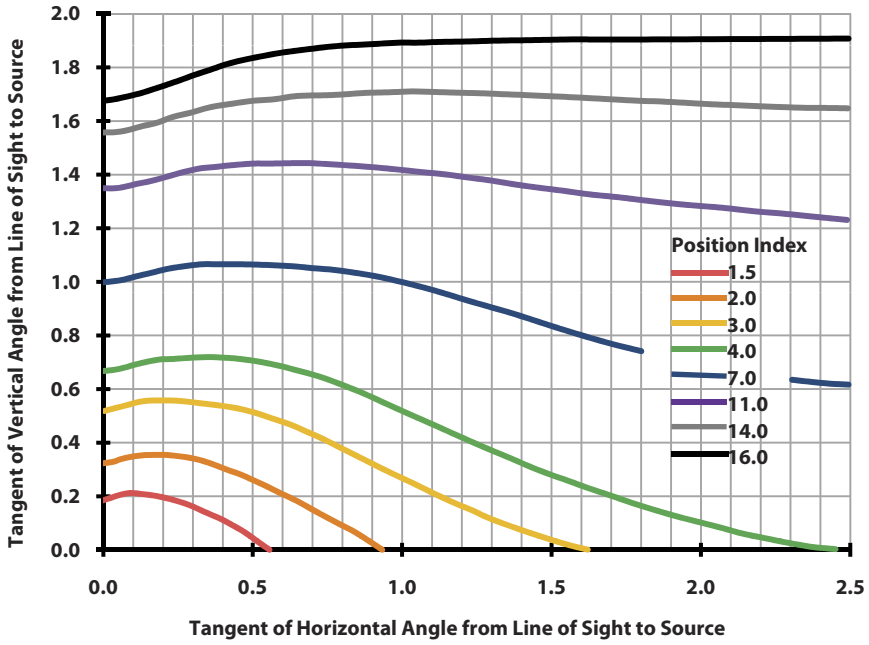


Figure 4.25 | Source Position and Discomfort Glare
Inverse of the effect of source position on the relative glare potential of the source. Position is specified by the tangents of the angle above the line of sight (V/R), and to the left or right of the line sight (L/R). The potential for discomfort glare rapidly decreases as the source moves off the line of sight.

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predict the level of discomfort produced by a glare source for a group of people has been shown to be high [74]. See 10.9.2 Calculating Glare for a description of the computational procedure for UGR and the limits of applicability.

The VCP and UGR systems are based on and are applicable to electric lighting systems. The Discomfort Glare Index (DGI) was developed for the evaluation of glare from windows. The determination of DGI involves the same parameters as those used to determine VCP and UGR. See 10.9.2 Calculating Glare for the computational process for DGI.

4.10.2 Disability Glare

Glare that reduces visibility is called disability glare and is due to light scattered in the eye, reducing the luminance contrast of the retinal image. The effect of scattered light on the luminance contrast of the target can be mimicked by adding a uniform "veil" of luminance to the target. The magnitude of disability glare can be estimated by calculating this equivalent veiling luminance. Different studies [75][76] [77] [78] [79] have examined the role of glare source luminance and angular separation from the primary object of regard as producers of disability glare; they have each produced slightly different functions, but a universal expression has been developed by the CIE [80]:

$$L_v = 10 \sum_{i=1}^{n} \left[\frac{E_i}{\theta_i^3} + \frac{E_i}{2\left[1 + \left(\frac{A}{6.25}\right)^4 \theta_i^2\right]} \right] \tag{4.13}$$

Where:

L_v = equivalent veiling luminance in cd/m^2,
E_i = illuminance from the ith glare source at the eye in lux,
θ_i = angle between the target and the ith glare source in degrees, and
A = age of observer in years.

Figure 4.26 plots values of equivalent veiling luminance calculated from Eq 4-12 and shows the effect of an off-line-of-sight source as function of position, for different age observers.

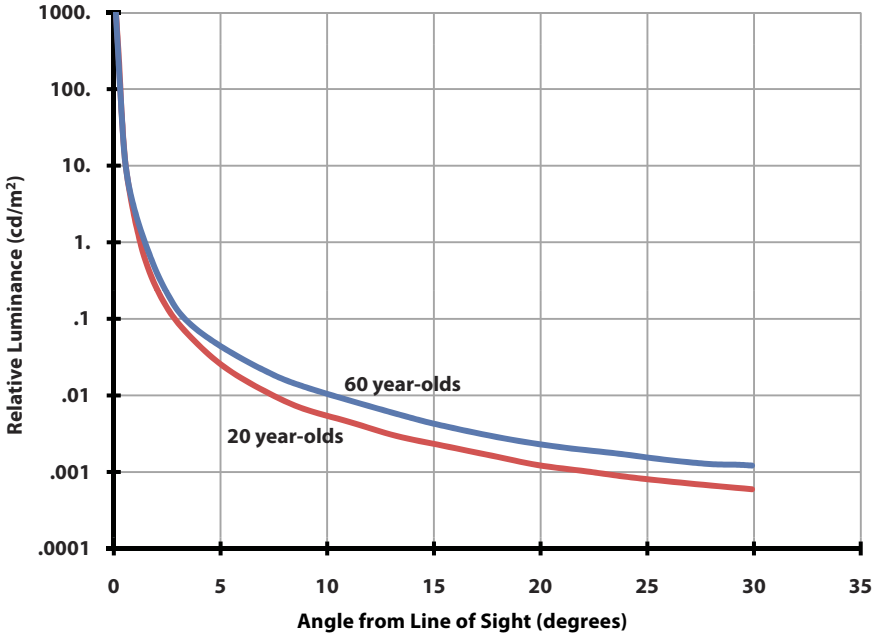


Figure 4.26 | Disability Glare
Veiling luminance per unit illuminance at the eye produced by a source, as a function of angular distance from the line of sight, for three observer age groups.

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The effect of disability glare on the luminance contrast of the perceived target can be determined by adding the equivalent veiling luminance to all elements in the formulas for luminance contrast (Equations 4-5 through 4-7).

Although disability glare is most commonly thought of as coming from discrete sources, such as oncoming automobile headlamps, every luminous point in space acts as a source of stray light and reduces contrast, thereby making edges in the visual field less conspicuous. The illuminance at the eye term in Equation 4.12 integrates the scattering effects produced by stray light from all points. Disability glare is rarely important in interior applications but is common on roads at night from oncoming headlights and during the day from the sun. Disability glare usually also causes discomfort, but it is possible to have disability glare without discomfort when the glare source is large. This can be seen by looking at art hung on a wall adjacent to a window. The art will usually be much easier to see when the eyes are shielded from the window.

4.11 Performance, Perceptions and Lighting Recommendations

The quality of the visual environment is determined by how well it supports the visual activities within a lighted space or area, how well it reveals the characteristics of the space or area, and what effect the environment has on the physical and emotional state of occupants. The dimensions of visual environmental quality include: visibility; task performance; mood and atmosphere; visual comfort; aesthetic judgment; health, safety, and well-being; and social communication. Lighting design guidance spans all these dimensions and since some issues assume more importance than others in certain lighting situations, guidance should be and is usually application specific. Guidance for specific lighting applications is found in respective application chapters.

There are some dimensions of visual environmental quality that are important when considering lighting recommendations. These dimensions are common to many applications, are amenable to quantification, and can be informed by lighting performance and perceptual research. These include two important aspects of many lighted environments: the illuminance required for visibility; and luminance limits and ratios to enhance task performance, avoid discomfort glare, and avoid fatigue associated with transient adaptation. These two aspects of visual environmental quality are discussed here with quantitative recommendations presented in respective application chapters.

4.11.1 Research Results

As described in 4.1 Psychophysical Experimentation, one goal of lighting research is to link simple, quantifiable parameters to complex visual phenomenon. In some cases, experimental results can be interpreted in a straightforward way. An example is a visual detection task performed under static threshold conditions, as described in 4.6.2 Threshold performance. Investigations of more practical and common visual tasks yield results that are very useful but less definitive; as with suprathreshold tasks described in 4.6.3 Practical suprathreshold performance. These results are less definitive because suprathreshold performance can be influenced by many factors, and practical considerations limit investigations to only the most important or influential parameters. Realistic suprathreshold tasks differ importantly from one another and it is difficult to generalize the results from the investigation of one task. Additionally, there are often interactions between influential parameters that have not or cannot be fully explored. Nevertheless, scientific research results have proven to be useful in guiding quantitative recommendations, especially when coupled with common sense and a consensus-based process for making recommendations [81].

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There are two principal difficulties with the direct application of lighting research results: individual differences and uncertainties, and competing and overlapping design goals.

4.11.1.1 Individual Differences and Uncertainties

Any research results, however simple and limited the visual phenomenon, reveals a range of responses to the parameters that influence it. This reflects the natural and unavoidable variance in the human population and the inherent uncertainty in research results. And so establishing a single-valued, rigidly interpreted quantifiable result can almost never be justified. For even a relatively small population, the responses to luminous stimuli usually follow a normal distribution, the so-called "bell curve." Thus, it is always necessary to decide what fraction of the population to include when applying research results to recommendations. This latter decision can almost never be wholly guided by research.

4.11.1.2 Competing and Overlapping Design Goals

Most luminous environments are complex and have multiple activities in the same space or area. Research results may guide the lighting of an individual task at a single location, but research does not provide the mechanisms to establish the trade-offs between task importance, localization, and resource or energy use.

4.11.2 Consensus

Judgment and consensus are necessary to bridge the gap between relatively isolated lighting research results and the practical need for reasonable, quantitative recommendations of illuminance and luminance levels and ratios. Consensus includes the consideration of experience and case studies, and the accompanying knowledge of what is necessary or adequate illuminance.

4.12 An Illuminance Determination System

This section describes a system to determine illuminance target values. The overall structure of the system is presented, including the aspects of tasks, observers, and context that are taken into account. Modifications to accommodate observer age and conditions of mesopic adaptation are also described. Use of this general system with factors specific to an application results in illuminance recommendations. This final step is described in respective application chapters.

Illuminance recommendations provide guidance for one aspect of the lighting design process: to provide sufficient illuminance. Whether to ensure adequate task visibility or to generate the appropriate general level of some surfaces' luminances in a space, illuminance recommendations are consensus values informed by scientific research, experience, available technology, economic considerations, best practice, and energy concerns. Since these recommendations often form part of lighting design criteria or specifications and codes, the intent is to provide defensible, specific guidance based on the sources of information listed above and factors that include characteristics of the tasks and observers. Illuminance recommendations should be used only in conjunction with other relevant lighting criteria such as illuminance uniformity, facial or task modeling, color, flicker, architectural appearance, direct and reflected glare, and luminance ratio limits.

4.12.1 Factors

Three factors are used in the determination of recommended illuminances: task characteristics, task importance, and observer characteristics. Task characteristics describe the physical and photometric properties of the task and thus define it as a visual stimulus. Task importance is taken into account as part of the process of balancing interaction with other tasks, the intrinsic importance of the visual performance of a particular task, and energy concerns. Observer characteristics are here limited to the effects of age on the function of the visual

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system and the visual system of the partially sighted. This includes loss of accommodation, and the reduction and spectral change of retinal illuminance. See 2.6.3 Effects of Age.

4.12.1.1 Task Characteristics

As shown in 4.5 Contrast sensitivity and 4.7 Visual performance, visual task size and contrast are important influences on task visibility and performance. In all cases it is necessary to convert the physical extent of a task to a visual size; either visual angle or solid angle. To do this, the viewing distance must also be known or estimated.

The luminance contrast of a task used here is that defined by equation 4-5. In many cases the task and its immediate background exhibit a reflectance diffuse enough to be considered perfectly diffuse, in which case the luminance contrast is determined entirely by reflectances:

$$C = \left|\frac{L_t - L_b}{L_b}\right| = \left|\frac{\frac{M_t}{\pi} - \frac{M_b}{\pi}}{\frac{M_b}{\pi}}\right| = \left|\frac{\frac{E\,\rho_t}{\pi} - \frac{E\,\rho_b}{\pi}}{\frac{E\,\rho_b}{\pi}}\right| = \left|\frac{\rho_t - \rho_b}{\rho_t}\right| \qquad (4.14)$$

Where:

M_t = exitance of the task
M_b = exitance of the background
ρ_t = task diffuse reflectance
ρ_b = background diffuse reflectance

In this case luminance contrast is a fixed property of the task that is not affected by illumination provided in the application. Some task materials exhibit directional reflectance and so task and background luminance can be a function not only of the illuminance but also the directions of incidence and view. In this case, recommendations of illuminance are accompanied by guidance for lighting equipment placement relative to the task or by cautions regarding effects of lighting geometry.

Unless otherwise indicated, it is assumed that the time for viewing the task is not limited and that the observer has control over the time to view the task. In some cases, the task is moving or can only be viewed in glimpses. In these cases the task is more difficult to perform and the recommended illuminances are higher than for static tasks.

Some tasks are best performed at low illuminance levels and the recommended illuminances are presented as maxima. Examples include some work with computer visual display units and some self-illuminated tasks.

For some tasks, the visibility required is only detection, recognition, or comprehension and task performance has only modest consequences. Examples include reading a newspaper or walking in a corridor. However, for some tasks the importance of speed and accuracy is high and health and wellbeing are at risk. Examples include work in pharmacies, medical diagnosis, surgery, driving, and kitchen work with knives. In these cases the recommended illuminances are higher than for tasks where speed and accuracy is not important.

4.12.1.2 Observer Characteristics

"Visual age" is used here to indicate the state of observers' visual systems. For normal-sighted individuals, this is their chronological age. Visual impairments may affect an individual's visual system so that it functions like that of an older person; their visual age may be greater than their chronological age. Visual age determines the ultimate effect of task luminance, size, and contrast. Reduced retinal illuminance, spectral change, scattered light, and image blur are all consequences of advancing visual age. Where appropriate, recommended illuminances are adjusted to account for visual age. See 2.6 Consequences for Lighting Design.

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4.12.2 Basis

Support for and a check against consensus values of illuminance recommendations are provided by research results of suprathreshold visual tasks, including the relative visual performance model (see 4.7.2 Relative Visual Performance). Additionally, data describing the effects of visual age on the amount and spectral composition of retinal illuminance are also taken into account.

The fundamental form of illuminance recommendations is a series of illuminance ranges that span from 0.5 lux to 20,000 lux, grouped for low-level primarily outdoor lighting applications, and higher-level primarily indoor applications. The increments between each range of illuminances is approximately 30%, reflecting the psychophysical fact that a change in stimulus of about ½ logarithmic unit is required to change the response in a significant way. These increments are also designed to provide the granularity necessary for accommodating an increasing refinement of tasks, new tasks, and better targeting of lighting energy. Table 4.1 shows the illuminance ranges involved and some discussion of the corresponding tasks.

A particular value from this stepped series is assigned to a task based on an assessment of the task's likely inherent contrast, size, reflectance, and the likely importance of speed and accuracy in its performance. It is also assumed that observers are between 25 and 65 years old. If it is known that more than 50% of the population using the proposed lighting system is older than 65, then the recommended illuminance is doubled. If it is known that more than 50% of the population using the proposed lighting system is younger than 25, then the recommend illuminance is halved.

A task with characteristics so difficult, or an importance that is so extraordinary, or has performance consequences so dire, that it is assigned a recommended illuminance outside the series described above. These are very special cases and are noted as such. In other cases, a task may be self luminous or have reflectance characteristics that are best served by low illuminance levels, and so those recommendations are for a maximum illuminance.

4.12.3 Spectral Effects

In applying illuminance recommendations, it is to be assumed that the adaptation state of the visual system is photopic, unless it can be determined otherwise. However, peak visual system efficacy is adaptation dependent and, as described in 2.4.3 Mesopic Vision, shifts to shorter wavelengths as adaptation luminance decreases. If the adaptation state is known to be mesopic, then some adjustment may be made based on the spectral composition of the luminances. In these applications, it is very likely that the reflectances involved are achromatic, or nearly so, and thus the spectral composition of surface luminances can be assumed to be the same as the spectral composition of the illuminance, which is, in turn, the same as the spectral composition of the source.

The scotopic-photopic (S/P) ratio of the optical radiation is used as a single-value indicator of the nature of its spectrum; the larger the value, the more dominant are the shorter wavelengths. Illuminance recommendations assume that the spectral composition of the luminances involved have S/P = 1.0. If the spectral composition is known to have a different ratio, then an adjustment may be made to the recommended illuminance that accounts for the shift in peak efficacy due to mesopic adaptation. Figure 4.27 shows multipliers that can be used to adjust recommended illuminances for mesopic adaptation. Mesopic adaptation is assumed to be at or below 3 cd/m^2 and the multipliers of Figure 4.27 may be used only for adaptation luminances at or below 3 cd/m^2. Though accounting for mesopic adaptation applies to many outdoor nighttime lighting situations, it should not be used to adjust recommended illuminance or luminances for roadways where the speed limit is greater than 40 kph (25 mph). Table 4.2 shows multiplier values for specific combinations of photopic adaptation luminance and S/P from the data used to construct Figure 4.27.

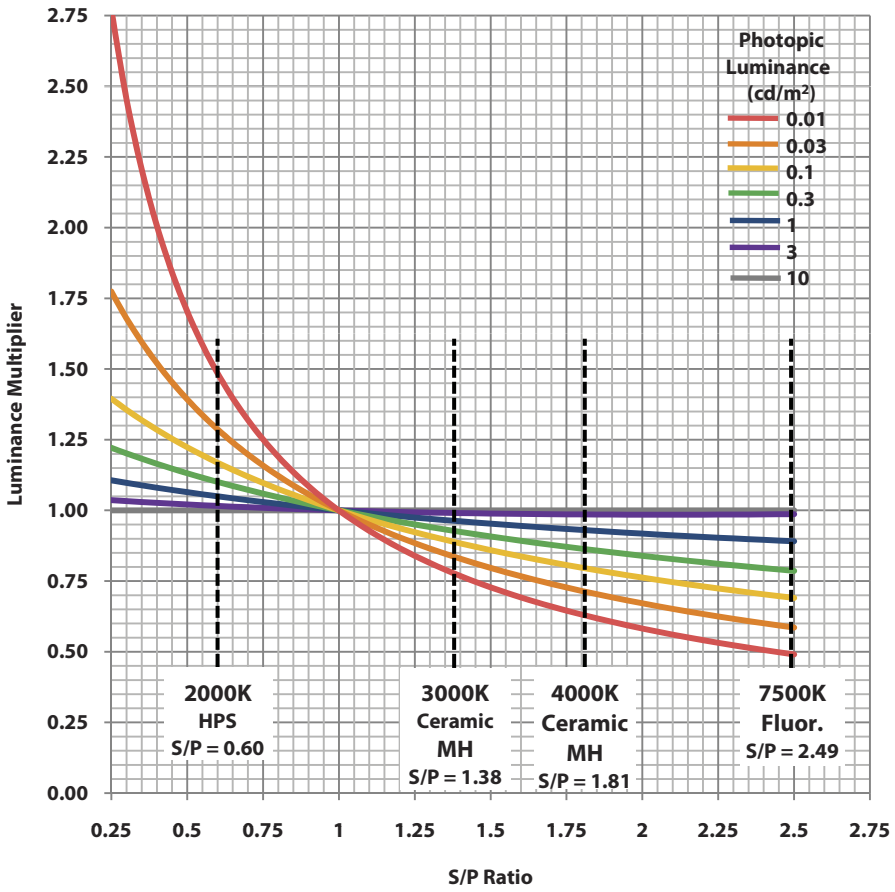
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Table 4.1 | Recommended Illuminance Targets

Category		Recommended Illuminance Targets (lux) Visual Ages of Observers (years) where **at least half** are <25	25 to 65	>65	Some Typical Application and Task Characteristics	Visual Performance Description
interior and **exterior** applications	A	0.5	1	2	• Dark adapted situations • Basic convenience situations • Very-low-activity situations	**Orientation, relatively large-scale, physical (less-cognitive) tasks** Visual performance is typically not work-related, but related to dark sedentary social situations, senses of safety and security, and casual circulation based on landscape, hardscape, architecture, and people as visual tasks.
	B	1	2	4		
	C	2	4	8	• Slow-paced situations • Low-density situations	
	D	3	6	12	• Slow-to-moderate-paced situations • Moderate-to-high-density situations	
	E	4	8	16		
	F	5	10	20	• Moderate-to-fast-paced situations • High-density situations • Some indoor very subdued circulaton situations • Some indoor social situations	
	G	7.5	15	30		
	H	10	20	40		
interior and **exterior**	I	15	30	60	• Congested and significant outdoor intersections, important decision-points, gathering places, and key points of interest • Some indoor social situations • Some indoor commerce situations	
interior and exterior applications	J	20	40	80	• Some outdoor commerce situations • Some indoor social situations • Some indoor commerce situations	**Common social activity and large and/or high-contrast tasks** Visual performance involves higher-level assessment of landscape, hardscape, architecture, and people and can be work related.
	K	25	50	100		
	L	37.5	75	150		
	M	50	100	200		
	N	75	150	300		
	O	100	200	400		
	P	150	300	600	• Some indoor social situations • Some indoor education situations • Some indoor commerce situations • Some indoor sports situations	**Common, relatively small-scale, more cognitive or fast-performance visual tasks** Visual performance is typically daily life- and work- related, including much reading and writing of hardcopies and electronic media consecutively and/or simultaneously.
	Q	200	400	800	• Some indoor education situations • Some indoor commerce situations • Some indoor sports situations • Some indoor industrial situations	
	R	250	500	1000		
	S	375	750	1500		
	T	500	1000	2000	• Some sports situations • Some indoor commerce situations • Some indoor industrial situations	**Small-scale, cognitive visual tasks** Visual performance is work- or sports-related, close and distant fine inspection, very small detail, high-speed assessment and reaction.
	U	750	1500	3000		
	V	1000	2000	4000		
	W	1500	3000	6000	• Some sports situations • Some indoor industrial situations • Some health care procedural situations	**Unusual, extremely minute and/or life-sustaining cognitive tasks** Visual performance is of the highest order in respective fields of health care, industrial, and sports.
interior applications	X	2500	5000	10000	• Some health care procedural situations	
	Y	5000	10000	20000		

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Figure 4.27 | Mesopic Multipliers
Multipliers to adjust recommended photopic illuminance target values for mesopic adaptation.



For most applications, the prevailing photopic luminance can be found from:

$$L_{photopic} = \frac{1}{\pi} \bar{E}_{photopic} \rho_{target} \quad (4.15)$$

Where:

$E_{photopic}$ = average photopic illuminance in lux
ρ_{target} = appropriate value of target background reflectance

Table 4.2 | Mesopic Multipliers

S/P	Photopic Luminance (cd/m²) 3	1	0.3	0.1	0.03	0.01
0.25	1.0364	1.1065	1.2215	1.3951	1.774	2.7717
0.5	1.021	1.0645	1.1315	1.2235	1.3931	1.7044
0.75	1.009	1.0295	1.0594	1.0972	1.159	1.2514
1	1	1	1	1	1	1
1.25	0.9934	0.9748	0.9502	0.9227	0.8846	0.8396
1.5	0.9888	0.9531	0.9078	0.8596	0.7968	0.728
1.75	0.986	0.9343	0.8712	0.8069	0.7276	0.6456
2	0.9848	0.9178	0.8392	0.7623	0.6716	0.5823
2.25	0.9851	0.9035	0.8111	0.7239	0.6251	0.5319
2.5	0.9867	0.8908	0.786	0.6905	0.586	0.4908

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4.12.4 Application of Recommended Illuminance Targets

Recommended illuminance targets are considered maintained illuminances of electric light and/or daylight at the area of coverage as defined by the designer, unless otherwise noted. Recommendations are considered minimum, maintained illuminances at the area of coverage where the task is deemed by the design tem/client to involves life safety or where human-vehicular proximity and/or personal safety and security are significant concerns. Additionally, code requirements supersede these recommendations. See 10.7.1 Light Loss Factors for a discussion of maintained illuminance.

These values are design goals and, as a practical matter, variation from them is expected and may be found at two stages in the construction process: at design time and at commissioning or occupancy time.

4.12.4.1 Recommended Illuminances at Design Time

Quantitative assessments are usually performed during the design process, using lighting analysis software to predict maintained illuminance. If calculations show that predicted illuminance values differ by more than 10% from the recommended illuminance target, this should be noted and may require attention. If predicted values are below the illuminance target by more than 10% then the expected visibility may not be supported by the illuminance provided for a significant fraction of the population using the lighting system. See 4.11.1.1 Individual Differences and Uncertainties. If a predicted value is above a recommendation by more than 10% then overlighting and energy misuse are arguable results.

4.12.4.2 Recommended Illuminances at Occupancy Time

Assessment of illuminance in the field by measurement is very much more complicated. Nonrecoverable light loss factors and measurement equipment performance can seriously affect results. See 9.15 Field Measurements. Field measurement of illuminances made soon after lighting equipment installation or occupancy need to account for anticipated recoverable light loss factors and the non-recoverable light loss factors that were employed in calculations performed during design. For purposes of visual performance, such adjusted values that are within 30% of the illuminance targets might be considered acceptable. See 15.3.2 Field Results.

4.12.4.3 Localized Tasks

In some applications task locations are known, such as metal working locations in a machine shop. If task locations are known then the recommended illuminance target applies only to those locations.

4.12.4.4 Area Tasks

In some applications the target is a larger area over which tasks are performed, such as the floor of a corridor. For area tasks, the recommended illuminance target is to be achieved over that area. When the illuminance target is an average, the uniformity ratio establishes a minimum illuminance that prevents individual values over the area from deviating too far from the illuminance target. As long as the minimum is met, the *average illuminance* attained may deviate from the target by as much as 10% and the recommended illuminance target may be considered obtained.

Average Illuminance is calculated from an array of points. The accuracy of the resulting average illuminance depends of the density of analysis points in the calculation grid.

4.12.4.5 Tasks at Uncertain Locations Over a Large Area

Sometimes the task is localized and performed at specific locations in a large area, but for reasons of space use, planning, or future flexibility, the precise locations are not known at design time. This is the case, for example, with the student seating area in a classroom. As with area tasks, average illuminance can be used as an indicator of having achieved the illuminance target.

In these applications the criterion rating, CR, is more descriptive than the average, and can be determined for the area and used as a performance measure. CR is defined by

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$$CR = \frac{\text{Number of calculation or measurement points at or above the criterion}}{\text{Number of calculation or measurement points}} \quad (4.16)$$

It is recommended that the CR of an area of uncertain task locations not be less than 70% [82]. See 10.8.4 Criterion Ratings for details of computing this performance measure.

Another performance measure that can be used in this situation is the coefficient of variation (C_v). C_v is defined by

$$C_v = \frac{\sigma}{\mu} = \frac{\text{Standard Deviation}}{\text{Mean}} \quad (4.17)$$

See 10.8.2 Minima and Maxima for details of computing this performance measure.

4.12.4.6 Multiple Tasks

It is often the case that the illuminance in some areas of an application must support multiple tasks. In these cases it is usually necessary to rank the tasks by importance, prevalence, or frequency using data that may be available from the client, to determine the commonly occurring task with the highest recommended illuminance, and it should govern the illuminance made available on the task area. It is not necessary to provide for the highest illuminance level with the general lighting system. Localized task lighting should be employed for the more visually demanding tasks, with the benefits of lower energy use and increased user satisfaction.

4.12.5 Illuminance Ratios

In applications that present areas to be lighted, it is usually necessary to assess the variation in illuminance and characterize the uniformity. Average, minimum, and maximum are often used in these assessments to form ratios of

- Average/minimum
- Maximum/minimum
- Average/maximum

Minimum and maximum values are found from an array of calculated illuminances and they often depend on calculation point placing and spacing. Averages are found from the entire array and may need to account for nonuniform calculation point spacing. Minimum or maximum values should be used with caution, as a single very low or high value can skew ratios and misrepresent the general illuminance uniformity in an area. The criterion rating or coefficient of variation are alternative metrics for these assessments.

Task performance can be degraded by high luminance ratios involving the task itself and both the immediate and more distant background. Discomfort glare and disability glare can both be involved. To limit high luminance ratios, reasonable assumptions are made about the range of reflectances involved and limits on luminance ratios are converted to limits on illuminance ratios. Where appropriate, illuminance ratios have been recommended to control these effects on task performance.

4.13 Luminance Recommendations

Luminance recommendations provide guidance for another aspect of the lighting design process: to provide appropriate surface brightness in the space, limit discomfort and disability glare, and establish or control brightness variations for aesthetic, architectural, balance, or form-modeling purposes.

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4.13.1 Brightness Basis

Luminance recommendations are based on what is known of how the visual system maps luminance to brightness, and are informed by experience and consensus.

4.13.2 Factors

Brightness is a function of adaptation state and the luminance of the object. For foveal tasks, adaptation state is determined by the central 10º of the visual field. Brightness ratio is a function not only of adaptation and object luminance but also of luminance gradient and chromaticity. See 4.3 Brightness.

4.13.3 Recommendations

Aside from a few general principles, luminance recommendations are application specific and are provided in respective application chapters.

4.14 References

[1] Gescheider G. 1997. Psychophysics: the fundamentals. 3rd ed. Lawrence Erlbaum Associates. 448 p.

[2] Bruce V, Green PR, Georgeson MA. 1996. Visual perception. 3rd ed. Psychology Press. 496 p.

[3] Boyce P. 2005. Reflections on relationships in behavioral lighting research. Leukos 2(2):97-113.

[4] Rea MS. 1982. Calibration of subjective scaling responses. J Illum Eng Soc. 14:121-129.

[5] Tiller, DK. 1990. Towards a deeper understanding of psychological effects of lighting. J Illum Eng Soc. 19(2):59-65.

[6] Tiller DK, Rea MS. 1992. Semantic differential scaling: Prospects for lighting research. Light Res Tech. 24(1):43-51

[7] Fotios AS, Houser KW, Cheal C. 2008. Counterbalancing needed to avoid bias in side-by-side brightness matching tasks. Leukos. 4(4):207-223.

[8] Fotios SA, Houser KW. 2009. Research methods to avoid bias in categorical rating of brightness. Leukos. 5(3):167-181

[9] Figueiro MG, Rea MS, Bullough JD. 2006. Does architectural lighting contribute to breast cancer? J Carcinogenesis. 5(1):20

[10] Bedford RE, Wyszecki GW. 1958. Wavelength discrimination for point sources. J Opt Soc Am. 48(2):129–135.

[11] Wright WD. 1946. Researches on normal and defective color vision. London. Henry Kimpton. 376p.

[12] Robertson AR. 1981. Color differences. Die Farbe. 29:273.

[13] Boyce PR. 1978. Variability of contrast rendering factor in lighting installations. Light Res Tech. 10(2):94–105.

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[14] Boff KR, Lincoln JE. 1988. Engineering data compendium: Human perception and performance. Wright- Patterson Air Force Base, Ohio: Harry G. Armstrong Aerospace Medical Research Laboratory.

[15] Blackwell, H. R. 1946. Contrast thresholds of the human eye. J. Opt. Soc. Am. 36(11):624–643.

[16] Bartleson CJ, Brenenman EJ. 1967. Brightness perception in complex fields. J Opt Soc Am. 57(1):953-957.

[17] Stevens SS. 1960. Psychophysics of sensory function. Am Sci. 48(2):226–252.

[18] Marsden, A. M. 1970. Brightness-luminance relationships in an interior. Light. Res. Tech. 2(1):10–16.

[19] Bodmann H-W, LaToison M. 1994. Predicted brightness-luminance phenomena. Light Res Tech. 26(3):136-143.

[20] Ashdown I. 1996. Luminance gradients: Photometric analysis and perceptual reproduction. J Illum Eng Soc. 25(1):69-82.

[21] Lythgoe RJ. 1932. The measurement of visual acuity. Medical Research Council Special Report, No. 173. London. H.M. Stationary Office.

[22] Blackwell OM., Blackwell HR. 1971. Visual performance data for 156 normal observers of various ages. J Illum Eng Soc. 1(1):3–13.

[23] Blackwell HR, Blackwell OM. 1980. Population data for 140 normal 20–30 year olds for use in assessing some effects of lighting upon visual performance. J Illum Eng Soc. 9(3):158–174.

[24] Nadler, MP, Miller D, Nadler DJ. 1990. Glare and contrast sensitivity for clinicians. New York: Springer- Verlag. 150 p.

[25] Lamming D. 1991. Contrast sensitivity. In: Cronly-Dillon, J editor. Vision and Visual Dysfunction. London. Macmillan. 5272 p.

[26] Baron WS, Westheimer G. 1973. Visual acuity as a function of exposure duration. J Opt Soc Am. 63(2):212-219.

[27] Brown JL. 1965. Flicker and intermittent stimulation. In: Graham CH, ed. Vision and Visual Perception. New York. Wiley. 637 p.

[28] Hart WM. 1992. The temporal responsiveness of vision. In: Moses RA, Hart WM, editors. Adler's Physiology of the eye: Clinical applications. Mosby. St. Louis. 888p.

[29] Salvendy G, editor. 1997. Handbook of human factors and ergonomics. 2nd ed. John Wiley. New York. 2137 p.

[30] Weston HC. 1935. The relation between illumination and visual efficiency: The effect of size of work. Prepared for Industrial Health Research Board (Great Britain), and Medical Research Council (London). London: H M Stationery Office.

[31] Weston HC. 1945. The relation between illumination and visual efficiency: The effect of brightness contrast. (Great Britain) and Medical Research Council (London). Industrial Health Research Board Report no. 87. London. H M Stationery Office.

[32] Inditsky B, Bodmann HW, Fleck H J. 1982. Elements of visual performance: Contrast metric—visibility lobes—eye movements. Light Res Tech. 14(4):218–231.

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[33] Rea MS. 1983. The validity of the relative contrast sensitivity function for modeling threshold and suprathreshold responses. In: The Integration of Visual Performance Criteria into the Illumination Design Process. Ottawa. Public Works Canada. 483 p.

[34] Roethlisberger, F. J., andW. J. Dickson. 1934. Management and the worker: Technical vs. social organization in an industrial plant. Boston: HarvardUniversity Press.

[35] Smith, S. W., and M. S. Rea. 1978. Proofreading under different levels of Illumination. J. Illum. Eng. Soc. 8(1):47–52.

[36] Smith, S. W., and M. S. Rea. 1980. Relationships between office task performance and ratings of feelings and task evaluations under different light sources and levels. Proceedings: 19th Session, Commission Internationale de l'Éclairage. Paris: BureauCentral de la CIE.

[37] Smith, S. W., andM. S. Rea. 1982. Performance of a reading test under different levels of illumination. J. Illum. Eng. Soc. 12(1):29–33.

[38] Smith, S. W., andM. S. Rea. 1987. Check value verification under different levels of illumination. J. Illum. Eng. Soc. 16(1):143–149.

[39] Rea, MS. 1987. Toward a model of visual performance: A review of methodologies. J Illum Eng Soc. 16(1):128–142.

[40] Rea, M. S. 1981. Visual performance with realistic methods of changing contrast. J. Illum. Eng. Soc. 10(3):164–177.

[41] Rea MS. 1986. Toward a model of visual performance: Foundations and data. J Illum Eng Soc. 15(2):41–57.

[42] Boyce PR, Rea MS. 1987. Plateau and escarpment: The shape of visual performance. Proceedings: 21st session, Commission Internationale de l'Éclairage. Paris: Bureau Central de la CIE.

[43] Rea, MS, Ouellette MJ. 1988. Visual performance using reaction times. Light Res Tech. 20(4):139–153.

[44] Rea, MS, Ouellette MJ. 1991. Relative visual performance: A basis for application. Light Res Tech. 23(3):135–144.

[45] Bailey IR, Clear R, Berman S. 1993. Size as a determinant of reading speed. J Illum Eng Soc. 22(2):102–117.

[46] Eklund NH, Boyce PR, Simpson SN. 2001. Lighting and sustained performance: Modeling data-entry task performance, J Illum Eng Soc. 30(2):126-141.

[47] Clear R, Mistrick RG. 1996. Multilayer polarizers: A review of the claims. J Illum Eng Soc. 25(2):70–88.

[48] DeValois RL, DeValois KK. 1988. Spatial Vision. Oxfor. New York. 381 p.

[49] Tolstov GP. Silverman RA, translator. 1962. Fourier series. Dover. New York. 336 p.

[50] Wright CE, Drasdo N. 1985. The influence of age on the spatial and temporal contrast sensitivity function. Documenta Ophthal. 59(4):385-395.

[51 Verhoeff FH. 1928 An optical illusion due to chromatic aberration. Am J Ophthal. 11:898–900.

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[52] Egusa H. 1983. Effects of brightness, hue, and saturation on perceived depth between adjacent regions in the visual field. Perception. 12(2):167–175.

[53] Simonet P, Campbell MCW. 1990. Effect of luminance on the directions of chromatostereopsis and transverse chromatic aberration observed with natural pupils. Ophthal Physiol Opt. 10(3):271–279.

[54] Rohaly AM, Wilson HR. 1993. The role of contrast in depth perception. Investig Ophthalmol Vis Sci. 34(4):1437.

[55] Guibal C, Dresp B. 2004. Interaction of color and geometric cues in depth perception: When does "red" mean "near"? Psychological Research 69(1):30–40.

[56] Flynn JE, Spencer TJ, Martyniuk O, Hendrick C. 1973. Interim study of procedures for investigating the effect of light on impression and behavior. J Illum Eng Soc. 3(1):87-94.

[57] Flynn JE, Spencer TJ, Martyniuk O, Hendrick C. 1975. The Influence of Spatial Light on Human Judgment. Proc CIE 18th Session. London. 39-46.

[58] Flynn JE. 1977. A study of the subjective responses to low energy and nonuniform lighting systems. Light Des Appl. 7(2):6-15.

[59] Hawkes RJ, Loe DL, Rowlands E. 1979. A note towards the understanding of lighting quality. J Illum Eng Soc. 8():111-120.

[60] Veitch JA, Newsham GR. 1998. Determinants of lighting quality and energy efficiency effects on task performance, mood, health, satisfaction, and comfort. J Illum Eng Soc. 27(1): 92-106.

[61] Luckiesh M, Guth SK. 1949. Brightness in visual field at borderline between comfort and discomfort (BCD). Illum Eng 44(11):650–670.

[62] Hopkinson RG. 1957. Evaluation of glare. Illum Eng. 52(6):305–316.

[63] Guth SK, McNelis JF. 1959. A discomfort glare evaluator. Illum Eng. 54(6):398–406.

[64] Bradley RD, Logan HL. 1964. Auniform method for computing the probability of comfort response in a visual field. Illum Eng 59(3):189–206.

[65] Guth SK. 1963. A method for the evaluation of discomfort glare. Illum Eng. 57(5):351–364.

[66] Allphin W. 1966. Influence of sight line on BCD judgments of direct discomfort glare. Illum Eng. 61(10):629–633.

[67] Allphin W. 1968. Further studies of sight line and direct discomfort glare. Illum Eng. 63(1):26–31.

[68] Fischer D. 1991. Discomfort glare in interiors. First International Symposium on Glare. Lighting Research Institute. NewYork.

[69] Manabe H. 1976. The assessment of discomfort glare in practical lighting situations. Oteman Economic Studies no 9. Osaka: Oteman Gakuin University.

[70] Waters CE, Mistrick RM, Bernecker C 1995. Discomfort glare from sources of non-uniform luminance. J Illum Eng Soc. 24(2):73-85.

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[71] Eble-Hankins ML, Waters CE. 2004. VCP and UGR glare evaluation systems: a look back and a way forward. Leukos. 1(2):7-38.

[72] Boyce PR., Crisp VHC, Simons RH., Rowlands E. 1980. Discomfort glare sensation and prediction. Proceedings: 19th Session. Commission E. Internationale de l'Éclairage. Bureau Central la CIE. Paris.

[73] [CIE] Commission Internationale de l'Éclairage. 1995. Discomfort glare in interior lighting. CIE Publication 117. Bureau Central de la CIE. Vienna.

[74] Akashi, Y., R. Muramatsu, and S. Kanaya. 1996. Unified Glare Rating (UGR) and subjective appraisal of discomfort glare. Light. Res. Tech. 28(4):199–206.

[75] Holladay LL. 1926. The fundamentals of glare and visibility. J Opt Soc Am. 12(4):271–319.

[76] Holladay LL. 1927. Action of a light source in the field of view on lowering visibility. J Opt Soc Am. 14(1):1–15.

[77] Stiles WS. 1929. The effect of glare on the brightness difference threshold. Proc R Soc Lond. Ser. B 104(731): 322–351.

[78] Fry, GA. 1954. A re-evaluation of the scattering theory of glare. Illum Eng. 49(2):98–102.

[79] Wolf, E., and J. S. Gardiner. 1965. Studies on the scatter of light in the dioptric media of the eye as a basis of visual glare. Arch. Ophthalmol. 74(3):338–345.

[80] Boyce PR. 2009. Lighting for driving. Taylor & Francis. Boca Raton. 371 p.

[81] Boyce PR. 1996. Illuminance selection based on visual performance—and other fairy stories. J Illum Eng Soc. 25(2):41-49.

[82] {IES} Design Practice Committee. 1977. Recommended practice for the specification of an ESI Rating in interior spaces when specific task locations are unknown. J Illum Eng Soc. 6(2):111-123.

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5 | CONCEPTS AND LANGUAGE OF LIGHTING

If language is not correct, then what is said is not what is meant. If what is said is not what is meant, then what must be done remains undone. Hence there must be no arbitrariness in what is said.
Confucius 500 BC

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Lighting's language fulfills the need to describe, specify, and evaluate luminous environments. Like any language, it is based on concepts and vocabulary: The concepts result from a consideration of the nature of light, vision, and architecture. The vocabulary results from the need for clarity, specificity, and precision. The structure of lighting's concepts is an inverted pyramid: a very few fundamental ideas are identified and described and from these, in turn, more complex concepts are constructed. Simpler concepts form the constituents of the more complex ones required to unambiguously specify luminous quantities or the photometric behavior of materials. In this chapter the fundamental or most basic concepts are described first, many of which have their roots in the work of Johann Lambert and André Blondel [8]. These followed by more complex or derived concepts.

5.1 Introduction

5.1.1 Scope of This Chapter

Only the most important quantities and units used in lighting design and illuminating engineering that relate directly to optical radiation, light, and vision are described and defined in this chapter. The technical words associated with lighting equipment, photometry, lighting calculations, color, and daylighting are defined in their respective chapters and they rely on an understanding of the material presented in this chapter. See INDEX for the locations of the definition of specific words.

A full nomenclature and many more derived and specialized quantities are described in two additional resources. The International Lighting Vocabulary is established by the CIE and published jointly with the International Electrotechnical Commission. More than 900 technical definitions of concepts and quantities are given in English, French, German and Russian [1]. The IES publishes Nomenclature and Definitions for Illuminating Engineering as RP-16, which is also an ANSI standard [2].

5.1.2 General Words

Lighting's conceptual vocabulary adopts words found in common usage and gives them a special, technical meaning. Precision in describing concepts makes this necessary.

5.1.2.1 Radiant Energy

This is the general term for energy propagated by radiation through a vacuum or a material, in distinction to energy transported by conduction or convection. The term is used when no particular model of energy transport is implied or when any wavelength or frequency can be involved.

5.1.2.2 Radiant Energy: Electromagnetic Radiation

In some cases, it is necessary or convenient to imply one of the two physical models of radiative energy transport: electromagnetic waves or photons. See 1.1.1 Physical Models of Optical Radiation. Electromagnetic radiation is radiant energy propagated in a way consistent with the model of electric and magnetic waves. For example, radiant energy

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Descriptive words are an important part of Lighting's vocabulary. In English, lighting concept names often derive from a stem word, usually a verb, to which suffixes are added, abiding by the following general customs of usage:

- -ance added to the verb creates a noun related to an action. This is usually the noun of quantity.
- -ive or -ing added to the verb creates an adjective of nature that describes having the character of an action.
- -ivity added to the verb, or –ity added to a noun, creates a noun of abstraction, giving a name to the active property.
- -tion added to the verb creates a noun of state or condition.

An example of this vocabulary construction using the word "reflect" is:

Reflect	verb: to bounce off
Reflect**ance**	noun of quantity, the amount of reflecting
Reflect**ive**	adjective of nature; able to reflect
Reflect**ivity**	adjective of nature; able to reflect
Reflec**tion**	noun of state: being reflected

moving through glass or plastic optical components is conveniently described using the electromagnetic wave model.

5.1.2.3 Radiant energy: Photon Radiation

This is radiant energy propagated in a way consistent with the quantum model. The energy transport within a light emitting diode is best described with the photon model.

5.1.2.4 Radiant energy: Optical Radiation

This is energy propagated by radiation when its wavelengths are between 100 nm and 10,000 nm. That is, radiant energy with wavelengths limited to the ultraviolet, visible, and infrared. No particular model of energy transport is implied with this term.

5.1.2.5 Radiant Power

In electrical engineering, the distinction between energy and power is essential and is clear from the different uses and meanings of kilowatt (power) and kilowatt-hour (energy). This distinction between energy and power is also made when dealing with radiant quantities: radiant power is the time-rate-of-flow radiant energy. It is customary to refer to radiant power as radiant flux; "flux" coming from the Latin participle "fluxus", meaning flowing.

5.1.2.6 Light

This term is reserved for visually evaluated radiant power. The process of visual evaluation is defined below in 5.4.1 Action spectrum for vision. Light can be considered as the luminous equivalent of power and is properly called luminous flux. "Light" is often used as shorthand for luminous flux, especially in applications. As is often the case, power is more easily and accurately measured than is energy, and this is the case with radiant quantities. In this practical sense, luminous power (light or luminous flux) is more fundamental or basic than luminous energy (time-quantity of light). It should be noted that this definition is entirely different from the use of this term in physics, where it is synonymous with radiant energy of any wavelength.

5.1.2.7 Illumination

This term is reserved to describe the general circumstance of light incident on a surface or body, or the general condition of being illuminated. It is used as a term of quality rather than quantity. The term of quantity is "illuminance". See 5.6.1 Illuminance.

5.1.2.8 Source

This is a general term used to reference a source of light. It can refer variously to an electric lamp, an LED, an entire luminaire with lamp and optical control, or fenestration for daylighting.

Finally, words such as "intensity" and "efficiency" are used in special and precise ways in lighting design and illuminating engineering and their everyday meaning or the substitution of a seeming synonym can be misleading, if not incorrect. Thus, "intensity of illumination" is incorrect and "visible light" is redundant.

5.1.3 Radiant and Luminous Concepts

Each concept involving radiation, light, and vision has a name, its quantification specified by a unit, and its presence indicated by a symbol. In many cases a concept's unit has a name. Concepts constructed from more fundamental ones have constituent units and names. In most cases a concise definition of a concept can be expressed as a mathematical equation using the symbols for the more fundamental concepts.

In general, words based on "radiate" refer to purely physical, radiant quantities, as in the case of radiant power and optical radiation. This is in distinction to "luminous" which designates quantities involving radiant power that is visually evaluated. Some concepts have parallel radiant and luminous forms: one set used when optical radiation is considered simply as a physical entity, and another set when it is visually evaluated.

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Radiometry and radiometric concepts deal with the measurement and conceptualization of radiant power as a physical entity; photometry and photometric concepts with visually evaluated radiant power. Photometric quantities always involve radiant power evaluated when the adaptation state is either photopic or scotopic. See 2.4 Vision and the State of Adaptation. If there are parallel radiometric and photometric concepts, the same symbol is used, with the radiometric symbol being augmented with a subscript 'e'.

5.1.4 Wavelength Dependencies

When it is necessary to indicate a quantity's dependence on the wavelength of the optical radiation involved, the adjective "spectral" is added to the name and the standard pair-of-parentheses notation of mathematical functions is used, along with the universal symbol for wavelength: λ. As an example, Φ is the symbol for luminous flux and Φ(λ) is the symbol for spectral luminous flux. That is, flux as a function of wavelength. When it is necessary to indicate how a quantity changes with wavelength, λ is used as a subscript to indicate the first derivative with respect to wavelength. Thus, the spectral luminous flux per unit wavelength is indicated by $\Phi_\lambda(\lambda)$ with $\Phi_\lambda(\lambda) = d\Phi(\lambda)/d\lambda$. See 1.3.3 Wavelength.

5.2 Radiant Power, Radiant Flux

Electric light sources convert electrical power to radiant power which is then emitted by the source. The emission can be conceived as either electromagnetic radiation or as photons. The following concepts and quantities are used to describe and quantify this power.

5.2.1 Specifying Radiant Energy and Power

5.2.1.1 Radiant Energy

This defines the electromagnetic or photonic radiant energy from a source.

Concept:	Energy emitted, transferred or received in the form of radiation
Concept name:	Radiant energy
Concept symbol:	Q_e, $Q_e(\lambda)$
Constituent units:	kg m^2 s^{-2}
Unit name:	Joule
Mathematical definition:	None

5.2.1.2 Radiant Power or Radiant Flux

This defines the electromagnetic or photonic radiant power from a source; that is, the time rate of flow of radiant energy.

Concept:	The rate of flow of electromagnetic or photonic radiation, the radiant power from a source.
Concept name:	Radiant flux
Concept symbol:	Φ_e, $\Phi_e(\lambda)$
Constituent units:	Joules per second
Unit name:	radiant watt
Mathematical definition:	$\Phi_e = \frac{dQ_e}{dt}$

5.2.1.3 Spectral Power Distribution

This expresses the radiant power emitted by a source of optical radiation over a range of particular wavelengths. This is also referred to as "spectral power concentration" in the international lighting vocabulary.

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Concept:	Amount of optical radiation emitted by a source with wavelengths defined by a narrow band, $\Delta\lambda$, centered on a particular wavelength, λ.
Concept name:	Spectral Power
Concept symbol:	Q_e, $Q_e(\lambda)$
Constituent units:	radiant watts per unit length
Unit name:	None
Mathematical definition:	$\Phi_{e\lambda}(\lambda) = d\Phi_e(\lambda)/d\lambda$; with $\Phi_{e\lambda}(\lambda) \approx \Delta\Phi_e(\lambda)/\Delta\lambda$

5.2.1.4 Relative Spectral Power Distribution (SPD)

This is the quantity most commonly used in lighting to express the nature of radiant power emitted by a source. To make the spectral power distribution relative, all the data are divided by either the average value, by the maximum value within the wavelength range of interest, or some arbitrarily chosen value. Although relative SPDs are provided in all practical work, the adjective "relative" is seldom used. See 1.4.2 Spectral Power Data and 9.7.1.1 Measurement of SPDs.

Concept:	Normalized spectral power distribution.
Concept name:	Relative Spectral Power
Concept symbol:	$S(\lambda)$
Constituent units:	Relative radiant watts per unit wavelength
Unit name:	None
Mathematical definition:	$S(\lambda) = \Phi_{e\lambda}(\lambda)/R$; where R = some fixed value of $\Phi_{e\lambda}$

5.2.2 Data Conventions for SPDs

Some sources of optical radiation, such as incandescent sources, exhibit a continuous spectrum of radiant power over a wide range of wavelengths. Although the measurement process can only sample the spectrum at a discrete number of points, the data are usually presented as a continuum. Figure 5.1 shows a continuous relative spectral power distribution of an incandescent lamp.

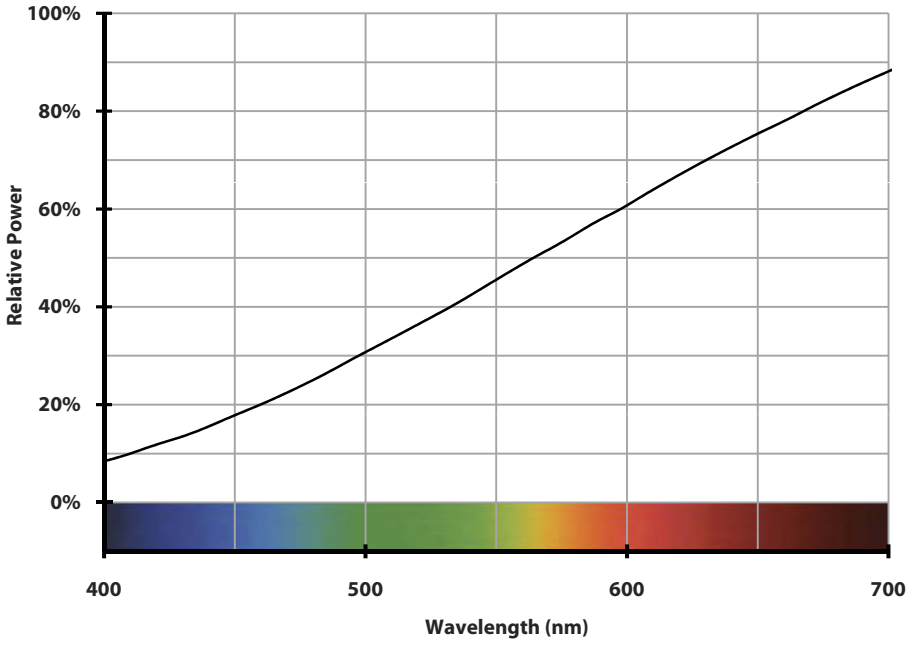


Figure 5.1 | Tungsten Halogen SPD
Relative spectral power distribution of an incandescent lamp operating at 3000 K. These data are relative to the value at 750 nm, the wavelength at which the distribution is maximum in the visible reigon of the spectrum, expressed as a percentage of that maxiumum.

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Some sources of optical radiation emit radiant power only at a few discrete wavelengths or within very narrow ranges of wavelengths, each range centered on a particular wavelength. These are called line spectra. A low pressure mercury discharge is such a source. To help compare spectral power distributions, it is customary to plot a line spectrum as a histogram with bars of small but fixed widths and heights such that the areas within the fixed-width bars represent the total power at the lines. The bars are centered on the wavelengths of the lines they represent. Figure 5.2 show the relative line spectral power distribution of a low pressure mercury discharge.

Many sources emit not only a continuous spectrum of optical radiation but also emit strongly at certain wavelengths or in very narrow wavelength bands. These spectra are represented as a continuous function with a superimposed histogram. Metal halide and fluorescent lamps have this type of spectral power distribution. Figure 5.3 shows the distribution of a metal halide lamp.

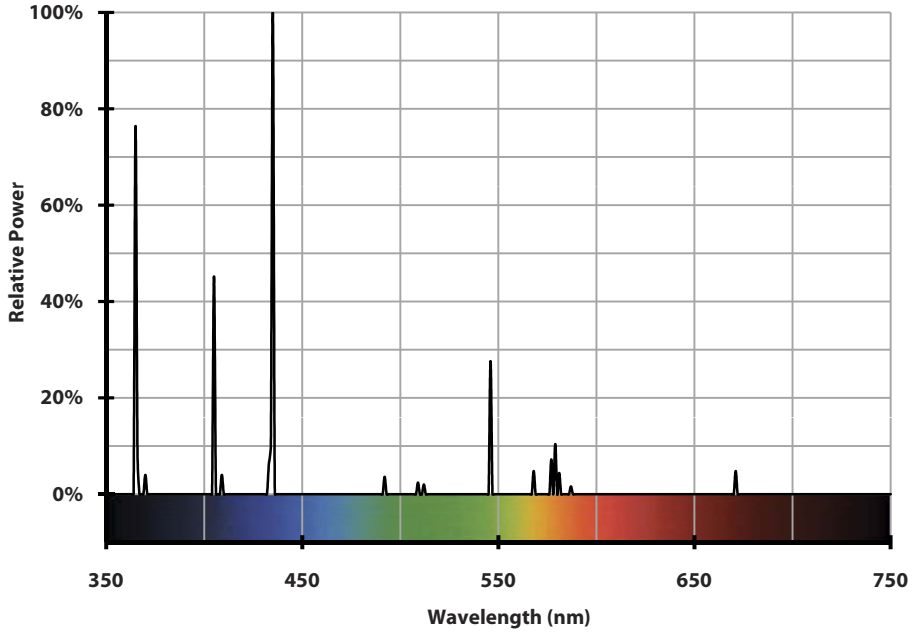


Figure 5.2 | Low Pressure Mercury Discharge SPD
Relative line spectral power distribution of a low pressure mercury discharge. These data are relative to the value at 254 nm, the wavelength at which the distribution is maximum.

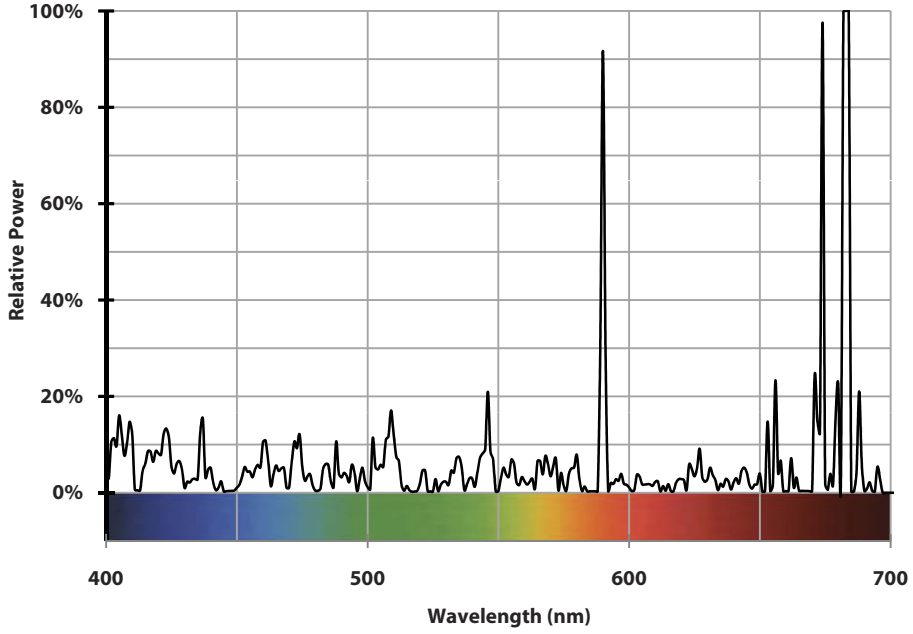


Figure 5.3 | Metal Halide Discharge SPD
Relative spectral power distribution of a Sodium-Scandium metal halide lamp exhibiting both continuous and line spectra.

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5.3 Action Spectra

A photochemical effect produced by radiant power is said to be an actinic effect. Actinic effects can be direct, as in the case of chemical activity triggered by atoms or molecules absorbing photons, or indirect as in the case of a high-level change in a biological organism produced by absorbed radiant power in photoreceptors. Actinic effects are usually the result of complicated physical and chemical mechanisms that are affected by exposure time, previous exposure, and exhibit interactions (constructive or opponent) between wavelengths. But these mechanisms are usually ignored and action spectra are used to simply link radiant input to the final actinic effect [3].

Examples of actinic effects are the reaction of photodiodes (photoionization, see 9.4.1.2 Solid-State Detectors), skin reddening (erythema, see 3.4 Effects of Optical Radiation on the Skin), the bleaching of photopigments (isomerization, see 2.1.3.1 Photoreceptors) in the rods and cones of the retina, and photosynthesis or phototropism in plants. The action spectrum of an actinic effect is the magnitude of the effect produced by various wavelengths of monochromatic radiant power through some range of wavelengths. Figure 5.4 shows the action spectrum for photosynthesis in green plants.

Concept:	Photochemical effect of optical radiation of individual wavelengths over a range of wavelengths of interest
Concept name:	Action spectrum
Concept symbol:	$\sigma(\lambda)$
Constituent units:	Actinic response per unit wavelength
Unit name:	None
Mathematical definition:	$\sigma(\lambda) = \text{Response}(\lambda)$ or $\text{Response}(\lambda)/R$ where R = fixed value of $\text{Response}(\lambda)$

The units of an action spectrum depend on the actinic effect. In many cases, an action spectrum is normalized using its maximum value and so becomes a unitless efficiency function of wavelength.

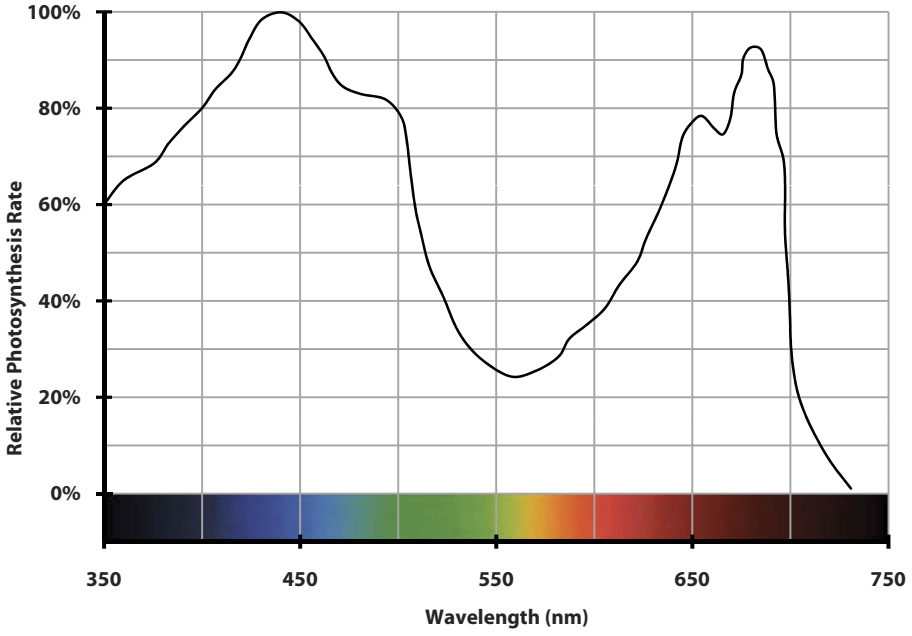


Figure 5.4 | Photosynthesis Action Spectrum
The relative action spectrum of photosynthesis for common green plants.

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By convention, the total actinic effect (TAE) of a source of optical radiation is defined by the wavelength-by-wavelength product of the spectral power distribution of the source and the action spectrum of the actinic effect:

$$TAE = K \int_{\lambda_1}^{\lambda_2} \sigma(\lambda) S(\lambda) d\lambda \approx K \sum_{i=1}^{N} \sigma(\lambda_i) S(\lambda_i) \Delta\lambda \tag{5.1}$$

Where:

λ_1 and λ_2 = limits of the wavelength range of interest
K = scaling constant for the action spectrum and/or the spectral power distribution

It is important to understand that simply summing effects at individual wavelengths assumes that either the cumulative effect does not exhibit interactions between effects at different wavelengths, or that such interactions are negligible. In this case the process is said to be linearly additive. Strict linear additivity is rarely the case for real, total actinic responses, especially in biological effects. Nevertheless, linear additivity can be used to adequately represent the total response of some actinic effects for a wide spectrum of radiant power. Linear additivity implies both proportionality and that the total actinic effect of two sources is the sum of the two individual total effects:

$$\begin{aligned} TAE &= K \int_{\lambda_1}^{\lambda_2} \sigma(\lambda)(\alpha_1 S_1(\lambda) + \alpha_2 S_2(\lambda)) d\lambda \\ &= K\,\alpha_1 \int_{\lambda_1}^{\lambda_2} \sigma(\lambda) S_1(\lambda) d\lambda + K\,\alpha_2 \int_{\lambda_1}^{\lambda_2} \sigma(\lambda) S_2(\lambda) d\lambda \end{aligned} \tag{5.2}$$

5.4 Defining Light

The definition of light involves radiant power and the assessment of its efficacy using an action spectrum that must be, in some sense, a quantification of vision.

5.4.1 Action Spectrum for Vision

Light is defined as visually evaluated radiant power and it has been customary to use the process defined by equation 5.1 to perform this evaluation [4]. This, in turn, requires that an indirect actinic effect be defined, presumably beginning with retinal photoreceptors changed by the absorption of optical radiation. This indirect actinic effect must be, in some sense, "vision" and the action spectrum must assign to each wavelength a power to invoke "vision" or a visual sensation. It would be possible to define this sensation as any of the following: brightness, detection, recognition, conspicuity, or reaction time. The earliest attempt at such an assessment used recognition [5], but beginning with the work of Koenig [6], brightness has been used to define the action spectrum of vision.

5.4.2 Photopic Luminous Efficiency

A photopic, brightness-based action spectrum was adopted internationally in 1924 by the CIE [7]. The data used to define this action spectrum resulted from a series of experiments that determined the relative brightness of monochromatic radiant power throughout the visible spectrum [8] [9]. The method involved comparing and equilibrating the brightnesses produced by radiant power at neighboring wavelengths, moving step-by-step through the spectrum. This avoided both the problem of matching brightnesses in the presence of large color differences and the use of flicker photometry. Foveal vision was used, with observers photopically adapted, using a 2° visual field. The inverse of the power required at each wavelength to produce a constant brightness is a measure of the efficacy

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of that wavelength. These data were made relative to the value at λ=555 nm and thus defined a unitless efficiency function: the photopic luminous efficiency function of wavelength. Since the adoption of the standard values for this function, the CIE has modified and corrected them. Standard values given in 1983 are shown in Table 5.1 and plotted in Figure 5.5 [10]. Recent research has proposed further modification [11]

Concept:	Action spectrum of vision at photopic adaptation
Concept name:	Photopic luminous efficiency function of wavelength
Concept symbol:	$v(\lambda)$
Constituent units:	None
Unit name:	None
Mathematical definition:	None

5.4.3 Scotopic Luminous Efficiency

A scotopic, brightness-based action spectrum was adopted internationally in 1951 by the CIE [12]. The data used to define this action spectrum resulted from experiments that determined the relative brightness of monochromatic optical radiation throughout the visible spectrum [13] [14]. A large, off-axis visual field of 20° was used with observers scotopically adapted. The data were made relative to the value at λ=505 nm and thus defined a unitless efficiency function. Standard values at 10 nm intervals given in 1983 are shown in Table 5.1 and plotted in Figure 5.5.

Concept:	Action spectrum of vision at scotopic adaptation
Concept name:	Scotopic luminous efficiency function of wavelength
Concept symbol:	$v'(\lambda)$
Constituent units:	None
Unit name:	None
Mathematical definition:	None

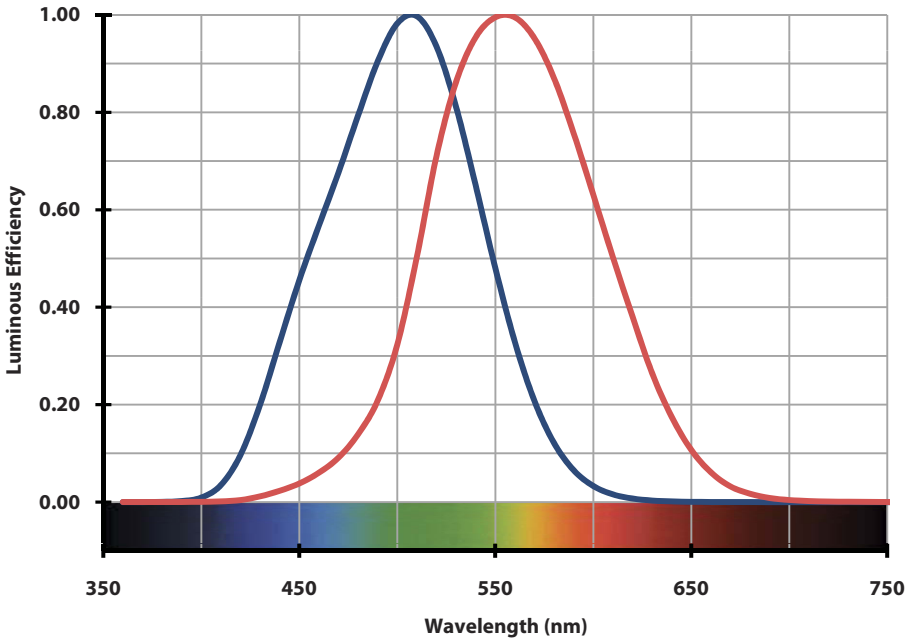


Figure 5.5 | CIE Luminous Efficiency Functions of Wavelength
The CIE 2° photopic and scotopic luminous efficiency functions of wavelength. The standard values are at 10 nm intervals a smooth line is interpolated between them.

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5.5 Luminous Flux

Luminous flux is visually evaluated radiant flux and defines "light" for purposes of lighting design and illuminating engineering. Following the customary use of action spectra, radiant flux is evaluated wavelength-by-wavelength using either of the two standard action spectra for vision: the photopic or scotopic luminous efficiency functions of wavelength. The sum of the individual wavelength evaluations defines the total effect.

5.5.1 Photopic Luminous Flux

This is the most common unit of light. It can be considered photopic luminous power and, akin to radiant power, is the time rate of flow of the quantity of photopic light. The constant 683 scales the total visually-evaluated radiant watts of the source to the modern photometric unit of the photopic lumen.

Concept:	The flow of photopic luminous power from a source
Concept name:	Photopic luminous flux
Concept symbol:	Φ
Constituent units:	None
Unit name:	Photopic Lumen, lm
Mathematical definition:	$\Phi \equiv 683 \int_0^\infty \Phi_{e\lambda}(\lambda) v(\lambda) d\lambda \approx 683 \sum_{\lambda=400}^{750} \Phi_{e\lambda}(\lambda) v(\lambda) \Delta\lambda$

5.5.2 Scotopic Luminous Flux

An uncommon unit of light. It can be thought of as scotopic luminous power. The constant 1700 scales the total visually-evaluated radiant watts of the source to the modern photometric unit of the scotopic lumen and results from the assumption that when using the V'(λ) function, its values are all scaled up so that V'(555 nm) = V(555 nm).

Concept:	The flow of scotopic luminous power from a source
Concept name:	Scotopic luminous flux
Concept symbol:	Φ'
Constituent units:	None
Unit name:	Scotopic Lumen
Mathematical definition:	$\Phi \equiv 1700 \int_0^\infty \Phi_{e\lambda}(\lambda) v'(\lambda) d\lambda \approx 1700 \sum_{\lambda=400}^{750} \Phi_{e\lambda}(\lambda) v'(\lambda) \Delta\lambda$

5.5.3 Quantity of Light

This is luminous power integrated over time; the luminous equivalent of energy. The quantity of light may arise when total light exposure is of interest; as happens when dealing with plants, or assessing the possible damage light might cause to a piece of art, or when medical light dosage must be considered. See 3.5 Phototherapy.

Concept:	The time-integrated amount of light.
Concept name:	Quantity of light
Concept symbol:	Q_v
Constituent units:	lumens, seconds
Unit name:	Lumen-seconds
Mathematical definition:	$Q_v = \int \Phi \, dt$

Table 5.1 | CIE Standard 2° Photopic and Scotopic Luminous Efficiency Functions of Wavelength

Wavelength (nm)	V(λ)	V'(λ)
360	0.0000	0.0000
370	0.0000	0.0000
380	0.0000	0.0006
390	0.0001	0.0022
400	0.0004	0.0093
410	0.0012	0.0348
420	0.0040	0.0966
430	0.0116	0.1998
440	0.0230	0.3281
450	0.0380	0.4550
460	0.0600	0.5670
470	0.0910	0.6760
480	0.1390	0.7930
490	0.2080	0.9040
500	0.3230	0.9820
510	0.5030	0.9970
520	0.7100	0.9350
530	0.8620	0.8110
540	0.9540	0.6500
550	0.9950	0.4810
560	0.9950	0.3288
570	0.9520	0.2076
580	0.8700	0.1212
590	0.7570	0.0655
600	0.6310	0.0332
610	0.5030	0.0159
620	0.3810	0.0074
630	0.2650	0.0033
640	0.1750	0.0015
650	0.1070	0.0007
660	0.0610	0.0003
670	0.0320	0.0001
680	0.0170	0.0001
690	0.0082	0.0000
700	0.0041	0.0000
710	0.0021	0.0000
720	0.0010	0.0000
730	0.0005	0.0000
740	0.0002	0.0000
750	0.0001	0.0000
760	0.0001	0.0000
770	0.0000	0.0000

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5.5.4 Luminous Efficacy of Radiation

This efficacy is reserved to describe a characteristic of radiation: the ratio of the lumens it contains to its power in watts. Though uncommon when referring to electric light sources, efficacy of radiation is used to describe the optical radiation from the sun and sky in daylighting applications.

Concept:	The ratio of luminous power to radiant power
Concept name:	Luminous efficacy of radiation
Concept symbol:	K
Constituent units:	Lumens, radiant watts
Unit name:	None
Mathematical definition:	$K = \frac{\Phi}{\Phi_e}$

5.5.5 Luminous Efficacy of a Source

This efficacy is reserved to describe a characteristic of a source of radiation: the ratio of the lumens emitted to the watts required to produce the radiation that contains those lumens. This efficacy is a frequently cited characteristic of electric light sources and provides a measure of how effectively they convert electric power to luminous power.

Concept:	The ratio of luminous power to the power consumed by the source
Concept name:	Luminous efficacy of a source
Concept symbol:	η
Constituent units:	Lumens, watts
Unit name:	None
Mathematical definition:	$\eta \equiv \frac{\Phi}{W}$

5.6 Surface Flux Densities

The most common concepts used to quantify aspects of lighting involve not the absolute amount of luminous flux but rather the density of flux. Quantities involving flux density onto or from a surface are used in lighting to state some design recommendations and to describe the final luminous condition of a task or architectural surface.

5.6.1 Illuminance

Illuminance is the incident luminous flux density on a differential element of surface located at a point and oriented in a particular direction, expressed in lumens per unit area. Since the area involved is differential, it is customary to refer to this as illuminance at a point. The unit name depends on the constituent unit for area. It is footcandles if square feet are used for area, and lux if square meters are used.

Concept:	Local surface density of incident luminous flux
Concept name:	Illuminance
Concept symbol:	E
Constituent units:	Lumens, area
Unit name:	Footcandle (lumens/square foot), fc Lux (lumens/square meter), lx
Mathematical definition:	$E \equiv \frac{d\Phi_{on}}{dA}$

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Aside from the general notion that flux is incident, illuminance does not describe the amount arriving from various directions, only the total incident. Without additional information, this can limit the utility and significance of illuminance. Figure 5.6 shows two very different illumination conditions that have the same illuminance.

5.6.1.1 Average Illuminance

In certain circumstances knowing the average illuminance over a large area is useful in the lighting design or analysis process. Like any simple average, average illuminance reveals nothing about any local variations in illuminance that might exist over the area for which it is determined, nevertheless it can describe in a general way a useful attribute of a lighted surface.

Concept:	Mean surface density of incident luminous flux over an extended area
Concept name:	Average illuminance
Concept symbol:	$\bar{E}$
Constituent units:	Lumens, area
Unit name:	Footcandle (lumens/square foot), fc Lux (lumens/square meter), lx
Mathematical definition:	$\bar{E} \equiv \frac{\Phi_{on}}{A} = \frac{1}{A}\int_0^A E\,dA \approx \frac{1}{A}\sum_{i=1}^{N}\Delta A_i\,E_i = \frac{\Delta A}{A}\sum_{i=1}^{N}E_i = \frac{1}{N}\sum_{i=1}^{N}E_i$

5.6.2 Exitance

Exitance is the exitant (leaving) luminous flux density on a differential element of surface located at a point, expressed in lumens per unit area. Exitance is emitted flux density, and so can be related to how luminous the emitting surface is or how bright it appears. Exitance does not have a named unit and "lumens per square foot" or "lumens per square meter" are used when describing exitance.

Concept:	Local surface density of emitted luminous flux
Concept name:	Exitance
Concept symbol:	M
Constituent units:	Lumens, area
Unit name:	None
Mathematical definition:	$M \equiv \frac{d\Phi_{off}}{dA}$

Like illuminance, exitance does not provide information about the directions into which the surface emits flux, only the total amount. Figure 5.7 shows extreme cases of two surfaces with identical exitances but radically different emitting characteristics.

Exitance is useful in that is describes the general light emitting power of a surface. But because of its non-directionality, it may not indicate how luminous an object or surface appears from a particular point of view. Only in the case of a surface emitting flux diffusely can a reliable relationship be established between exitance and luminance. See 5.7.3 Luminance.

5.6.2.1 Average Exitance

Like average illuminance, knowing the average exitance over a large area is useful in the lighting design or analysis process, but it too reveals nothing about any local variations that might exist over the area for which it is determined.

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Concept:	Mean surface density of emitted luminous flux
Concept name:	Average exitance
Concept symbol:	$\bar{M}$
Constituent units:	Lumens, area
Unit name:	None
Mathematical definition:	$\bar{M} \equiv \frac{\Phi_{off}}{A} = \frac{1}{A}\int_0^A M\,dA \approx \frac{1}{A}\sum_{i=1}^{N}\Delta A_i\,M_i = \frac{\Delta A}{A}\sum_{i=1}^{N}M_i \approx \frac{1}{N}\sum_{i=1}^{N}M_i$; or $= \bar{E}\,\rho$

Figure 5.6 | Two Illuminance Conditions
Two different illumination conditions that have the same illuminance. On the left, all the flux arrives at the surface from the same direction, on the right is arrives uniformly from all directions. In both cases the density of lumens to area is the same.

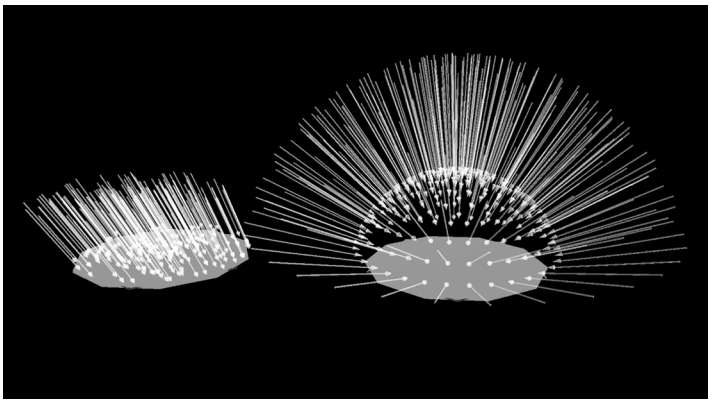
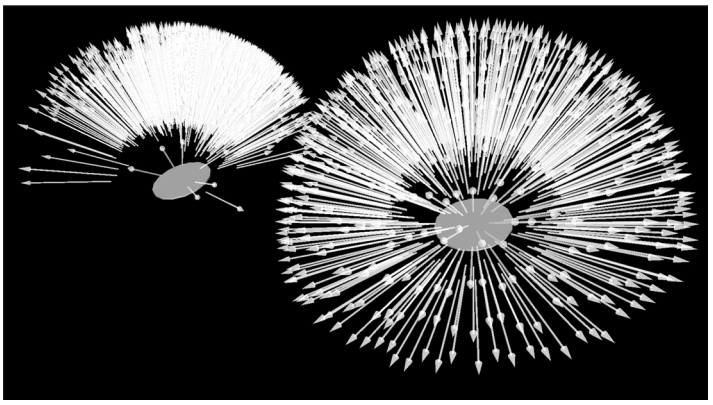


Figure 5.7 | Two Exitance Conditions
Two different emitting conditions that have the same exitance. On the left, all the flux leaves the surface into the same direction, on the right it leaves uniformly into all directions. In both cases the density of exitant lumens to area is the same.



5.7 Spatial Flux Densities

In order to describe the density of flux in space, a measure of "space" is required. This is not volume but rather a quantity that describes the apparent extent or size of an object from a point of regard.

5.7.1 Solid Angle

Solid angle is used to define spatial extent for the purposes of establishing spatial flux densities. Just as plane angle specifies the extent of separation between two intersecting lines of indeterminate length, solid angle specifies the extent of a cone of indeterminate length. Figure 5.8 shows such a cone of solid angle and how three discs of different sizes and orientations can exhibit the same solid angle from a point of regard. Solid angles are measured in steradians.

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Concept:	Spatial extent
Concept name:	Solid angle
Concept symbol:	ω
Constituent units:	Area, distance
Unit name:	Steradian, sr
Mathematical definition:	$d\omega \equiv \frac{dA\cos(\theta)}{D^2};\ \omega = \int_A \frac{dA\cos(\theta)}{D^2}$

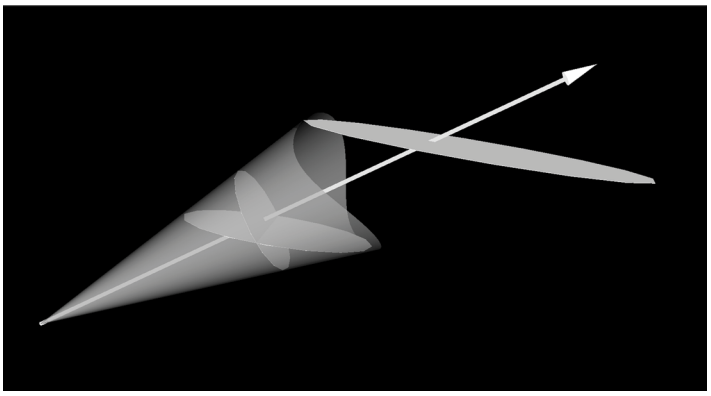


Figure 5.8 | Solid Angle
The solid angle (represented by the open-ended cone) for three discs of different sizes and orientations. Though of different surface extent and orientation, they have the same spatial extent with respect to the apex of the cone, the point of regard.

5.7.2 Luminous Intensity

Luminous intensity specifies the light emitting power of a point source in a particular direction and is defined as the density of luminous flux in space in that direction. This ratio of lumens per steradians has the name candela. Luminous intensity is also called candlepower. It is common to use the spherical coordinate system to specify a direction from a point source and so the luminous intensity distribution of a source is often expressed as a function of the two spherical coordinate angles. Luminous intensity is invariant with distance from the source. Figures 5.9 and 5.10 show how luminous intensity describes the spatial distribution of light from sources.

Concept:	Spatial density of luminous flux from a point source
Concept name:	Luminous intensity (candlepower)
Concept symbol:	I
Constituent units:	Lumens, steradians
Unit name:	Candela, cd
Mathematical definition:	$I(\theta,\psi) \equiv \frac{d\Phi(\theta,\psi)}{d\omega}$

5.7.2.1 Equivalent Luminous Intensity

An operational definition of luminous intensity can be used to approximately describe the light emitting power of sources that are luminous areas and not points. The illuminance, E, produced by a point source at a point on a surface located a distance D from the source and oriented so that the surface perpendicular points directly back to the source, is

$$E = \frac{I(\theta,\psi)\cos(\theta)}{D^2} = \frac{I(\theta,\psi)\cos(0°)}{D^2} = \frac{I(\theta,\psi)}{D^2} \qquad (5.3)$$

Where:

$I(\theta,\psi)$ = luminous intensity of the point source in the direction of the illuminated point
D = distance from point source to the illuminated point

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Equation 5.3 is inverted to give an operational definition of luminous intensity:

$$\bar{I}(\theta,\psi) = E\,D^2 \tag{5.4}$$

That is, intensity can be operationally defined as the product of the illuminance it produces at some distant point and the square of the distance to that point.

If an area source produces an illuminance, E′, at a point some distance D from its center and in a particular direction (θ,ψ), then equation 5.4 gives an operational definition of luminous intensity of this area source. This is the equivalent luminous intensity, Ī, of the area source. Note that equivalent luminous intensity is not invariant with distance, since for a real area source the ratio of illuminance produced to distance-squared does not remain constant with distance. In practice, relatively large distances are used and equivalent luminous intensity is the quantity used to describe the distribution of light from virtually all practical lighting equipment. This photometric procedure is described in detail in 9.9.2 Distribution Photometry.

5.7.3 Luminance

Luminance is a measure of the light emitting power of a surface, in a particular direction, per unit apparent area. This is expressed as a density of luminous intensity per unit apparent area. Implicit in the definition is the assumption that the area is small.

Luminance is perhaps the most important quantity in lighting design and illuminating engineering, as it is one of the direct stimuli to vision and many measures of performance and perception have been shown to depend on luminance. Figure 5.11 depicts the definition of luminance.

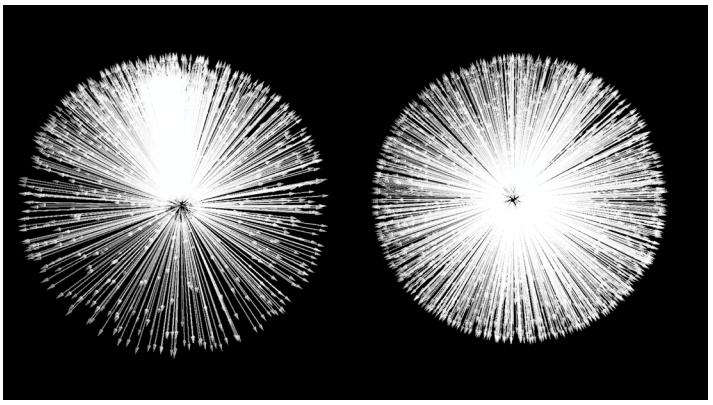


Figure 5.9 | Spatial Distribution of Flux
Spatial distribution of flux for two sources, indicated by the density of rays emitted in various directions. The source on the left distributes light more or less uniformly in all directions, while that on the right emits more light in the downward direction.

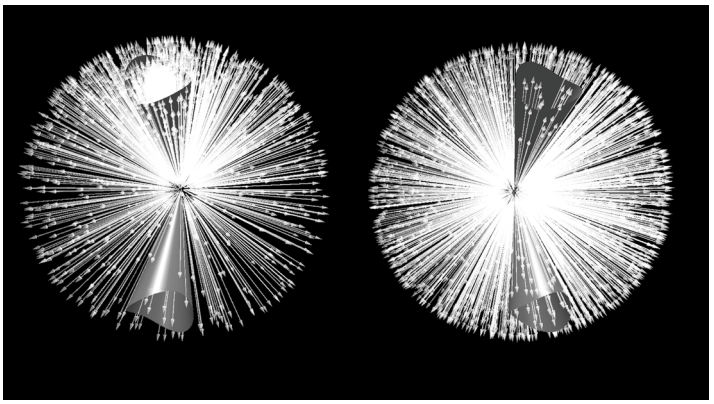


Figure 5.10 | Luminous Intensity
Luminous intensities for two sources. For each source, two cones of solid angle are positioned around the source. The number of rays within each cone is a measure of the density, in lumens per steradians, that the source established and thus its luminous intensity in that direction.

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Concept:	Local surface density of light emitting power in a particular direction.
Concept name:	Luminance
Concept symbol:	$L(\theta,\psi)$
Constituent units:	Luminous intensity, area
Unit name:	Candela per meter-squared (nit)
Mathematical definition:	$L(\theta,\psi) \equiv \frac{dI(\theta,\psi)}{dA\cos(\theta)} = \frac{d^2\Phi}{d\omega\, dA\cos(\theta)}$

The mathematical definition also establishes an operational definition: the luminance of a surface is the ratio of the illuminance it produces at a distant point, to the solid angle it subtends at that point. See 10.2.2 Illuminance from Area Sources.

$$L \equiv \frac{dE}{d\omega}\cos(\theta) \tag{5.5}$$

Equation 5.5 expresses this operational definition and is the basis for all luminance meters: an illuminance measurement made through a cone of known solid angle. Equation 5.5 also shows that a surface need not be involved to establish a luminance.

Average luminance can be defined and approximated for a large area

$$\bar{L} = \int_A \frac{dI(\theta,\psi)}{dA\cos(\theta)} \approx \frac{\bar{I}(\bar{\theta},\bar{\psi})}{A\cos(\bar{\theta})} \tag{5.6}$$

5.8 Light and Materials

The interaction of the light and materials is an important aspect of architectural lighting. The following concepts are used to define these interactions, involving not only the quantity of lighting but the types of spatial distributions that result.

5.8.1 Reflectance

Reflectance is the ratio of exitant to incident luminous flux. It may or not be specified with regard to the incident or exitant (reflected) directions. Reflectance may involve the sum of all luminous wavelengths or be determined as a function of wavelength, in which case it is spectral reflectance. Reflectance is affected by the geometry, wavelength, and polarization of the incident flux. See 1.3.1.1 Reflection.

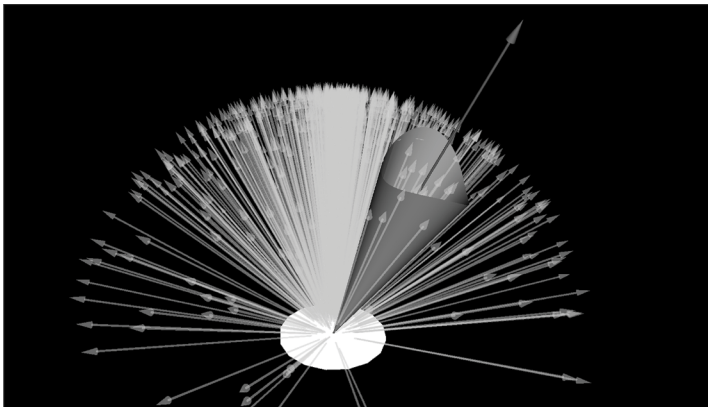


Figure 5.11 | Luminance of a Surface
The luminance of a surface is the luminous intensity (lumens per steradian) in a particular direction, per unit apparent area. The light distribution of a surface may be nonuniform (as shown here). The direction in which the luminance is determined is indicated by the dark arrow and the angle of view, θ, is measured from this direction to the surface perpendicular.

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Concept:	The fraction of incident light that is returned by a surface
Concept name:	Reflectance
Concept symbol:	$\rho, \rho(\lambda)$
Constituent units:	Lumens
Unit name:	None
Mathematical definition:	$\rho \equiv \frac{\Phi_{off}}{\Phi_{on}}; 0 \leq \rho \leq 1$

One common system for specifying the geometry of incident and reflected flux uses cones and hemispheres to define the extent and direction of flux. Incident flux can be specified as arriving from a particular direction in a cone, or uniformly from all directions in a hemisphere. Similarly, reflected flux can be specified as exitant in a particular direction in a cone, or into any direction within a hemisphere. The cones involved can be small but finite or vanishingly small in which case a single direction is involved. In all cases, the limiting values are zero and one since reflectance is defined as the ratio of luminous fluxes.

The most common arrangement used to measure and specify reflectance for architectural surfaces is conical-incident and hemispherical-exitant. Since the geometry is fixed, a single value defines the reflective power of the surface. As described in 1.3 Optics for lighting, reflectances can be specular, diffuse, and spread. Figure 5.12 depicts diffuse and specular reflectance.

5.8.1.1 Perfectly Diffuse Reflectance: A Useful Special Case

Most practical architectural surfaces reflect incident light into many directions. This property can be extended to define a hypothetical surface that exhibits a distribution of reflected light such that its density varies with the cosine of the exitant angle measured from the surface perpendicular. This special reflected distribution is called perfectly diffuse reflectance. Note that perfect diffuseness does not mean a uniform distribution, but rather a distribution that is most dense in the direction of the surface perpendicular, decreasing as the cosine of the angle of the reflected direction. Note also that perfect diffusion does not mean perfect reflection; that is, it does not mean a reflectance of 1.0

Surfaces that are perfectly diffuse reflectors, exhibit this distribution regardless of the incident direction of light. One consequence of diffusely reflected light is that such a surface exhibits a luminance that is constant and independent of view. Another is that very great simplification of lighting calculations is possible. See 10.5.2 Interreflection. Absent more detailed information about architectural surfaces, it is universally assumed within the lighting design process that surfaces are perfectly diffuse reflectors.

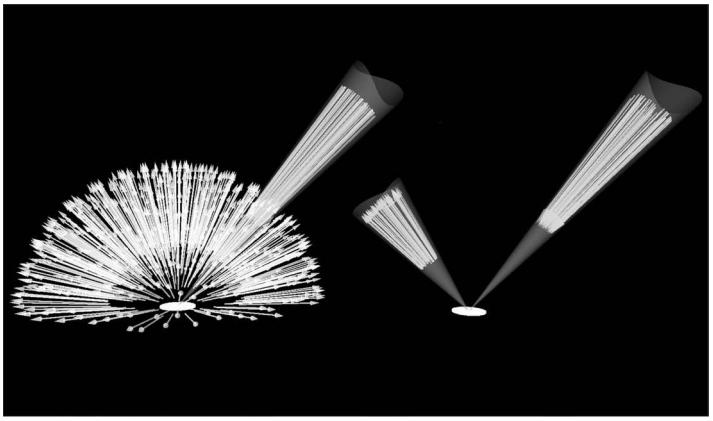


Figure 5.12 | Reflectance
Diffuse and specular reflectance. Diffuse reflectance (left) sends light uniformly in all directions regardless of the incident direction. Specular reflectance (right) sends light into the plane formed by the incident ray and the surface perpendicular, and at an angle from that perpendicular equal to that of the incident ray. Thus, in specular reflectance, the incident cone is preserved.

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Concept:	Perfect diffusion of incident light by scattering and reflection
Concept name:	Perfectly diffuse reflectance
Concept symbol:	$\rho, \rho(\lambda)$
Constituent units:	Lumens
Unit name:	None
Mathematical definition:	$\rho \equiv \frac{\Phi_{off}\,(\text{diffuse})}{\Phi_{on}}; 0 \leq \rho \leq 1$

5.8.1.2 Bidirectional Reflectance

In some cases, the form, texture, composition, or structure of a surface gives it reflectances that are strongly directional and a single value is cannot adequately describe the surface's interaction with light. In these cases incident and exitant directions must be accounted for and multiple values of reflectance are necessary to characterize the surface.

The conceptually simplest bidirectional reflectance assumes the conical-incident conical-exitant geometry and the reflectance is a function of the two directions. It is common to use the spherical coordinate system to specify these directions and so the bidirectional reflectance is the ratio of the luminous fluxes in the incident and exitant cones:

$$\rho(\theta_i, \psi_i; \theta_r, \psi_r) = \frac{\Phi(\theta_r, \psi_r)}{\Phi(\theta_i, \psi_i)}; 0 \leq \rho \leq 1 \qquad (5.7)$$

Where:

(θ_i,ψ_i) = incident direction
(θ_r,ψ_r) = exitant (reflected) direction

5.8.1.3 Bidirectional Reflectance Distribution Function

An alternative and more common way to specify directional reflectance is the Bidirectional reflectance distribution function (BRDF), f_r. It has the advantage of being simpler to measure in practice than directional conical-conical reflectance. BRDF is defined as:

$$f_r(\theta_i, \psi_i; \theta_r, \psi_r) = \frac{dL_r(\theta_r, \psi_r)}{E_i(\theta_i, \psi_i)}; 0 \leq f_r < \infty \qquad (5.8)$$

Where:

$Ei(\theta_i,\psi_i)$ = illuminance produced by flux from the incident direction (θ_i,ψ_i)
$Lr(\theta_r,\psi_r)$ = luminance of the surface in the exitant (reflected) direction (θ_r,ψ_r)

The units of f_r are inverse steradians, sr^{-1}. BRDF has been used to characterize visual tasks that do not exhibit perfectly specular or diffuse reflection for purposes of predicting visual performance [15], and to characterize the detailed reflecting properties of architectural surfaces for computer graphic rendering of architecture and lighting systems [16].

5.8.2 Transmittance

Transmittance is the ratio of emergent to incident luminous flux. It may or not be specified with regard to the incident or emergent (transmitted) directions. Transmittance may involve the sum of all luminous wavelengths or be determined as a function of wavelength, in which case it is spectral transmittance. The cone-hemisphere system of geometry used for reflectance is also used for transmittance. Limiting values are zero and one since transmittance is the ratio of luminous fluxes. Transmittance is affected by the geometry, wavelength, and polarization of the incident flux. See 1.3.1.2 Transmission.

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Concept:	The fraction of incident light that passes through and exits a material.
Concept name:	Transmittance
Concept symbol:	$\tau, \tau(\lambda)$
Constituent units:	Lumens
Unit name:	None
Mathematical definition:	$\tau \equiv \frac{\Phi_{out}}{\Phi_{on}}; 0 \leq \tau \leq 1$

Figure 5.13 shows the two kinds of transmittance common in architectural materials: diffuse and image-preserving.

5.8.2.1 Perfectly Diffuse Transmittance: A Useful Special Case

Some practical architectural materials redirect transmitted incident light into many directions. This property can be extended to define a hypothetical surface that exhibits a distribution of transmitted light such that its density varies with the cosine of the exitant angle measured from the surface perpendicular. This special transmitted distribution is called perfectly diffuse transmittance. Note that perfect diffuseness does not mean a uniform distribution, but rather a distribution that is most dense in the direction of the surface perpendicular, decreasing as the cosine of the angle of the transmitted direction. Note also that perfect transmittance does not mean perfect transmittance; that is, it does not mean a transmittance of 1.0

5.8.2.2 Bidirectional Transmittance

In some cases, the form, texture, composition, or structure of a surface give it transmittances that are strongly directional and a single value is cannot adequately describe the surface's interaction with light. In these cases incident and exitant directions must be accounted for and multiple values of transmittance are necessary to characterize the surface.

The conceptually simplest bidirectional transmittance assumes the conical-incident conical-exitant geometry and the transmittance is a function of the two directions. It is common to use the spherical coordinate system to specify these directions and so the bidirectional transmittance is the ratio of the luminous fluxes in the incident and exitant cones:

$$\tau(\theta_i, \psi_i; \theta_r, \psi_r) = \frac{\Phi(\theta_t, \psi_t)}{\Phi(\theta_i, \psi_i)}; 0 \leq \tau \leq 1 \quad (5.9)$$

Where:

(θ_i,ψ_i) = incident direction
(θ_t,ψ_t) = exitant (transmitted) direction

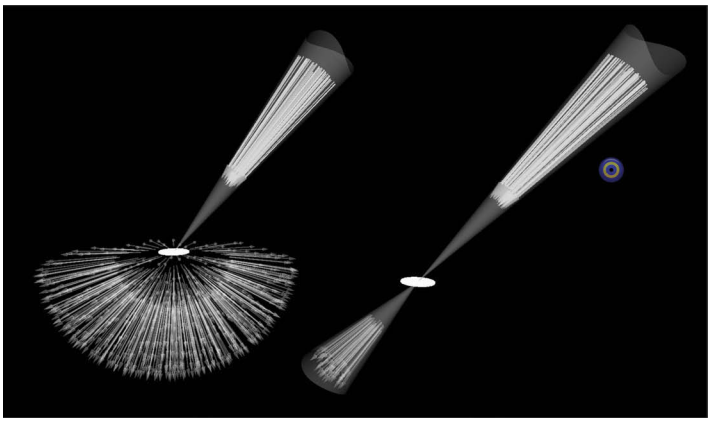


Figure 5.13 | Transmittance
Diffuse and image preserving transmittance. Diffuse transmittance (left) sends light uniformly in all directions regardless of the incident direction. Image preserving transmittance (right) preserves the direction in which the light travels. As a practical matter, there is always refraction which offsets the rays, even in thin media with parallel faces. See 1.5.1.2 Transmission.

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5.8.2.3 Bidirectional Transmittance Distribution Function

An alternative and more common for specifying directional reflectance is the Bidirectional transmittance distribution function (BTDF), ft. It has the advantage of being simpler to measure in practice than directional conical-conical transmittance. BTDF is defined as:

$$f_t(\theta_i, \psi_i; \theta_t, \psi_t) = \frac{dL_t(\theta_t, \psi_t)}{E_i(\theta_i, \psi_i)}; 0 \leq f_t < \infty \qquad (5.10)$$

Where:

$E_i(\theta_i,\psi_i)$ = illuminance produced by flux from the incident direction (θ_i,ψ_i)
$L_t(\theta_t,\psi_t)$ = luminance of the surface in the exitant (transmitted) direction (θ_t,ψ_t)

5.8.3 Absorptance

Absorptance defines the luminous flux that is absorbed by a material as flux passes through it. For most materials in architectural lighting whatever flux is not reflected or transmitted is absorbed.

Concept:	The fraction of incident light that is lost in the interior of a material
Concept name:	Absorptance
Concept symbol:	$Q_e, Q_e(\lambda)$
Constituent units:	Lumens
Unit name:	None
Mathematical definition:	$\alpha \equiv \frac{\Phi_{lost}}{\Phi_{on}} = \frac{\Phi_{on} - \Phi_{out}}{\Phi_{on}}; 0 \leq \alpha \leq 1$

5.9 Other Derived Concepts

Concepts derived from simpler ones are often used in lighting. Examples are contrast, used to specify one characteristic of a visual task, and brightness, the perceptual response to luminance.

5.9.1 Luminous Contrast

This unit specifies the luminance difference exhibited by a visual target or object of interest, from its immediate surround or background. Example of visual target and background are the print on this page and the paper immediately around it. Luminous contrast can be negative, as is the case for dark printing on white paper: the target luminance (luminance of the printed letters) is less than the background luminance (luminance of the paper). Sometimes contrast is defined absolutely; that is, it is always positive. In some cases, Contrast is defined as a modulation that involves both the difference in luminances and their summation. See 4.2.4 Luminance Contrast.

Concept:	The luminance difference between a visual target and its immediate surround, relative to the surround
Concept name:	Luminous contrast
Concept symbol:	C
Constituent units:	Luminance
Unit name:	None
Mathematical definitions:	$C = \frac{L_t - L_b}{L_b}$ or $C = \left\lvert \frac{L_t - L_b}{L_b} \right\rvert$ or $C = \frac{L_t - L_b}{L_t + L_b}$

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5.9.2 Brightness

Brightness is the perceptional response to luminance and is associated with the luminous power of a surface or object, and ranges from bright to dim. It is affected by luminance, surround luminance, adaptation, gradient, and spectrum. See 4.3 Brightness.

Concept:	The strength or power of the luminous sensation from a visual stimulus; The visual response counterpart to Luminance
Concept name:	Brightness
Concept symbol:	B
Constituent units:	None
Unit name:	None
Mathematical definition:	$B \propto L_t^{1/3} - B_0(L_b, \alpha)$

5.10 Tabulation

5.10.1 Radiometric Units

Some of the concepts shown in Table 5.1 are listed without having been explained previously. They are the radiant equivalent of a similarly named photometric unit and their significance should be clear.

5.10.2 Principal Photometric Units

Table 5.2 summarizes the principal photometric units commonly used in lighting. In each case the concept and concept name are provided. In some cases the concept unit has no name, as in the case of exitance. In other cases, the official name is seldom used and the constituent units are more common, as in the case of luminance, where the unit name is nit but the more common practice is to use cd/m^2. In all cases, the mathematical equations express the definition of the quantity and are not necessarily used in practical computation. See 10 | CALCULATION OF LIGHT.

Table 5.1 | Radiometric Quantities

Conept	Concept Name	Constituent Units	Symbol	Unit Name	Formula
Radiant energy	**Energy**		Q_e	Joule	
Radian flux	**Power**	energy, time	F_e	Watt	$\Phi_e = \frac{dQ_e}{dt}$
Spectral power	**Power per unit wavelength**	watt, length	$P(\lambda)$		$P(\lambda) = \frac{\Phi_e(\lambda)}{\Delta\lambda}$
Incident surface power density	**Irradiance**	watt, area	E_e		$E_e = \frac{d\Phi_{e\,on}}{dA}$
Exitant surface power density	**Radiant exitance**	watt, area	M_e		$M_e = \frac{d\Phi_{e\,off}}{dA}$
Spatial raidant power density	**Radiant intensity**	watt, steradian	I_e		$I_e(\theta,\psi) = \frac{d\Phi_e(\theta,\psi)}{d\omega}$
Radiant intensity per unit area	**Radiance**	radiant intensity, area	L_e		$L_e(\theta,\psi) = \frac{dI_e(\theta,\psi)}{dA\cos(\theta)} = \frac{d^2\Phi_e}{d\omega\, dA\cos(\theta)}$

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Table 5.2 | Photometric Quantities

Conept	Concept Name	Constituent Units	Symbol	Unit Name	Formula
Photopic visually evaluated radiant power	**Photopic Luminous flux**	lightwatts, lumens/watt	Φ	lumen lm	$\Phi \equiv 683 \int_0^\infty \Phi_{e\lambda}(\lambda) v(\lambda) d\lambda$
Scotopic visually evaluated radiant power	**Scotopic Luminous flux**	lightwatts, lumens/watt	Φ'	lumen lm	$\Phi \equiv 1700 \int_0^\infty \Phi_{e\lambda}(\lambda) v'(\lambda) d\lambda$
Time-integrated amount of luminous flux, dosage	**Quantity of light**	lumen	Q_v, $\Phi \cdot s$	lumen· seconds	$Q_v = \int \Phi \, dt$
Efficacy of radiation	**Efficacy**	lumens, radiant watts	K		$K = \frac{\Phi}{\Phi_e}$
Efficacy of a source	**Efficacy**	lumens, electrical watts	η		$\eta \equiv \frac{\Phi}{W}$
Incident surface flux density	**Illuminance**	lumens, area	E	footcandle lux (fc, lx)	$E \equiv \frac{d\Phi_{on}}{dA}$
Emergent surface flux density	**Exitance**	lumens, area	M		$M \equiv \frac{d\Phi_{off}}{dA}$
Spatial extent	**Solid angle**	area, distance	ω	steradian sr	$d\omega \equiv \frac{dA \cos(\theta)}{D^2}; \; \omega = \int_A \frac{dA \cos(\theta)}{D^2}$
Spatial flux density	**Luminous Intensity**	lumens, steradians	I	candela cd	$I(\theta, \psi) \equiv \frac{d\Phi(\theta, \psi)}{d\omega}$
Spatial flux density emitted by a surface	**Luminance**	candelas, area	L	cd m^{-2}	$L(\theta, \psi) \equiv \frac{dI(\theta, \psi)}{dA \cos(\theta)} = \frac{d^2\Phi}{d\omega \, dA \cos(\theta)} \approx \frac{I(\theta, \psi)}{A \cos(\theta)}$
Fraction of incident optical radiation reflected by a material	**Reflectance**	lumens	ρ		$\rho \equiv \frac{\Phi_{off}}{\Phi_{on}}; 0 \le \rho \le 1$
Reflectance of optical radiation as a function of wavelength	**Spectral Reflectance**	lumens	$\rho(\lambda)$		$\rho(\lambda) \equiv \frac{\Phi(\lambda)_{off}}{\Phi(\lambda)_{on}}$

Table 5.2 | Photometric Quantities continued next page

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Table 5.2 | Photometric Quantities continued from previous page

Conept	Concept Name	Constituent Units	Symbol	Unit Name	Formula
Reflectance of optical radiation from one direction into another	Bidirectional Reflectance	lumens	$\rho(\theta i,\psi i;\theta r,\psi r)$		$\rho(\theta_i,\psi_i;\theta_r,\psi_r)=\frac{\Phi(\theta_r,\psi_r)}{\Phi(\theta_i,\psi_i)};0\le\rho\le1$
Reflected Luminance per unit illuminance of a surface	Bidirectional Reflectance-distribution fuction	luminance, illuminance	$f_r(\theta_i,\psi_i;\theta_r,\psi_r)$	sr^{-1}	$f_r(\theta_i,\psi_i;\theta_r,\psi_r)=\frac{dL_r(\theta_r,\psi_r)}{E_i(\theta_i,\psi_i)};0\le f_r<\infty$
Fraction of incident light through a material	Transmit-tance	lumens	τ		$\tau\equiv\frac{\Phi_{out}}{\Phi_{on}};0\le\tau\le1$
Transmittance of optical radiation as a function of wavelength	Spectral Transmit-tance	lumens	$\tau(\lambda)$		$\tau(\lambda)\equiv\frac{\Phi(\lambda)_{out}}{\Phi(\lambda)_{on}};0\le\tau\le1$
Transmittance of optical radiation from one direction into another	Bidirectional Transmittance	lumens	$\tau(\theta i,\psi i;\theta r,\psi r)$		$\tau(\theta_i,\psi_i;\theta_r,\psi_r)=\frac{\Phi(\theta_t,\psi_t)}{\Phi(\theta_i,\psi_i)};0\le t\le1$
Transmitted Luminance per unit illuminance of a surface	Bidirectional Transmittance-distribution fuction	luminance, illuminance	$f_t(\theta_i,\psi_i;\theta_r,\psi_r)$	sr^{-1}	$f_t(\theta_i,\psi_i;\theta_t,\psi_t)=\frac{dL_t(\theta_t,\psi_t)}{E_i(\theta_i,\psi_i)};0\le f_t<\infty$
Fraction of incident light lost in a material	Absorptance	lumens	α		$\alpha\equiv\frac{\Phi_{lost}}{\Phi_{on}}=\frac{\Phi_{on}-\Phi_{out}}{\Phi_{on}};0\le\alpha\le1$
Luminous difference of a target and its surround	Luminous contrast	luminance	C		$C=\frac{L_t-L_b}{L_b}$ or $C=\left\lvert\frac{L_t-L_b}{L_b}\right\rvert$ or $C=\frac{L_t-L_b}{L_t+L_b}$
The perception of the luminous strength of luminance	Brightness	luminance	B		$B\propto L_t^{1/3}-B_0(L_b,\alpha)$

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5.11 References

[1] [CIE] Commission International de l'Eclairage. 1987. International Lighting Vocabulary, 4th edition. CIE 17.4-1987. Austria. 379 p.

[2] [IES] Illuminating Engineering Society. 2005. RP-16-05, Nomenclature and definitions for illuminating engineering. New York. 117 p.

[3] [BIPM] Bureau International des Poids et Measures. 2006. The international system of units (SI). 8th edition. Paris. BIPM. 180 p.

[4] Nutting PG. 1907. The luminous equivalent of radiation. Phy Rev. 24(2):202-13.

[5] Langley SP. 1888. Energy and vision. Am J Sci. 36(6):359-80.

[6] König A. 1891. Uber den helligkeitswert der spektralfarben bei vershiedener absoluter intensitat. In: Beitrage zur psychologie und physiologie der sinnesorgane. Hamburg. Voss. 388 p.

[7] [CIE] Commission Internationale de l'Eclairage. 1926. Sixieme session, 1924, Recueil des travaux et compte rendu des séances. Cambridge: Cambridge University Press.

[8] DiLaura DL. 2006. A history of light and lighting. New York: Illuminating Engineering Society. 402 p.

[9] Gibson KS, Tyndall EPT. 1923. The visibility of radiant energy. Sci Papers Bur Stand. 19(475):131-191.

[10] [CIE] Commission Internationale de l'Eclairage. 1983. CIE 18.2-1983 The basis of physical photometry. Vienna: CIE. 42 p.

[11] Sharpe LT, Stockman A, Jagla W, Jägle H. 2005. A luminous efficiency function, V*(λ), for daylight adaptation. J Vision. 5(11):3, 948-968,

[12] [CIE] Commission Internationale de l'Eclairage. Proceedings. 1951. Vol 1, Sec 4. Vol 3, p 37. Bureau Central de la CIE, Paris.

[13] Crawford BH. 1949. The scotopic visibility function. Proc Phys Soc B. 62(5):321-334.

[14] Wald G. 1945. Human vision and the spectrum. Sci. 101(2635):653-658.

[15] DiLaura DL. 1975. On the computation of ESI. J Illum Eng Soc. 4(2):129-149.

[16] Leonard, TA, Rudolph P. 1993. BRDF round robin test of ASTM E1392. In: Proceesings of the SPIE. 1995:285-293.

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6 | COLOR

It is difficult not to confuse that which derives from the objects with that which derives from our senses. Few men would hesitate to say that the Sun is luminous, fire warm, that the strings of the lute have a pleasant tone; and while these things do not act on us except through some movements, the remainder of the appearance stems from us and must be attributed entirely to us.

Edme Mariotte (1681) Treatise on the Nature of Colors

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6.2 Color Specification: CIE System 6.11
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Color is a result of spectra of optical radiation generated by light sources, perhaps modified by objects, and processed by the human visual system. The methods used to characterize color at each step from generation to perception are the basis for this chapter. Since its goal is to foster mutual understanding among those responsible for the luminous environment, the emphasis is on those aspects of color most important to people in occupied settings and their experience of the visual environment. Discussions related to color threshold discrimination, color vision abnormalities, and visual processing channels are provided in 4 | PERCEPTION AND PERFORMANCE.

Goals of color science are to quantify and predict human color experience. Though formulas and equations have been developed for this purpose, this chapter focuses on the practical application of color concepts rather than on the mathematical aspects.

Table 6.1 identifies design questions related to color, the concept that relates to the question, and the sections of the Handbook that contain additional information. Table 6.2 summarizes key terms that are used throughout this chapter. This chapter is written to be read sequentially and latter concepts build upon earlier ones.

6.1 Basic Concepts

This section describes the basic characteristics of the visual stimuli that produce color perceptions, how those perceptions are described, and how they are quantified for the purposes of analysis and prediction. Key terms used in the study of color are listed in Table 6.3.

6.1.1 Defining Color

Scientifically, color can be defined as the characteristic of optical radiation by which an observer can distinguish between luminous patches of the same size, shape, and structure. This definition reduces color to an assessment of the amounts of radiant power at different wavelengths in the visible spectrum. Treated as a physical quantity, color is an essential property of light sources, objects, and light source/object interactions, and helps predict human color perception under a wide and practical range of conditions. But full understanding must also include psychophysical effects: the relationships between the physical stimulus and human perceptual response.

Color perception has three components:

1. Optical radiation: The physical stimulus for vision and the initiator of color perception.

2. Objects: Either a light source viewed directly or a surface made luminous by interaction with optical radiation (reflection, transmission, scattering, or fluorescing).

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Table 6.1 | Color-related Design Questions

Source of Color	Design Question	Color Concept(s)	Section(s)
Light Source ("Optical Radiation Color")	• How is the color appearance of a light source quantified?	Chromaticity, dominant wavelength, color temperature, correlated color temperature	6.2.1, 6.2.4, 6.2.5
	• How are differences among the appearance of multiple sources quantified when they are viewed simultaneously?	Color difference, correlated color temperature	6.2.3, 6.2.5
	• How is color shift over time quantified, as with metal halide lamps?	MacAdam ellipses, color difference	6.2.1, 6.2.3
	• How is lamp-to-lamp color consistency quantified, as with LEDs?	MacAdam ellipses, color difference, dominant wavelength	6.2.1, 6.2.3, 6.2.4
	• How is the color of a narrow-band (aka spectral, monochromatic) source of optical radiation, such as a colored LED, charaterized?	Chromaticity, dominant wavelength, excitation purity	6.2.1, 6.2.4
Object ("Object Color")	• How does the choice of materials affect the visual environment?	Object color	6.1.3
	• How does the choice of glazing affect the indoor spectrum from daylight?	Spectral transmission	6.1.3.2
	• Is there a way to estimate surface reflectance from an object color system?	Relating Munsell value to reflectance	6.4.2
Light Source / Object Interaction ("Practical Color")	• Why do materials often look different under different light sources?	Color appearance	6.7
	• Why do two paints of the same color, but different levels of gloss, appear to be different colors?	Scatter, color appearance	6.1.3.4, 6.7
	• Why does a UV light source change the appearance of objects?	Fluorescence	6.1.3.5
Visual System ("Human Color Perception")	• At equal luminance, why do colored environments sometimes appear brighter than neutral environments?	Color appearance (Helmholtz Kohlrausch effect)	6.6
	• Why do colors appear to be less saturated in darkened environments?	Color appearance (Hunt effect)	6.6
Digital Media or Visual Display	• Why do renderings look different on different computer screens?	Device dependency, RGB primaries	6.5.1
	• Why do the colors on a projected presentation look different than the colors on a computer monitor?	Cross media color matching	6.7

3. Vision: The complex neurological system involving the receptor cells of the retina, nerve fibers, and the brain.

6.1.2 Optical Radiation Color: The Physical Stimulus

Figure 6.1 shows daylight that has been refracted through a glass prism into a spectrum of colors and shows that nominally "white" optical radiation from the sun consists of many wavelengths that elicit different color perceptions.

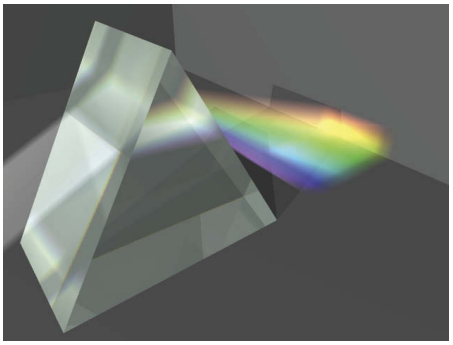


Figure 6.1 | Refraction of Daylight
When daylight is refracted through a glass prism it is dispersed into a spectrum of colors.

The optical radiation emitted from lamps can be separated into the relative amount of radiant power at each wavelength. This is the *spectral power distribution* (SPD) of the lamp. See 1.4.2 Spectral Power Data and 9.7 Measuring Spectra. The SPDs for three common light sources are shown in Figure 6.2. A light source's SPD is fundamental. All descriptions of a light source's color are derived from its SPD.

6.1.3 Object Color

Materials modify optical radiation by reflection, transmission, scattering, and/or fluorescence. It is convenient to think of the optical radiation produced by these object-based phenomena as the stimulus for "object color".

6.1.3.1 Spectral Reflection

Spectral Reflectance Distributions (SRDs) are relative amounts of radiant power reflected at each wavelength over a range of wavelengths. Spectral reflectance may vary with the

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Table 6.2 | Key Color Concepts

Color Concept	Basic Idea
Color	Color is used to mean many things: to describe the physical stimulus that is optical radiation; to colloquially describe the appearance of objects; and (perhaps most importantly) to describe the the effect of optical radiation in the mind of the viewer.
Color Constancy	The tendency for color samples to retain their color appearance despite changes in the light source color and levels of illumination.
Color Temperature (of a light source)	A general expression related to the whiteness of optical radiation on a scale from warm to cool. More technically, it is the absolute temperature of a blackbody radiator having a chromaticity equal to that of the light source, expressed in units of kelvin.
Color Rendering (of a light source)	A general expression for the effect of a light source on the color appearance of objects in conscious or subconscious comparison with their color appearance under a reference light source. Color rendering is not synonymous with the Color Rendering Index.
Color Difference	The difference in chromaticity and/or luminance between two colors that make them appear different. Perceptions of color
Color Appearance	A term to describe the gestalt effect of the optical radiation spectra entering the visual system on the resulting perception of color. By definition, color appearance models must at least characterize lightness, chroma, and hue. More complex models also characterize brightness and colorfulness.
Color Shift / Stability	Terms relating to the change in color that may occur over time, or due to a change in the operating voltage as with dimming.
Colorfulness	The attribute of a visual sensation by which the perceived color of an area appears to be more or less colorful (or chromatic).
Color Matching	The action of making a color appear the same as a given color.

incident and exitant directions. See 1.5.1 Important Optical Phenomena and 9.12 Measuring Reflectance and Transmittance. Examples of SRDs for several common fruits are shown in Figure 6.3.

Spectral Power Distribution (SPD) Radiant power per unit wavelength interval, considered within the extents of the visible spectrum. The units are typically watts/nm, normalized with the peak value at 1.0, or normalized to a relative percentage with the peak value at 100%.

6.1.3.2 Spectral Transmission

Spectral Transmittance Distributions (STDs) are the relative amounts of radiant power transmitted at each wavelength over a range of wavelengths. Spectral transmission varies with the incident and exitant directions. For transmissive surfaces such as windows and skylights, the effect of that object on optical radiation can be characterized using STDs. Examples for two types of window glazings are shown in Figure 6.4.

Spectral reflectance and transmittance may both be required to characterize translucent objects, since they both reflect and transmit optical radiation.

6.1.3.3 Spectral Absorption

The fraction of optical radiation that is absorbed by a material is either dissipated as heat, or reemitted at longer wavelengths. When dissipated as heat visible optical radiation is lost. Absorption is usually spectrally dependent.

6.1.3.4 Spectral Scattering

Scattering refers to the redirection of optical radiation from its incident direction by reflection, diffraction, or transmission. The color of a material depends upon the magnitude and geometry of the scattering and the amount of absorption. Color and scatter are a result of what occurs at the molecular level. Scattering increases with size of particles until they are about the same size as the wavelength of optical radiation, and then decreases as particle sizes get larger. An object will appear white when there is very little absorption and the same amount of scattering at each wavelength. A material will appear colored when scattering is dependent upon wavelength. An object that appears blue, for example, will scatter short wavelength optical radiation while absorbing longer wavelengths. Without surface

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Table 6.3 | Key Color Terms

Term	Basic Idea
Stimulus	In the context of this chapter, a stimlulus is that which is responsible for eliciting a visual response. The stimlus may be a light source, a reflective object, a self-luminous display, or anthing that results in radiant energy entering the eyes.
Hue	The perception of relative redness, blueness, greenness, or yellowness of a stimulus.
Lightness	The attribute by which a perceived color is judged to be equivalent to one of a series of grays ranging from black to white.
Value	When discussing color, value is synonymous with lightness. Value is more commonly used by artists and interior designers, whereas lightness is more commonly used by color scientists and engineers.
Chroma	The attribute of color that is used to indicate degree of departure from a gray of the same lightness.
Saturation	The degree to which the perception of the stimulus departs from neutral gray. A *saturated color* is a pure unmixed color that is not diluted by white.
Saturation of a percieved color	The attribute according to which a viewed surface (or luminous aperture) appears to exhibit more or less chromatic color judged in proportion to its brightness.
Brightness	The subjective attribute of any optical radiation sensation that gives rise to the perception of luminous magnitude, including the whole scale of qualities of being bright, light, brilliant, dim, or dark.

Saturated Color A pure color, like the colors of the spectrum, that has not been diluted by white or mixed with other colors. Saturated colors may be created by employing lamps that emit only a narrow range of optical radiation (as with some LEDs), or by employing subtractive filters (as with dichroic filters).

scattering an object will have a shiny or glossy appearance, which is the result of specular reflections. Scatter is therefore intimately tied with both surface color and specularity.

6.1.3.5 Fluorescence

Fluorescence can be responsible for object color in a complicated way by absorbing optical radiation and reemitting it at longer wavelengths. See 1.4.5.1 Photoluminescence: Fluorescence. Fluorescent lamp phosphors absorb UV optical radiation and reemit it as visible optical radiation. Fluorescent whitening agents, or optical brightening agents, that work in this way are used to whiten paper and textiles. They absorb UV optical radiation and reemit it as short-wavelength visible radiation. Fluorescent coloring agents absorb optical radiation within the visible range and reemit optical radiation at longer visible wavelengths; characterizing such surfaces is complex because they have a different reflected spectral distribution under different light sources. [1] [2] [3]

6.1.4. Practical Color

The color perceived in an object results from the optical radiation produced by a source, modified by the object due to reflection, transmission, scatter, or fluorescence, and finally entering the eyes. Figure 6.5 provides a schematic example of this source/object interaction.

Illuminant A real or theoretical source of optical radiation, including spectra from commercial lamps and mathematical models. For example, CIE D65 is a mathematical model—representative of light from the sun and sky—whose spectrum is not easily reproduced with a commercial light source.

In the leftmost column are SPDs for three common *illuminants*. The center column contains the inherent SRD for a Red Delicious apple. The rightmost column contains the spectrum that would be reflected by the apple under each of the three light sources. A Red Delicious apple appears red because it reflects predominantly red optical radiation while absorbing other wavelengths. But it will only appear red if it is illuminated by a source that emits optical radiation in the long-wavelength (red) region of the spectrum. In this example, the apple will have a deep-red appearance under both incandescent optical radiation and daylight. But under high pressure sodium, which emits proportionally less long-wavelength optical radiation, the apple will shift in color appearance and will be seen in a less saturated hue. Less saturated means that the color shifts toward neutral gray, which in this case would be a shift toward a brownish-red.

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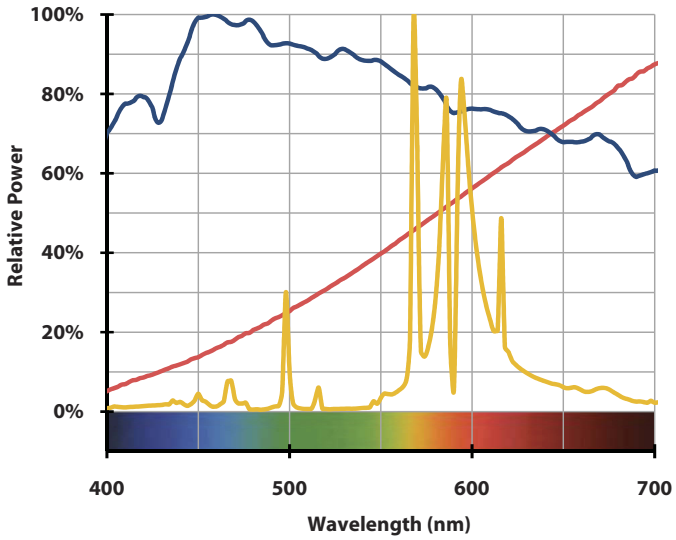


Figure 6.2 | SPDs
Spectral power distribution (SPD) plots for several common light sources showing relative radiant power as a function of wavelength.
» Blue: CIE D65, model of "average daylight" at 6504 K
» Red: Incandescent
» Gold: High pressure sodium

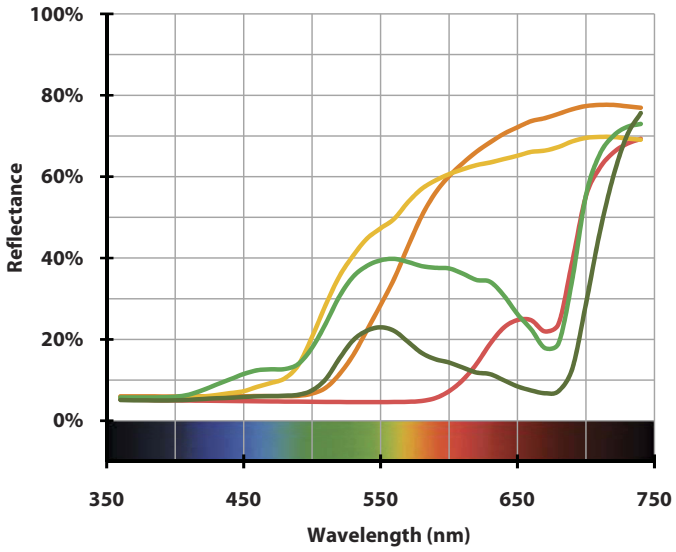


Figure 6.3 | SRDs
Spectral reflectance distribution (SRD) plots for several common fruits showing reflectance as a function of wavelength.
» Orange: Orange
» Gold: Lemon
» Light Green: Granny Smith apple
» Red: Red Delicious apple
» Dark Green: Lime

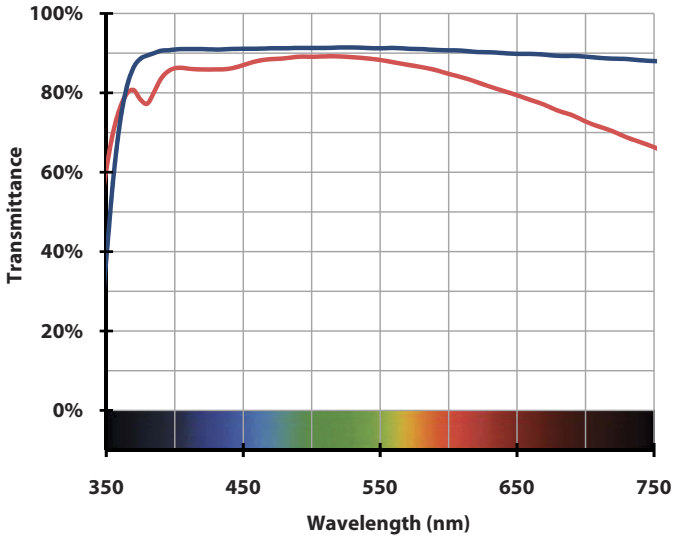


Figure 6.4 | STDs
Spectral transmittance distribution (STD) plots for two types of 19 mm (3/4 in.) clear architectural glass showing transmittance as a function of wavelength.
» Blue: High transmittance
» Red: Standard transmittance

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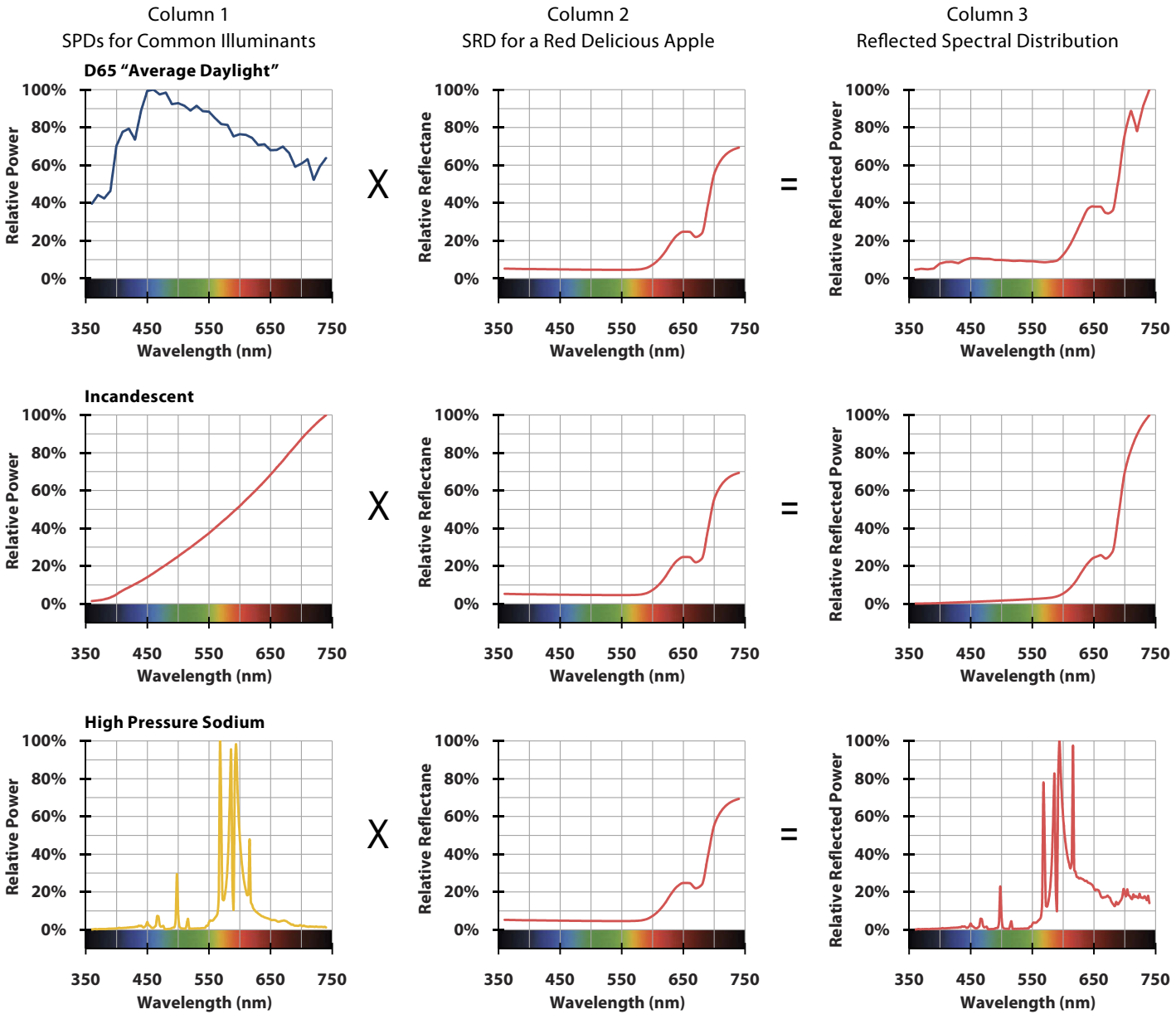


Figure 6.5 | Light Source / Object Interaction
When an object is viewed under various light sources both the object and the light contribute to color appearance. Objects lack inherent color, instead reflecting various wavelengths of light in different proportions. Column 1 shows spectral power distributions (SPDs) for three common illuminants. Column 2 shows the spectral reflectance distributions (SRDs) for a Red Delicious apple, representing the relative amounts of different wavelengths of reflected optical radiation. Column 3 illustrates the spectrum that would reflect from the apple for each source, and represents what would enter the eyes. The reflected spectrum is different under the different illuminants, meaning that the visual stimulus is different, and implying that the apple will have a different color appearance under the different illuminants.

6.1.4.1 Additive and Subtractive Color Mixing

Additive color mixing is that process by which different wavelengths are integrated or added and the resultant optical radiation contains more power. If two beams of long-wavelength (red) and medium-wavelength (green) optical radiation are integrated, the mixture is perceived as yellow. If long- (red), medium- (green), and short-wavelength (blue) beams of optical radiation are integrated in the appropriate proportions, the perception of the mixture will be white. This is shown schematically in Figure 6.6.

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Subtractive color mixing is that process by which different wavelengths are absorbed or subtracted and the resultant optical radiation contains less power. Color is perceived in an object when certain wavelengths of incident optical radiation are absorbed and others are reflected. The radiation reflected toward an observer's eyes no longer contains the wavelengths that were absorbed. Pigments, which are the basis for subtractive color mixing, are chemicals that selectively absorb and reflect different wavelengths of optical radiation.

Subtractive mixing can also occur with filters since they are designed to absorb certain colors within the spectrum while transmitting others. See 1.5.1.2 Transmission. Subtractive color mixing is shown in Figure 6.7. All reflected and transmitted optical radiation undergoes some amount of subtractive color mixing.

Paints and inks work on the principle of subtractive color mixing. A magenta paint or pigment appears magenta because it absorbs medium-wavelength (green) optical radiation and reflects the long- (red) and the short-wavelengths (blue). Recall that with additive mixing long- (red) and short-wavelength (blue) combine to make magenta. A cyan paint absorbs long- (red) and reflects medium- (green) and short-wavelengths (blue) while a yellow paint absorbs short-wavelengths (blue) and reflects long- (red) and medium-wavelengths (green). If magenta and cyan paints are combined the mixture will appear blue. This is because the combined pigments absorb the long-wavelengths (red) by the cyan paint, and the medium-wavelengths (green) by the magenta paint. Finally, if the new blue paint is mixed with yellow paint, all three primary colors will be absorbed and this new mixture will appear black. Figure 6.8 illustrates an example of subtractive mixing.

6.1.5 Human Color Perception

Color is not an intrinsic property of optical radiation or objects: it is a perceptual phenomenon that is part of the visual experience. Neither optical radiation nor objects are colored in the way that they are experienced. Though perhaps convenient to think that a lemon looks yellow because it is yellow, this is fundamentally incorrect. It is also common to assign different colors to different wavelengths of optical radiation, yet the wavelengths themselves are colorless.

The conversion of radiant energy to color perceptions is exceedingly complex and current understanding is incomplete. But there are many tools, derived from what is known, available to design professionals. These include metrics for quantifying light source color, color difference, the rendering of lighted objects, and metrics to predict how the human visual system will perceive color, even within complex environments. These application driven tools are based upon models of human color vision.

6.1.5.1 Photoreceptors

Color perception begins with *retinal photoreceptors*. See 2.1.3 Photoreceptors, Neural Layers, and Signal Processing and 2.5 Color Vison. Figure 2.4 shows the overlap among the spectral sensitivities of the three cone types, especially between the L- and M-cones. These overlaps imply that the visual system does not treat all wavelengths equally. This uneven sampling is important because it permits humans to have fine *color discrimination*.

In many regions of the retina individual photoreceptors pool their signals to form *receptive fields*. See 2.3.4 Receptive Fields. In all cases, the signals are sent through the optic nerve and into the brain. It is the brain that is the seat of vision; it is where signals are interpreted, color is created, and where vision is realized.

6.1.5.2 Metamerism

When two (or more) wavelengths are combined, it is impossible for an observer to identify the wavelengths, or to even know that the stimulus contains different wavelengths. The implication is that two different illuminants can appear identical even though they have

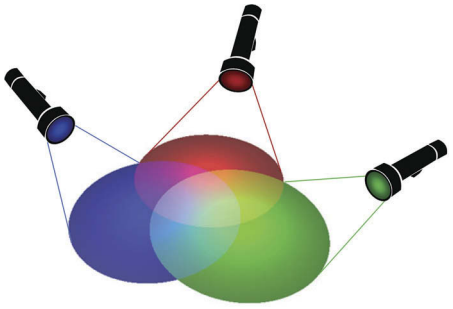


Figure 6.6 | Additive Color Mixing
The primaries shown are red, green, and blue. The secondary colors created where two primary beams overlap are yellow, magenta, and cyan. White light is created in the center where the three beams overlap, or "add together".

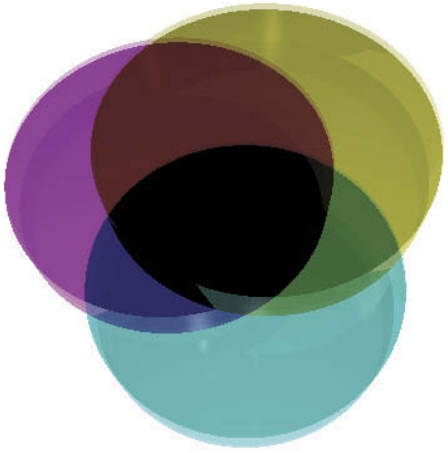


Figure 6.7 | Subtractive Color Mixing
Subtractive color mixing using cyan, magenta, and yellow glass filter is shown. The secondary colors shown where two filters overlap are blue, red, and green. Complete color subtraction occurs where all filters overlap, yielding black, because the three filters together block, or "subtract", all visible optical radiation.

Retinal Photoreceptors A nerve ending or cell specialized to sense optical radiation.

Color Discrimination The perception of differences between two or more colors.

Receptive Field A region around a neuron, that when acted upon with a sufficient amount of energy of appropriate wavelength(s), will cause the neuron to fire.

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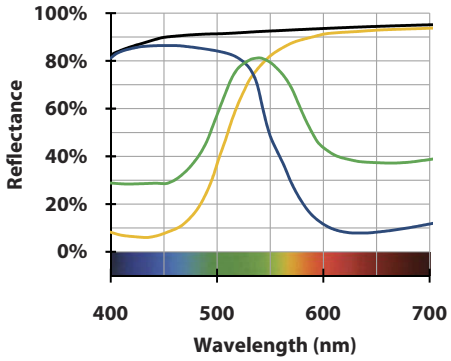


Figure 6.8 | Paper Dyes
Illustration of subtractive color mixing. Papermakers use a combination of yellow and blue dyes to reduce the reflectance in the blue and red parts of the visible spectrum, resulting in a maximum reflectance in the green wavelengths. Black: white paper with no dye. Yellow: paper with yellow dye only. Blue: paper with blue dye only. Green: paper with some blue and some yellow dyes. Adapted from [3].

Colorimetry The science of measuring color, as governed by the Commission Internationale de l'Eclairage (CIE).

Color Matching Functions (CMFs) The tristimulus values per unit wavelength interval and unit spectral radiant flux. Also know as spectral tristimulus values. Color matching functions come in sets of three, where a set is also known as a "standard observer".

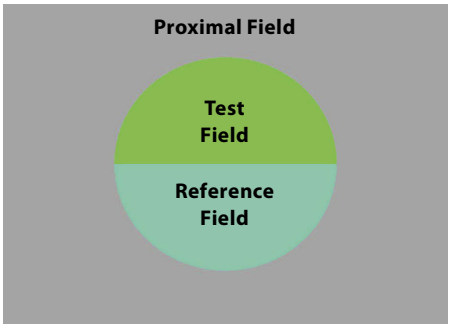


Figure 6.9 | Bipartite Visual Field
A schematic of a horizontally bisected circular visual field as used in vision experiments to derive CMFs. The color in the test field is adjustable. The color in the reference field may be adjustable. The proximal field is fixed.

different SPDs. The phenomenon in which optical radiation stimuli that are spectrally different appear identical to a given observer is known as metamerism.

Metamerism is the most important concept in color science, enabling many technologies that rely on the reproduction of color to succeed by using just three or four primaries to represent all colors. Examples are computer displays, television, printing, photography, tri-phosphor fluorescent lamps, and RGB LEDs. Matching materials that use different colorants also relies on metamerism, such as matching the plastic panel of a car fender to the painted door panel.

6.1.5.3 Trichromacy

Trichromacy is the characteristic of vision whereby complex stimuli can be reduced to three visual signals. It is believed that when two stimuli produce the same cone signals they will match in color. In applied *colorimetry*, cone sensitivity functions are not used directly to characterize a visual match. Rather, the simultaneous processing of the three visual channels is quantified using *color matching functions* (CMFs).

6.1.5.4 RGB Color Matching Functions

Even though most design professionals will not apply CMFs directly, it is useful to have a basic understanding of their derivation and how they lead to the practical tools of color analysis and specification.

A schematic description of the processes of finding color matching functions is as follows. A luminous disk is divided into two half-circles, a test field and a reference field, and viewed within an otherwise darkened room, as illustrated in Figure 6.9. The test and reference fields can each be separately illuminated with monochromatic optical radiation from different parts of the spectrum, such as red (R), green (G), and blue (B). These form an RGB primary set and are fixed for any given experiment. For example, the R, G, and B primaries may have wavelengths of 700, 546, and 436 nm, respectively.

With the reference field illuminated with a monochromatic radiation other than one of the primaries, an observer separately adjusts the R, G, and B primaries in the test field, attempting to visually match the reference field. When successfully matched, the amounts of R, G, and B optical radiation in the test field added together to produce a color that is a metamer of that in the reference field.

For some wavelengths in the reference field, the observer will be unable to produce a match. In such cases one of the primaries is moved to the reference field. Mathematically, adding a primary to the reference field is equivalent to subtracting it from the test field. This phenomenon, that color matching follows the laws of algebraic addition, is known as Grassmann's Law of Additivity.

This matching is conducted for each of many monochromatic radiations through the visible spectrum. At each match, the subject will have adjusted the primaries to create a metamer for the reference wavelength in the reference field. Metameric matching experiments like this have been performed by 17 observers and provide data that is now standard [4] [5].

The amounts of each primary required to produce a match for each monochromatic color define red, green, and blue CMFs, knows as $\bar{r}(\lambda)$, $\bar{g}(\lambda)$, and $\bar{b}(\lambda)$, as shown with solid lines in Figure 6.10. The $\bar{r}(\lambda)$, $\bar{g}(\lambda)$, and $\bar{b}(\lambda)$ functions define the tristimulus values of the spectrum for this particular set of primaries and define the relative amounts of each primary component that are required to match a given stimulus. The bar over each variable implies an average because the data in Figure 6.10 are based on the average of color matches made by the observers. The capital letters R, G, and B are used to denote the tristimulus values for this set of CMFs. Note that $\bar{r}(\lambda)$, $\bar{g}(\lambda)$, and $\bar{b}(\lambda)$ each have negative and positive components; the negative is most apparent in the $\bar{r}(\lambda)$ function.

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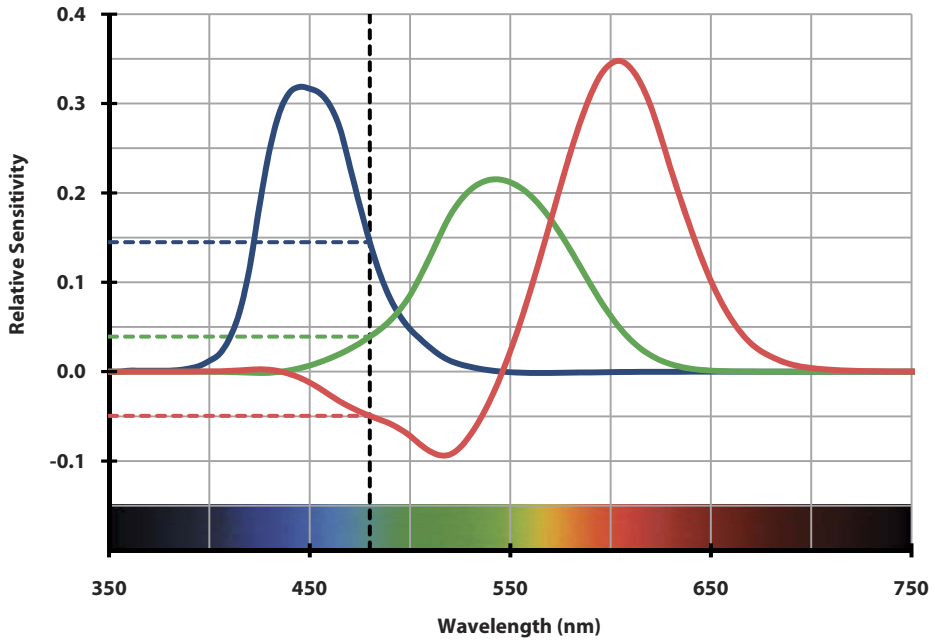


Figure 6.10 | RGB CMFs
These color matching functions (CMFs) are based on data from 17 observers and for a primary set comprised of 700, 546, and 436 nm spectral lights. The intersection of the dashed vertical line at 480 nm and each of the CMFs define the three tristimulus values required to match a 480 nm reference light.

Tristimulus values define the relative amounts of each primary component that are required to match a stimulus, as illustrated with the dashed lines in Figure 6.10. The vertical dashed line at 480 nm defines the wavelength of the reference field stimulus. A visual match is achieved when: the red primary is added to the reference field (because it has a negative value), and the green and blue primaries are in the test field (because they are positive). The relative amounts of the R, G, and B primaries required to make this match are indicated with the dashed horizontal lines that extend and correspond to values on the vertical axis. The tristimulus values required for this match are R = -0.049, G = 0.039, and B = 0.145. That is, the monochromatic reference field of 480 nm is metamerically equal to: $-0.049r(\lambda) + 0.039g(\lambda) + 0.145b(\lambda)$.

6.1.5.5 XYZ Color Matching Functions

A practical difficulty with the RGB system is that the CMFs have positive and negative values that complicate measurement; an instrument designed to exemplify the RGB CMFs would need to respond negatively to optical radiation at some wavelengths. This difficulty was overcome by mathematically transforming the RGB CMFs into a new system of CMFs with no negative values. At the same time, the new functions were created such that the middle CMF corresponds exactly to the V(λ) function (See 5.4.2 Photopic Luminous Efficiency). The new set of transformed CMFs do not represent the underlying psychophysics of human color matching. They are a numerically reliable way of quantifying metamerism, but are based on an imaginary set of primaries.

The transformed CMFs are denoted as $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, and $\bar{z}(\lambda)$, and the tristimulus values are denoted as X, Y, and Z. Additionally, there are two sets, both of which are illustrated in Figure 6.11, which plots the 1931 CIE 2° and the 1964 CIE 10° standard observers. The data are shown in Tables 6.4a and 6.4b. The different data sets result from the different field sizes in the experiments. Viewed from a distance of approximately arm's length, a 2° field is about the size of a US Quarter, and a 10° field is approximately the size of a small tea-saucer. The CIE recommends use of the 1931 Standard Observer when the angular subtense of the field of view is between 1 and 4°. The CIE 1964 Standard Observer is intended for use when the angular subtense is greater than 4°. CMFs have been developed for field sizes that approximate full-field viewing, concluding that CMFs continue to change with field sizes larger than 10° [6].

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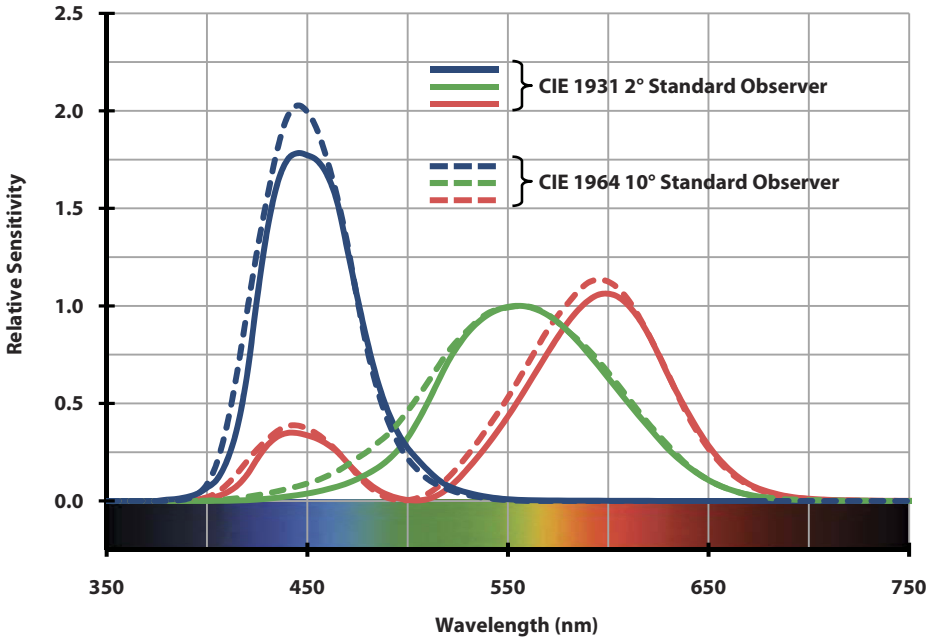


Figure 6.11 | XYZ 2° and 10° CMFs
The most common sets of color matching functions, those of the CIE 1931 2° and CIE 1964 10° standard observers. See Tables 6.4a and 6.4b for tabulated data.

6.1.5.6 Computing Tristimulus Values

Standard Observers, which approximate the average response of human observers, are used to reduce complex stimuli such as SPDs, SRDs, and STDs, into three tristimulus values.

Tristimulus values are computed by multiplying the spectrum of the stimulus by each of the CMFs, wavelength by wavelength, and then summing the results. Figure 6.12 provides a graphical illustration of this numerical operation. The leftmost graph in Figure 6.12 is identical to the top right graph from Figure 6.5; it represents the reflected spectrum from a Red Delicious apple illuminated by daylight. When this reflected optical radiation strikes the retina, it is selectively sampled in a way that can be characterized with the three CMFs, as represented by the center column in Figure 6.12. The tristimulus values (X, Y, and Z) are represented by the areas under the curve in the rightmost column of Figure 6.14. The numbers inset into these rightmost graphs are the computed tristimulus values.

If two stimuli have identical tristimulus values then the stimuli are metamers. The different reflected spectra shown in the last column of Figure 6.5 may at first suggest very different color perceptions for the red apple, the shapes of the reflected spectra being quite different. But the red apple will not look significantly different under each source because individual wavelength information is not retained, the perceptual result being a subtly different shade of red under each source.

6.1.5.7 Opponent Channels and Luminance

The higher orders of visual processing cannot be entirely explained with trichromacy. Figure 2.4 illustrates that the L, M, and S cones have different spectral sensitivities. Additionally, they have different distributions across the retina and are unequal in number, which leads to receptive fields with different properties. It has proven useful to organize receptive fields into three classes, referred to as the luminance, red-green, and yellow-blue opponent channels. See 2.5.1 Chromatic Receptive Field Opponency. The spectral response of the opponent signals is plotted in Figure 6.13.

All photometric units and all of applied photometry are based only on the luminance channel. Luminance does not include contributions from the red-green and blue-yellow opponent channels, but the perception of brightness does. The implication is that lumi-

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Table 6.4a | CIE 1931 2° Standard Observer

Wavelength (nm)	$\bar{x}(\lambda)$	$\bar{y}(\lambda)$	$\bar{z}(\lambda)$	Wavelength (nm)	$\bar{x}(\lambda)$	$\bar{y}(\lambda)$	$\bar{z}(\lambda)$
380	0.0014	0.0000	0.0065	585	0.9786	0.8163	0.0014
385	0.0022	0.0001	0.0106	590	1.0263	0.7570	0.0011
390	0.0042	0.0001	0.0201	595	1.0567	0.6949	0.0010
395	0.0077	0.0002	0.0362	600	1.0622	0.6310	0.0008
400	0.0143	0.0004	0.0679	605	1.0456	0.5668	0.0006
405	0.0232	0.0006	0.1102	610	1.0026	0.5030	0.0003
410	0.0435	0.0012	0.2074	615	0.9384	0.4412	0.0002
415	0.0776	0.0022	0.3713	620	0.8545	0.3810	0.0002
420	0.1344	0.0040	0.6456	625	0.7514	0.3210	0.0001
425	0.2148	0.0073	1.0391	630	0.6424	0.2650	0.0001
430	0.2839	0.0116	1.3856	635	0.5419	0.2170	0.0000
435	0.3285	0.0168	1.6230	640	0.4479	0.1750	0.0000
440	0.3483	0.0230	1.7471	645	0.3608	0.1382	0.0000
445	0.3481	0.0298	1.7826	650	0.2835	0.1070	0.0000
450	0.3362	0.0380	1.7721	655	0.2187	0.0816	0.0000
455	0.3187	0.0480	1.7441	660	0.1649	0.0610	0.0000
460	0.2908	0.0600	1.6692	665	0.1212	0.0446	0.0000
465	0.2511	0.0739	1.5281	670	0.0874	0.0320	0.0000
470	0.1954	0.0910	1.2876	675	0.0636	0.0232	0.0000
475	0.1421	0.1126	1.0419	680	0.0468	0.0170	0.0000
480	0.0956	0.1390	0.8130	685	0.0329	0.0119	0.0000
485	0.0580	0.1693	0.6162	690	0.0227	0.0082	0.0000
490	0.0320	0.2080	0.4652	695	0.0158	0.0057	0.0000
495	0.0147	0.2586	0.3533	700	0.0114	0.0041	0.0000
500	0.0049	0.3230	0.2720	705	0.0081	0.0029	0.0000
505	0.0024	0.4073	0.2123	710	0.0058	0.0021	0.0000
510	0.0093	0.5030	0.1582	715	0.0041	0.0015	0.0000
515	0.0291	0.6082	0.1117	720	0.0029	0.0010	0.0000
520	0.0633	0.7100	0.0783	725	0.0020	0.0007	0.0000
525	0.1096	0.7932	0.0573	730	0.0014	0.0005	0.0000
530	0.1655	0.8620	0.0422	735	0.0010	0.0004	0.0000
535	0.2258	0.9149	0.0298	740	0.0007	0.0002	0.0000
540	0.2904	0.9540	0.0203	745	0.0005	0.0002	0.0000
545	0.3597	0.9803	0.0134	750	0.0003	0.0001	0.0000
550	0.4335	0.9950	0.0088	755	0.0002	0.0001	0.0000
555	0.5121	1.0000	0.0058	760	0.0002	0.0001	0.0000
560	0.5945	0.9950	0.0039	765	0.0001	0.0000	0.0000
565	0.6784	0.9786	0.0028	770	0.0001	0.0000	0.0000
570	0.7621	0.9520	0.0021	775	0.0001	0.0000	0.0000
575	0.8425	0.9154	0.0018	780	0.0000	0.0000	0.0000
580	0.9163	0.8700	0.0017	Totals =	21.3715	21.3713	21.3715

Table 6.4b | CIE 1964 10° Standard Observer

Wavelength (nm)	$\bar{x}_{10}(\lambda)$	$\bar{y}_{10}(\lambda)$	$\bar{z}_{10}(\lambda)$	Wavelength (nm)	$\bar{x}_{10}(\lambda)$	$\bar{y}_{10}(\lambda)$	$\bar{z}_{10}(\lambda)$
380	0.0002	0.0000	0.0007	585	1.0743	0.8256	0.0000
385	0.0007	0.0001	0.0029	590	1.1185	0.7774	0.0000
390	0.0024	0.0003	0.0105	595	1.1343	0.7204	0.0000
395	0.0072	0.0008	0.0323	600	1.1240	0.6583	0.0000
400	0.0191	0.0020	0.0860	605	1.0891	0.5939	0.0000
405	0.0434	0.0045	0.1971	610	1.0305	0.5280	0.0000
410	0.0847	0.0088	0.3894	615	0.9507	0.4618	0.0000
415	0.1406	0.0145	0.6568	620	0.8563	0.3981	0.0000
420	0.2045	0.0214	0.9725	625	0.7549	0.3396	0.0000
425	0.2647	0.0295	1.2825	630	0.6475	0.2835	0.0000
430	0.3147	0.0387	1.5535	635	0.5351	0.2283	0.0000
435	0.3577	0.0496	1.7985	640	0.4316	0.1798	0.0000
440	0.3837	0.0621	1.9673	645	0.3437	0.1402	0.0000
445	0.3867	0.0747	2.0273	650	0.2683	0.1076	0.0000
450	0.3707	0.0895	1.9948	655	0.2043	0.0812	0.0000
455	0.3430	0.1063	1.9007	660	0.1526	0.0603	0.0000
460	0.3023	0.1282	1.7454	665	0.1122	0.0441	0.0000
465	0.2541	0.1528	1.5549	670	0.0813	0.0318	0.0000
470	0.1956	0.1852	1.3176	675	0.0579	0.0226	0.0000
475	0.1323	0.2199	1.0302	680	0.0409	0.0159	0.0000
480	0.0805	0.2536	0.7721	685	0.0286	0.0111	0.0000
485	0.0411	0.2977	0.5701	690	0.0199	0.0077	0.0000
490	0.0162	0.3391	0.4153	695	0.0138	0.0054	0.0000
495	0.0051	0.3954	0.3024	700	0.0096	0.0037	0.0000
500	0.0038	0.4608	0.2185	705	0.0066	0.0026	0.0000
505	0.0154	0.5314	0.1592	710	0.0046	0.0018	0.0000
510	0.0375	0.6067	0.1120	715	0.0031	0.0012	0.0000
515	0.0714	0.6857	0.0822	720	0.0022	0.0008	0.0000
520	0.1177	0.7618	0.0607	725	0.0015	0.0006	0.0000
525	0.1730	0.8233	0.0431	730	0.0010	0.0004	0.0000
530	0.2365	0.8752	0.0305	735	0.0007	0.0003	0.0000
535	0.3042	0.9238	0.0206	740	0.0005	0.0002	0.0000
540	0.3768	0.9620	0.0137	745	0.0004	0.0001	0.0000
545	0.4516	0.9822	0.0079	750	0.0003	0.0001	0.0000
550	0.5298	0.9918	0.0040	755	0.0002	0.0001	0.0000
555	0.6161	0.9991	0.0011	760	0.0001	0.0001	0.0000
560	0.7052	0.9973	0.0000	765	0.0001	0.0000	0.0000
565	0.7938	0.9824	0.0000	770	0.0001	0.0000	0.0000
570	0.8787	0.9556	0.0000	775	0.0000	0.0000	0.0000
575	0.9512	0.9152	0.0000	780	0.0000	0.0000	0.0000
580	1.0142	0.8689	0.0000	Totals =	23.3294	23.3320	23.3342

nance may not always correlate with the perception of brightness, a fact not characterized with conventional photometric quantities such as the lumen and candela. However, luminance has proven to be widely useful despite its limitations.

6.2 Color Specification: CIE System

The CIE color specification system is employed for virtually all colorimetric measures that are related to light sources, including the specification of CCT, CRI, and color tolerances [7].

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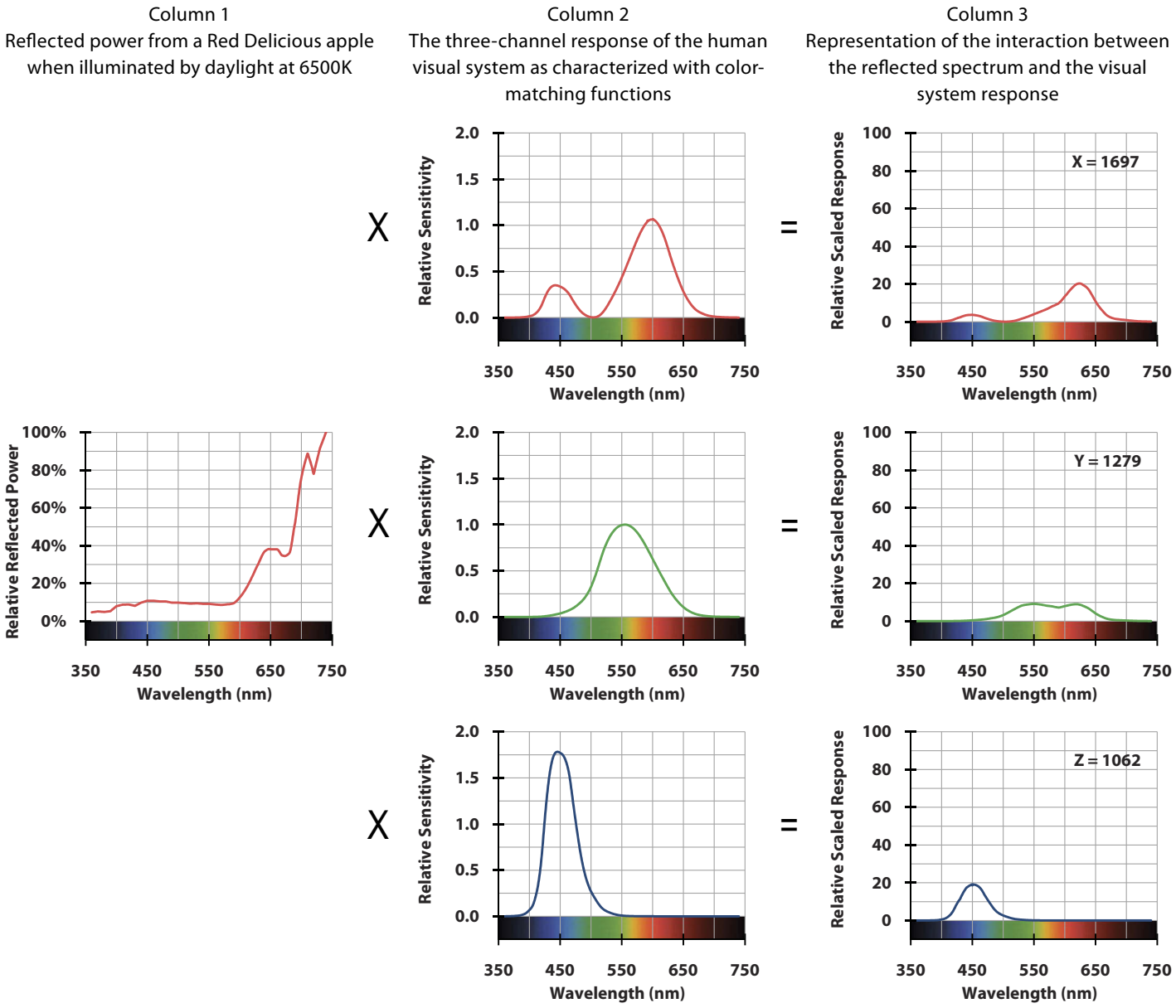


Figure 6.12 | Reflected Spectral Distribution to Tristimulus Values
A schematic representation of what happens when light enters the eyes. The figure in Column 1 represents the light reflected from a Red Delicious apple when illuminated by daylight at 6500K, as previously shown in Figure 6.5. Column 2 represents the CIE 1931 2° CMFs as previously given in Figure 6.13. Column 3 represents the interaction between the spectral stimulus that initiates vision when it enters the eyes (Column 1), and an imaginary proxy for the three-channel spectral responses of the eye-brain system (Column 2). Importantly, information about individual wavelengths is discarded in the process of simplifying the stimulus into three quantities, which is believed to be reflective of how the visual system operates. The quantities represented by the three "areas under the curves" in the Column 3 are known as tristimulus values.

6.2.1 Chromaticity Diagrams

A CIE chromaticity diagram is a two-dimensional quantitative representation of places where two stimuli will be metamers. Stimuli with the same tristimulus values have the same chromaticity coordinates and plot to the same point on the diagram. Chromaticity coordinates are the fraction of the X, Y, or Z tristimulus values of the stimulus, divided by their sum. That is:

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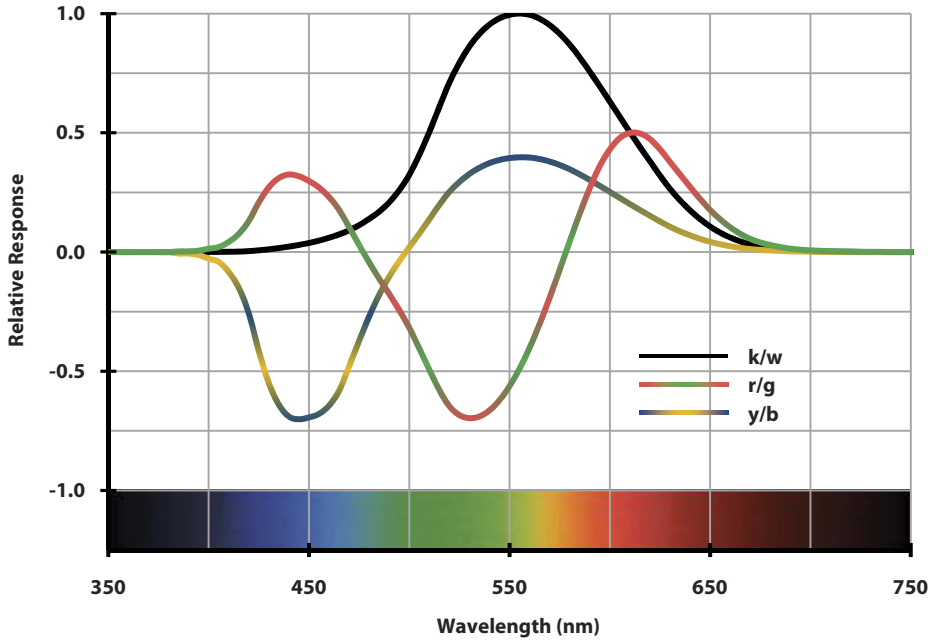


Figure 6.13 | Opponent Signals
The black line labeled k/w represents the luminance channel of the human visual system; it is equivalent to V(λ) and is the basis for photometry. The other opponent channels, r/g and y/b contribute to color and brightness perceptions, but not to photometric quantities such as the lumen and lux. The negative lobes in r/g and y/b indicate that brightness and color perceptions have subadditive components, whereas the luminance channel, k/w, is entirely additive.

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z} \qquad (6.1)$$

$$z = \frac{Z}{X+Y+Z}$$

Where:

x, y, and z = Chromaticity coordinates, which are unitless, each with a value between 0 and 1.0
X, Y, and Z = Tristimulus values, which are unitless, each with a value between 0 and infinity

Note that x + y + z = 1 and specification of any two fixes the third. By convention, chromaticity is stated in terms of x and y.

Figure 6.14 illustrates the *chromaticity diagram* for the CIE 1931 2° Standard Observer, which is the diagram that is most commonly used for colorimetric specification. Chromaticity diagrams are used in the determination of *correlated color temperature (CCT)*, *color rendering index (CRI)*, and some measures of color difference.

A chromaticity diagram is sometimes incorrectly interpreted as being a two-dimensional map of color, and chromaticity diagrams are often presented with a continuous array of colors, as if they were color diagrams, rather than chromaticity diagrams. It should be understood that when colors are shown, as with Figure 6.14, they are for orientation only. Since chromaticity coordinates are normalized tristimulus values, changing only the relative radiant power of a source does not change its chromaticity coordinates even though the color perception may change. Chromaticity diagrams do not account for the bright-dim dimension of color perception; they account for hue and saturation, but not for lightness. This is illustrated schematically in Figure 6.15.

Chromaticity Diagram A two-dimensional diagram formed by plotting one of the three chromaticity coordinates against another.

Correlated Color Temperature (CCT) The temperature in units of kelvin of a blackbody whose chromaticity most nearly resembles that of the light source in question.

Color Rendering Index (CRI) A measure of the degree of color shift that a set of test-color samples undergoes when illuminated by the light source in question, as compared with those same test-color samples when illuminated by a reference illuminant of comparable color temperature.

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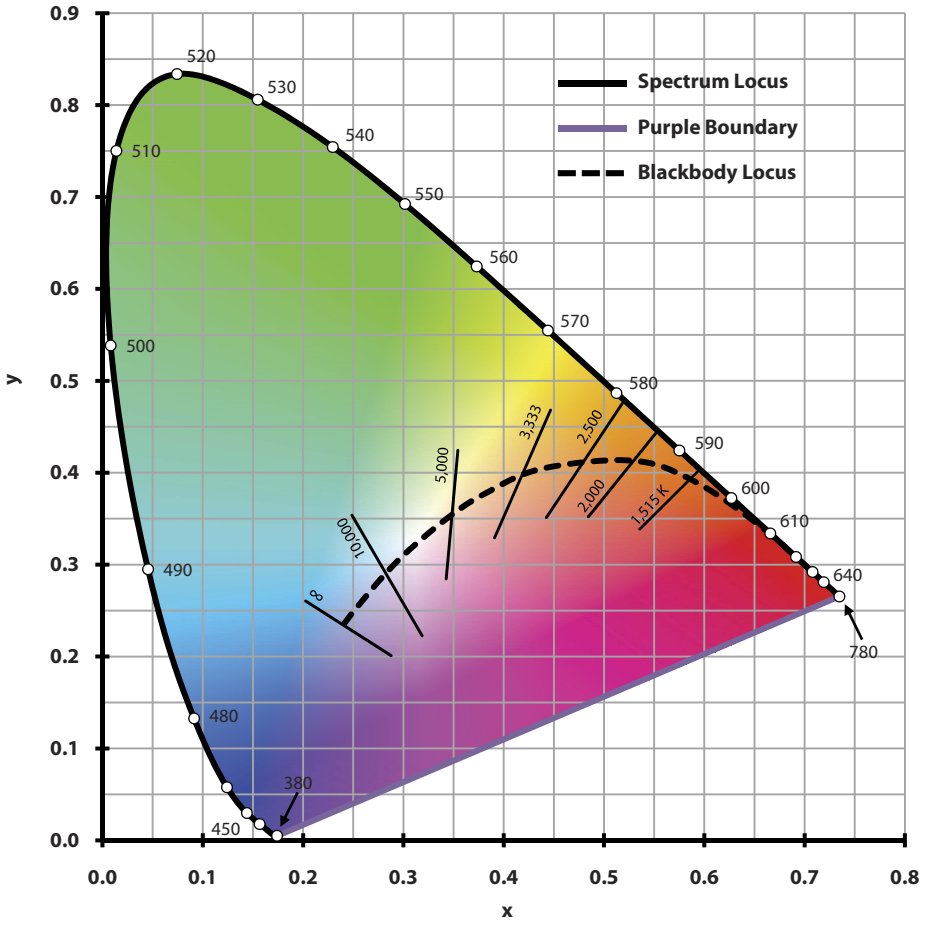


Figure 6.14 | x, y Chromaticity Diagram
The CIE 1931 2° chromaticity diagram showing the location of the spectrum locus, purple boundary and blackbody locus. Several linces of constant CCT are shown intersecting the blackbody locus.

Monochromatic In colloquial use, monochromatic means having the appearance of only one color. In its more technical usage, employed here, monochromatic optical radiation is composed of only one wavelength.

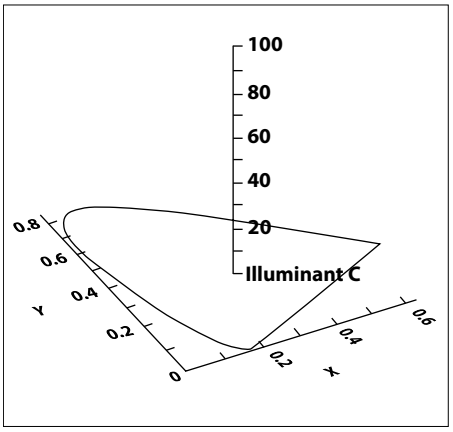


Figure 6.15 | Conceptual Extension of Chromaticity Diagram for Lightness
Lighter colors can be considered to be directly above the points representing their chromaticity, at a height representing their lightness.

Chromaticity coordinates can be determined for SPDs from lamps, SRDs from objects, STDs from transmissive materials, and for "practical colors" that spectrally account for light source / object interactions. Standards are available that cover these computations and for handling special cases [8].

The horseshoe-shaped curve in Figure 6.14 is called the spectrum locus and comprises the chromaticity coordinates for *monochromatic* optical radiation from 360 to 830 nm. The line joining the extremities of the spectrum locus is the purple boundary. It consists of the coordinates of the most saturated purples obtainable. Purple is created by combining deep-red with deep-blue, and so purple plots between the extremities of the spectrum locus.

All colors are contained within the area bounded by the spectrum locus and purple boundary. A saturated color appears toward the perimeter and less saturated colors toward the center. Thus, a light source with very narrow spectral emission centered about one wavelength will plot near the spectrum locus, whereas a source that emits broadband or full spectrum optical radiation will plot in the central region.

In many situations it is more important to have an accurate method for describing color difference than it is to have an accurate model of predicting absolute color appearance. For example, it is often desirable for lamps in architectural interiors to match in appearance since color differences between sources can be visually discordant. An important limitation of the CIE 1931 and 1964 chromaticity diagrams is that the same distance between a pair of coordinates does not correspond to the same amount of perceived color difference everywhere on the diagram.

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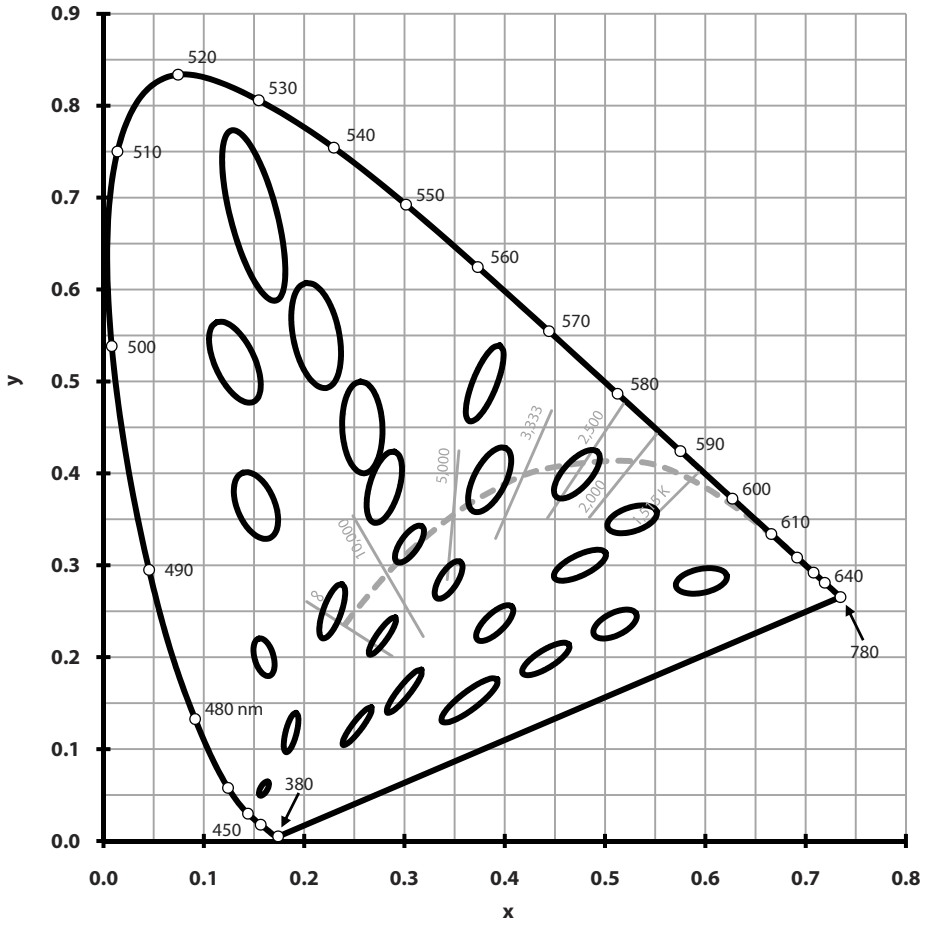


Figure 6.16 | MacAdam Ellipses
The CIE 1931 2° chromaticity diagram showing MacAdam ellipses enlarged by a factor of ten.

An ellipse can be established around a chromaticity coordinate that sets the boundary at which a given percentage of people are able to determine that two colors, one with chromaticity coordinates at the center of the ellipse and one with chromaticity coordinates on the ellipse are just noticeably different [9]. The ellipses change size over the diagram as illustrated in Figure 6.16. These MacAdam ellipses are employed to set color tolerances for some light sources [10].

That these boundaries are ellipses of different sizes means that the chromaticity diagram is not perceptually uniform: a uniform chromaticity space would bound color differences with circles of equal radii. Various transformations have been suggested that provide more uniform spacing.

6.2.2 More Nearly Uniformly Spaced Systems

Based on earlier work [11], the CIE adopted a Uniform-Chromaticity Scale (UCS) diagram in 1960. The computations of correlated color temperature may still employ this scale. The 1960 scale was modified and superseded in 1976 and is show in Figure 6.17. Both scales are produced by a simple linear transformation of chromaticity coordinates or tristimulus values. [7] [12] [13]

Both systems improve the relationship between perceived color difference and separating distance, but an important limitation of these and all chromaticity diagrams is the lack of perceptual uniformity as a function of lightness, or *luminous reflectance factor*. The achromatic properties of lightness, blackness and whiteness are important color attributes. For example, brown and orange may have the same chromaticity but they are perceived as different colors because they have different values for lightness. Achromatic characteristics

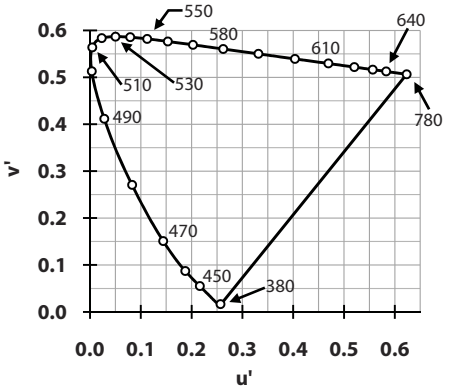


Figure 6.17 | u′ v′ Chromaticity Diagram
The CIE 1976 UCS diagram, which has more visually uniform spacing than the 1931 diagram shown inFigure 6.16.

Luminous Reflectance Factor The Y tristimulus value of the optical radiation reflected from an object, it is equivalent to the percentage of optical radiation that would be reflected, to that which would be reflected from a perfectly reflecting Lambertian surface.

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cannot be assessed from any chromaticity diagram because only two dimensions are represented, as previously illustrated in Figure 6.15. This is an inherent limitation that makes all two-dimensional chromaticity diagrams ill suited for characterizing color difference.

In 1976 the CIE recommended two new uniform color spaces, known as CIELUV and CIELAB, signaling the change from a chromaticity scale to a color space, and related to the change from two to three dimensions. The official terminology is the CIE 1976 L*, a*, b* space, with the official abbreviation CIELAB, and the CIE 1976 L*, u*, v* space, with the official abbreviation CIELUV [12]. The a* and u* coordinates are visually related to a redness-greenness perceptual dimension. The b* and v* coordinates are visually related to a yellowness-blueness perceptual dimension. The a*, b* and u*, v* dimensions are conceptually analogous to and can be derived from x, y chromaticity coordinates. The L* coordinate is an index of lightness. The CIELAB and CIELUV color spaces are therefore organized in a manner that is analogous to the opponent channels of human vision. Figure 6.18 is a schematic representation of CIELAB.

Although these color spaces provide more uniform representation of color differences and supersede the chromaticity scales for most purposes, the 1976 UCS diagram has been retained for the computation of the CIE color rendering indices.

6.2.3 Color Difference

Color-difference is computed within three dimensional color spaces that have approximately uniform visual spacing. CIELAB and CIELUV are examples of such spaces and color difference formulae are associated with both. The outputs from color-difference formulae include a single value that represents the perceptual difference between two colors. The equations can be applied to any spectral stimuli, whether from objects or illuminants.

Initially, color difference in these spaces was simply computed as Euclidian distance, designated ΔE^*_{ab} in the L*a*b* color space. Correlates for the subjective attributes of lightness, saturation, and hue can also be computed. Procedures for calculating these quantities are available elsewhere. [7] [12] [14] Subsequent refinements in 1994 and 2000 provided color difference values known as ΔE^*_{94} and ΔE^*_{00}. ΔE^*_{00} is the most accurate but also the most mathematically complex color difference formulation. The relevant CIE documents should be referenced for the systems of equations required to compute ΔE^*_{00} and for additional application considerations [14].

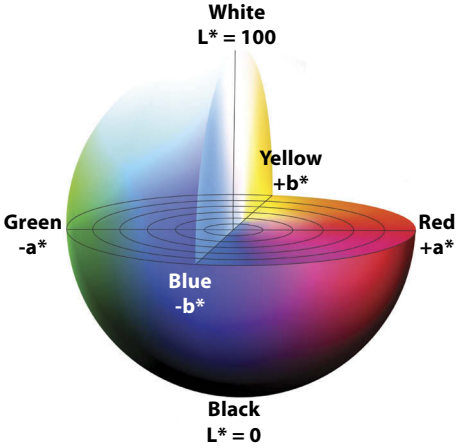


Figure 6.18 | CIELAB
Schematic representation of the CIELAB color space, also known as L*a*b*, illustrating the redness-greenness, yellowness-blueness, and lightness-darkness perceptual dimensions
» Image ©Konica Minolta Sensing Americas, Inc.

6.2.4 Dominant Wavelength, Excitation Purity, and Complimentary Dominant Wavelength

The use of dominant wavelength, excitation purity, and complimentary dominant wavelength is no long encouraged. They are defined here because they remain in common use—especially in the specification of colored LEDs—and because they are more suggestive of the color appearance of a light source or object than x, y chromaticity coordinates.

These quantities are derived from a chromaticity diagram by considering the optical radiation stimulus in relation to the spectrum locus and an assumed achromatic point. The assumed achromatic point for a light source, such as an LED, is often the chromaticity coordinates for an equal energy illuminant, but might also be blackbody radiation or a phase of daylight. The assumed achromatic point for objects is usually the point defined by the chromaticity coordinates of the light source that will be used to illuminate the object.

The dominant wavelength of all colors whose x, y coordinates fall on a straight line connecting the achromatic point with a point on the spectrum locus is the wavelength indicated at the intersection of that line with the spectrum locus. This is illustrated in Figure 6.19. For some colors, the straight line from the achromatic point through the

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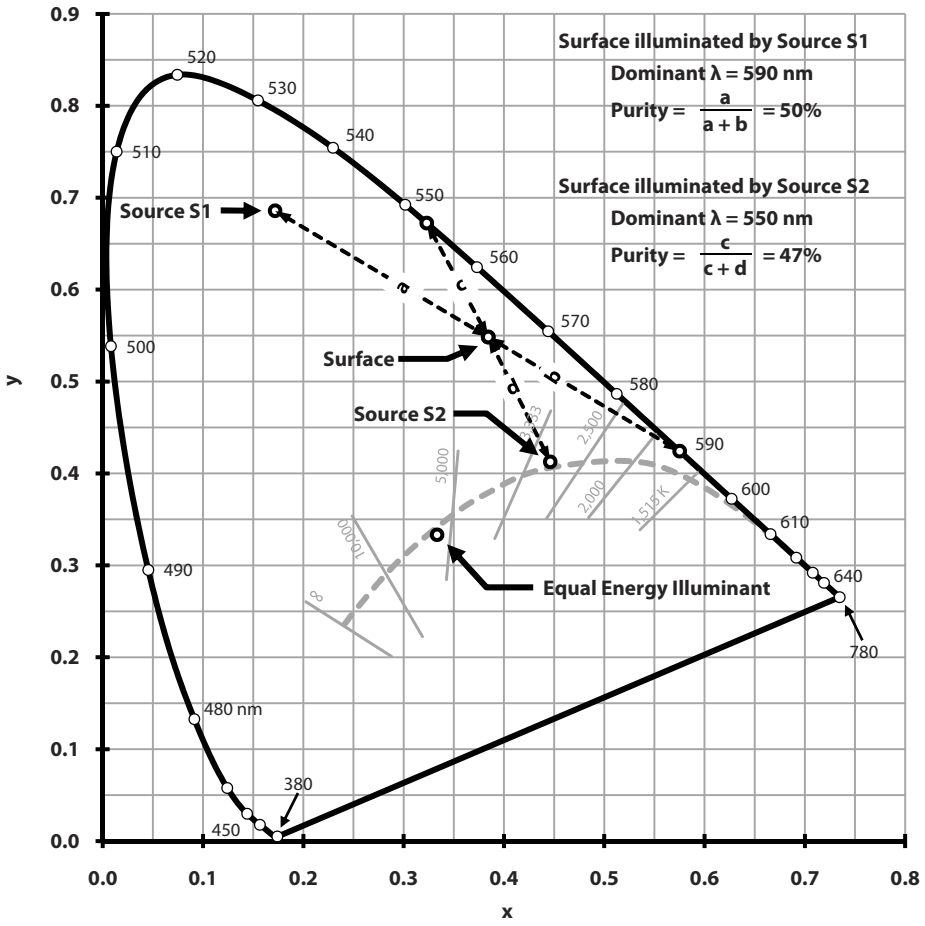


Figure 6.19 | Dominant Wavelength and Purity
The CIE 1931 2° chromaticity diagram illustrating the method of obtaining dominant wavelength and purity for a single surface under two different illuminants.

test chromaticity will strike the purple boundary rather than the spectrum locus. These colors do not have a dominant wavelength, but instead have a complimentary dominant wavelength, which is determined by extending the line backwards from the achromatic point. The point where the backward extended line strikes the spectrum locus determines the complementary dominant wavelength for such a color.

The excitation purity, sometimes simply called purity, is defined as the distance from the achromatic point to the chromaticity coordinates of the stimulus, divided by the total distance along the same line from the achromatic point to the spectrum locus or to the purple boundary. It is a unitless quantity from 0 and 1, or from 0 to 100 if expressed as a percent.

Excitation purity correlates somewhat with saturation. A monochromatic light source plots on the spectrum locus and has an excitation purity of 1.0. It follows that, for any given light source, the nearer the excitation purity is to 1.0, the more saturated the color will appear. Dominant wavelength correlates somewhat with hue. Light sources with different dominant wavelengths will have different hues. For example, dominant wavelengths of 450, 530, and 610 nm suggest blue, green and orange-red hues, respectively. Two sources with the same dominant wavelength may have different hues, particularly if a different achromatic point is used for each.

6.2.5 Color Temperature and Correlated Color Temperature

The spectrum of optical radiation, and therefore the apparent color, of a blackbody is solely dependent upon its temperature. See 1.4.4.1 Blackbody Radiation. The apparent color and temperature of a blackbody are linked and so the temperature of a blackbody

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can be used to describe the color appearance of a light source, said to be its Color Temperature. Blackbody temperatures are absolute temperatures, expressed in units of kelvin (K). A theoretical blackbody becomes yellowish white at 3000 K, white at 5000 K, bluish white at 8000 K, and deep blue at 60,000 K.

Color Temperature The absolute temperature (in units of kelvin, K) of a blackbody radiator having a chromaticity equal to that of the light source.

Blackbody Locus The locus of points on a chromaticity diagram representing the chromaticities of blackbodies having various color temperatures. Also known as the Planckian locus.

Color temperature can be related to the chromaticity diagrams previously discussed. The curve running through the center of Figure 6.14 is the *blackbody locus*, or blackbody curve. The blackbody locus represents the chromaticity for a blackbody radiator at different temperatures, some of which are labeled. The values for the x chromaticity coordinate are largest for the rightmost portion of the blackbody locus, where the blackbody temperature is low. A large value for x means that the long-wavelengths are dominant, which corresponds to color appearances that are reddish and visually warm. Moving left along the locus corresponds with increasing blackbody temperatures and to changes in the visual appearance of the blackbody, from pale-red to orange-white, then to yellowish-white, and eventually to bluish-white. The far left point of the curve, labeled with the symbol for infinity, represents a deep blue color appearance. Low blackbody temperatures produce visually warm colors and high blackbody temperatures produce visually cool colors.

If the chromaticity for a light source falls exactly on the blackbody locus the appearance of that source can be specified with a specific color temperature, since at that temperature a blackbody emits optical radiation that produces a color matching that of the light source. However, in many cases an exact match of source and blackbody chromaticities is not possible and correlated color temperature (CCT) is used to describe the nearest visual match. CCT is the *absolute temperature* a blackbody has when it has approximately the same color appearance as the source. Like color temperature, CCT is also expressed in units of kelvins (K). Figure 6.20 is a magnified view of the central portion of the chromaticity diagram. It shows where some common light sources plot with respect to the blackbody locus. The straight lines are lines of constant CCT. As with Color Temperature, CCTs exhibit the same pairing of low temperatures with visually warm colors, and high temperatures with visually cool colors.

Absolute Temperature The temperature measured on the Kelvin scale in which the lowest limit of physical temperatures is assigned the value absolute zero. Also known as Thermodynamic Temperature.

Note that CCT usually has nothing to do with the surface temperature of an actual lamp or any of its components. Also note that CCT is a single number, intended to encapsulate something about the color appearance of a light source. Since color perception is multidimensional color information is being discarded.

Single number indices are convenient and expedient, but their inherent limitations should be acknowledged. Looking at the lines of constant CCT in Figure 6.20, for example, it can be observed that two light sources can have the same CCT but very different chromaticities. This means that two lamps with identical values for CCT may have very different color appearances. As an example of this phenomenon, the fluorescent lamp at point “D” and the metal halide lamp at point “E” both have a CCT of about 3000 K. Yet they will not match because they do not plot at the same point on the chromaticity diagram.

It is often desirable to match the color appearance of the light sources within a single architectural environment and in these cases CCT may be insufficient. A retail store, for example, may employ linear fluorescent lamps for general lighting, metal halide for accenting vertical displays, and LEDs within casework. In situations where lamp-to-lamp color appearance is a critical feature of the luminous environment it is prudent to create mock-ups. In this example, a mock-up would allow the owner to visually assess whether or not the differences would be acceptable within the overall retail strategy. As a practical matter, selecting lamps with matching CCTs (and high CRIs, see next section) are as good as can be expected if the design specification will be made without assessing samples or performing mock-ups.

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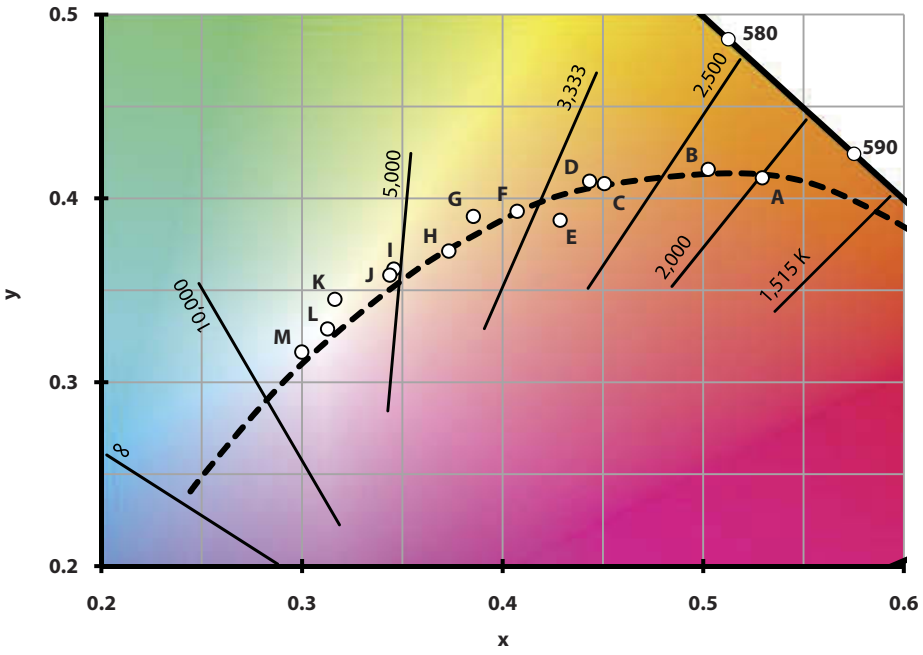


Figure 6.20 | CCT
Magnified view of the CIE 1931 2° chromaticity diagram diagram showing the region near the blackbody locus with isotemperature lines for CCT and the chromaticity coordinates for some light sources.
A = Clear high pressure sodium, 2000 K
B = High CRI high pressure sodium, 2200 K
C = Standard GLS incandescent, 2800 K
D = T8 triphosphor fluorescent, 3000 K
E = Ceramic metal halide, 3000 K
F = T8 triphosphor fluorescent, 3500 K
G = T8 triphosphor fluorescent, 4000 K
H = Ceramic metal halide, 4100 K
I = T12 fluorescent for color-evaluation, 5000 K
J = T8 triphosphor fluorescent, 5000 K
K = T8 triphosphor fluorescent, 6200 K
L = CIE D65, 6500 K
M = T12 fluorescent for color-evaluation, 7500 K

6.3 Color Rendition

When selecting architectural finishes and designing lighting systems so that people and objects look as expected, it is relevant to consider both the absolute color appearance of objects and how color might shift under different light sources. Though there are many ways to assess color rendering, it is most commonly characterized by assigning a single number index to a light source that is computed using CIE colorimetry.

6.3.1 CIE Test-Color Method

The CIE Test-Color Method rates lamps using indices of color rendering that represents the degree of resultant color shift of a test object under a test lamp in comparison with its color under a reference illuminant of the same CCT. The indices are based on a general comparison of the lengths of chromaticity-difference vectors in the 1964 UCS diagram. The rating consists of a general index, R_a or CRI, which is the mean of the special indices, R_i, for a set of eight test-color samples that are of moderate lightness and approximately equally spaced in hue. Figure 6.21 plots the eight test-color sample under one reference illuminant and illustrates the graphical basis for the computation. CRI is measured on a scale of 0-100. Lamps that render the eight test colors very similarly to the reference illuminant will have small chromaticity shifts and a high CRI. Conversely, lamps with a low CRI produce large chromaticity shifts when compared to the reference.

For lamps with a CCT below 5000 K, the reference is a blackbody radiator operating at the same color temperature. For lamps with a CCT equal to or greater than 5000 K, the reference is a mathematical model of daylight derived from measurements of the daylight spectrum. The daylight spectra used in the computation of CRI is reconstituted from daylight measurements made in Enfield, England; Rochester, NY; and Ottawa, Canada. The daylight spectrum is computed to be at the same CCT as the test light source. Tabulated spectral data are included in the CIE recommendations for blackbody radiators up to 5000 K, for the reconstituted daylight spectra from 5000 K to infinity, and for the eight general and six special test-color samples [15]. The six special test-color samples include four saturated colors, and one each representative of Caucasian skin and moderate green foliage. Table 6.5 provides their specification and schematic color representations. The colors shown are approximations and should not

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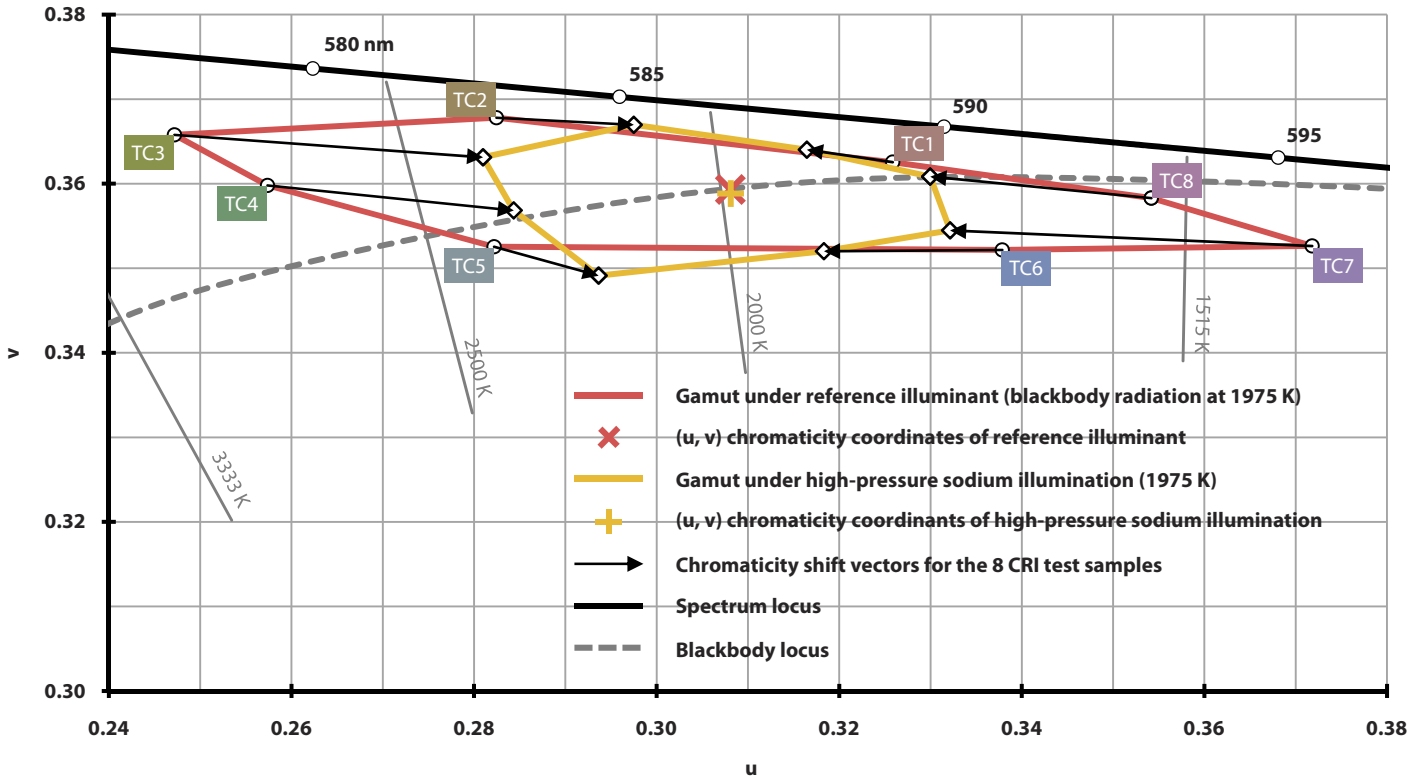


Figure 6.21 | Graphical Basis for CRI
Magnified view of the CIE 1960 2° uv chromaticity diagram diagram illustrating the chromaticity-shift magnitudes and directions for the eight CRI test color samples for the high pressure sodium lamp whose SPD is illustrated in Figure 6.2. This figure illustrates the the large chromaticity shifts and decreased gamut area associated with high pressure sodium illumination. Large chromaticity shifts are associated with poor CRI; this particular high pressure sodium illumination has a CRI of 16 and a CCT of 1975 K.

be used in place of actual samples. Definitive specifications are in terms of the SRD functions, provided in CIE 13.3 [15]. Of particular interest is R_9, which is a saturated red. Light sources with low values for R_9 are less likely to be accepted for general illumination. Since a lamp exhibiting a weak R_9 may still exhibit a high CRI, mock-ups are recommended. The CIE document should be referenced for the formulas and calculation process [15].

Because the reference illuminant for CRI changes with CCT, it is only valid to compare the CRI of different lamps if their CCT is similar. For example, a 6500 K daylight fluorescent lamp with a CRI of 84 should be expected to render objects differently than a 3000 K tri-phosphor fluorescent lamp with a CRI of 84. This occurs because the CRI for the 6500 K lamp was derived based on comparison to a model of daylight and the 3000 K lamp was compared against a blackbody. Even though both lamps in this example have a CRI of 84, the number has a different meaning for each lamp. Despite this restriction, lamps with a higher CRI are generally (but not always) better at making objects appear as expected. For example, common sense suggests that a 3000 K tri-phosphor fluorescent lamp with a CRI of 84 will render a broad array of colored objects better than a 2100 K high pressure sodium lamp with a CRI of 21.

6.3.2 Limitations of the CIE Test-Color Method

The CIE method of assessing the color rendering properties of illuminants was introduced in 1965 [16] and updated in 1974 [17]. The importance of adopting an easy and rational method for assessing color rendering properties of light sources is self evident, so despite the challenges and other readily available measures, the CIE method is the most utilized

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Table 6.5 | CIE Test Color Samples for the Computation of CRI

Test Color # (R_1-R_{14})	Munsell Notation	CIE Specification			ISCC-NBS Name	Approximate Appearance
		x	y	Y		
1	7.5 R 6/4	0.375	0.331	29.9	Light grayish red	
2	5 Y 6/4	0.385	0.395	28.9	Dark grayish yellow	
3	5 GY 6/8	0.373	0.464	30.4	Strong yellow green	
4	2.5 G 6/6	0.287	0.4	29.2	Moderate yellowish green	
5	10 BG 6/4	0.258	0.306	30.7	Light bluish green	
6	5 PB 6/8	0.241	0.243	29.7	Light blue	
7	2.5 P 6/8	0.284	0.241	29.5	Light violet	
8	10 P 6/8	0.325	0.262	31.5	Light reddish purple	
9	4.5 R 4/13	0.567	0.306	11.4	Strong red	
10	5 Y 8/10	0.438	0.462	59.1	Strong yellow	
11	4.5 G 5/8	0.254	0.41	20	Strong green	
12	3 PB 3/11	0.155	0.15	6.4	Strong blue	
13	5 YR 8.4	0.372	0.352	57.3	Light yellowish pink (Caucasian complexion)	
14	5 GY 4/4	0.353	0.432	11.7	Moderate olive green (leaf green)	

tool within the lighting community. Though a single number index is desirable for ease of use, it is unrealistic to expect any single number to fully characterize the multidimensional experience of color. Table 6.6 summarizes the primary limitations of CRI.

CRI does not reasonably characterize highly structured, narrow band spectra, like those from LEDs that rely on additive mixing from red, green, and blue components with narrow spectral emissions. CRI cannot correctly rank sources by color rendering when LEDs are included [18]. Mock-ups remain the recommended method of assessing lamp color rendering properties, particularly in color critical applications.

6.3.3 Other Methods for Assessing Color Rendition

Because of the limitations of the CIE method there have been ongoing efforts seeking alternative tools to characterize color rendition. Table 6.7 summarizes some of these; except for the CIE Test Color Method, none are endorsed by an institutional authority, but all can be considered to provide meaningful supplementary information about a light source's ability to render object colors. They may be especially useful in the spectral design of lamplight, where there is the need to model color rendition potential as part of the lamp design process. The references provide the numerical details for computing each index.

6.3.4 Recommendations on the use of Measures for Color Rendering

Despite the alternatives, CRI is the numerical tool most utilized within the lighting community for the assessment of color rendering. It was developed as a metric of 'naturalness' or 'fidelity' in comparison to rendering under incandescent or daylight. CRI should be used, but with the caveat that it provides only gross information about color rendering potential. No single number can fully encapsulate the multidimensional problem of color rendition [19].

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Table 6.6 | Limitations of the CIE Color Rendering Index (CRI)

Limitation	Explanation
Averaging the Color Shifts	CRI is computed by averaging the scores for test color samples 1 - 8. A light source can therefore attain an acceptable score even if one or more of the test sample colors are rendered poorly. CRI implies nothing about the rendering of any particular surface color unless CRI = 100. Caution should especially be exercised when specifying white light sources that employ narrow-emitting primary components, as with some LEDs, since they are more susceptible to rendering some color poorly.
Test-Color Samples	All of the test color samples have moderate saturation; none are highly saturated. As a result the color rendering of saturated colors can be poor even when CRI is high. Test color samples 9 - 12 are for saturated colors, but they do not contribute to the computation of the general CRI. This weakness can be especially acute when white light is created with narrow-emitting primary components, as with some LEDs.
Color Space	Chromaticity shifts are computed within the 1964 UCS chromaticity diagram, which is no longer recommended for any other use. The red region of this color space is particularly non-uniform, which is important since the faithful rendering of human complexions is dependent upon this spectral region. Other color spaces, such as CIE LAB or CIE LUV, could be employed.
Penalties for All Chromaticity Shifts	CRI always relates a pattern of chromaticity (for a set of test-color samples) under the test source to an archetypal pattern of chromaticity (for the same set of test-color samples) under the reference. This assumes that the pattern of chromaticity under the reference is ideal, which is not always, or even generally, true. In practical applications it has been shown that an increase in saturation is desirable, in comparison to reference illuminants, which is likely due to an increase in perceived brightness and improved color discrimination.
All CCTs are Treated Equally	The reference illuminants are defined to have a perfect CRI irrespective of CCT. This means that a very reddish blackbody (say, 2,000 K) and a very bluish daylight spectrum (say, 20,000 K) both have a CRI of 100, despite the fact that both will render objects in peculiar ways.
Dependence upon CCT	A different reference illuminant is used at each CCT, making it incorrect to compare the CRI of light sources that have different CCTs. An absolute scale that would allow comparisons between all light sources, irrespective of CCT, may be more desirable.
Chromatic Adaptation	Chromatic adaptation is accounted for with a Von Kries transform, which has been shown to perform poorly and is no longer recommended for any other use. The most recent CIE chromatic adaptation transform, CIE CAT02 could be employed.
Single Number Index	Single number indices for describing color rendering are both intrinsically useful and fundamentally flawed. Any measure of color rendering that reduces the multidimensional experience of color into a single value will discard information that may be important to a design professional.
Discontinuity at 5000 K	At 5000 K the reference illuminant changes from a blackbody to a phase of daylight. This is significant for anyone developing solid-state lighting with variable color temperature since the discontinuity is noticeable as the color temperature is varied through 5000 K. The typical engineering solution is to use the blackbody locus for all color temperatures. But this does not solve the problem with CRI: a 4999 K source with a CRI of 100 will receive a lower CRI simply by increasing its CCT to 5000 K.

Table 6.8 summarizes a wide range of colorimetric properties for common light sources, including values for many of the indices summarized in Table 6.6. The alternative measures for color rendition may be employed by design professionals to assess the listed lamps as part of schematic design. Use CCT, CRI, and the supplementary indices in Tables 6.6 and 6.7 to narrow choices, but mock ups are recommended to finalize specifications.

6.4 Materials Color Specification

The Munsell Color System, Natural Color System, and Color Card systems may be used in the specification of architectural materials. This includes the CMYK and the Pantone Matching System, both of which are employed primarily in the printing industry. All of these systems relate to the specification of colored objects, including architectural materials.

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6.4.1 Munsell Color System

The Munsell Color System specifies color on scales of hue, value, and chroma. The hue scale consists of 100 steps in a circle containing five principal and five intermediate hues. The value scale contains ten steps, with 0 corresponding to black and 10 to white. The chroma scale can contain 20 or more steps from neutral gray to highly saturated. Each of the three scales is divided so that increments represent equal visual intervals for a normal observer, fully adapted to daylight viewing conditions (CIE source C), with gray to white surroundings. Under these conditions the hue, value, and chroma of a Munsell specification correlate closely with the hue, lightness, and chroma of color perception.

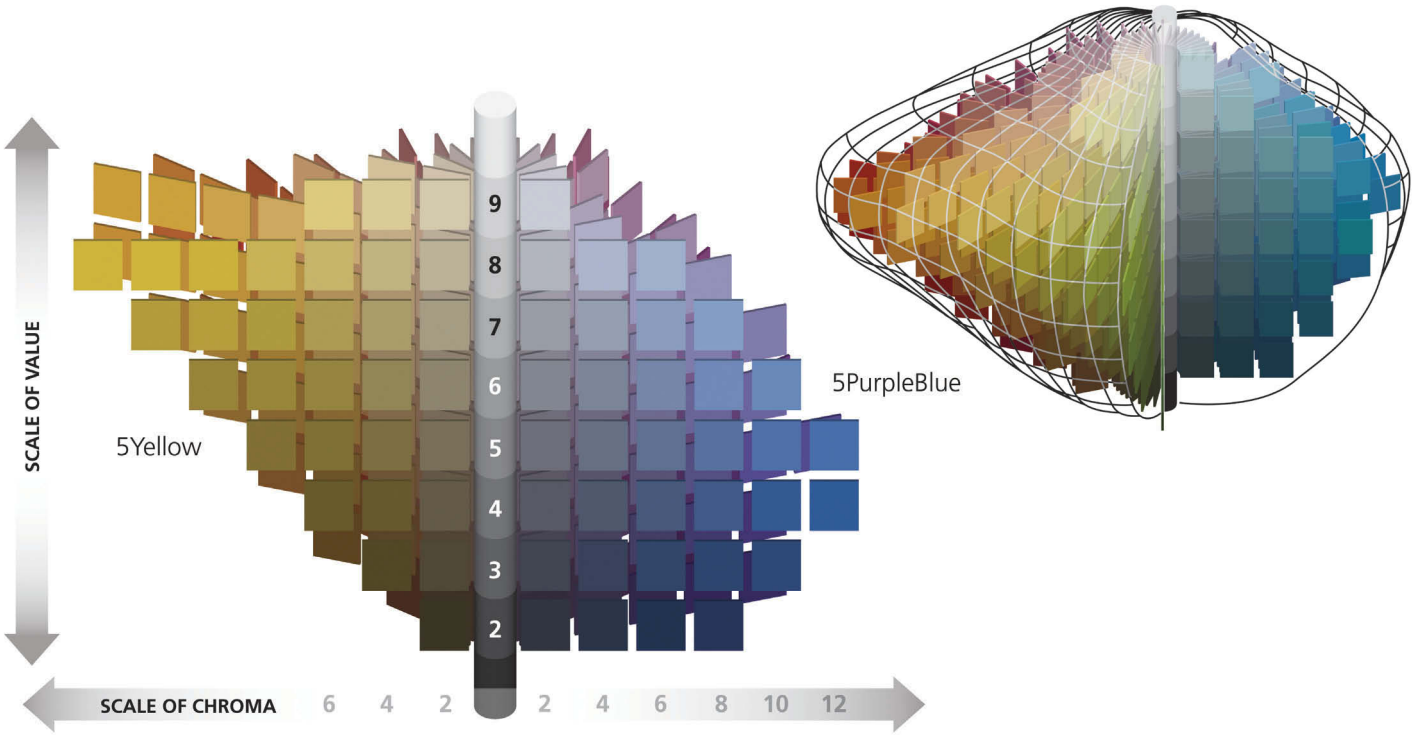
Munsell notation is useful whether or not Munsell samples are used. It has the form [hue] [value] / [chroma] as, for example, 5R 4/10 [32]. Colors of zero chroma, which are known as neutral colors, are written N1/, N2/, etc., as shown in Figure 6.22. One widely used approximation of visual equivalence between hue, value, and chroma units is 1 value step = 2 chroma steps = 3 hue steps (when the hue is at chroma 5).

The Munsell scales are exemplified by a collection of color chips that form an atlas of charts showing linear series for which two of the three variables are constant. Collections of carefully standardized color chips in matte and glossy finishes are commercially available [33]. Munsell colors have become standards in many industries and within several government agencies, including ANSI, NEMA, and USDA.

6.4.2 Relating Munsell Value to Reflectance

Munsell value is related to luminous reflectance as plotted in Figure 6.23. Luminous reflectance can also be approximated with the expression:

Figure 6.22 | Munsell Color Solid
Left: Cut-away view of the Munsell color solid showing notation scales of hue, value, and chroma. Right: A three-dimensional representation of the Munsell color tree.
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Table 6.7 | Indices of Color Rendition

Index	Symbol or Abbrev.	Method* R	G	S	M	Concept	Scale of Principal Index	Date	Author(s) [Institution]	Ref.
CIE Test Color Method	CRI, R_a	**R**				Rating of light sources that represents the mean resultant color shifts of 8 test-color samples under a test lamp in comparison with its color under a standard lamp of the same CCT, within the CIE 1964 UCS diagram.	0 - 100	1965 orig.; 1974 mod.; 1995 reaff.	[CIE]	[17]
Flattery Index	R_f	**R**				The human color preference for a select group of test-color samples has been considered in determining an ideal configuration of chromaticity coordinates. The pattern takes into account desirable shifts in hue and saturation. 14 test-colors are considered with unequal weighting. The test-color that simulates Caucasian complexion is weighted most heavily.	0 - 100	1967	D. Judd [NBS, precursor to NIST]	[20]
Color Discrimination Index	CDI		**G**			A higher CDI is associated with a larger gamut in the 1960 UCS diagram. The gamut is normalized to 100 based on CIE illuminant C.	0 - 100	1972	W. Thornton [Westinghouse]	[21]
Color Preference Index	CPI	**R**				Conceptually similar to R_f in that it credits light sources for rendering an array of test-color samples in desirable ways. Unlike R_f, it equally weights the 8 test-colors that contribute to the index.	0 - 156	1974	W. Thornton [Westinghouse]	[22]
Pointer's Index	--	**R**			**M**	This is a special application of Hunt's 1982 color appearance model. It yields 15 intermediate parameters related to hue, chroma, and lightness. The composite index is an average of the intermediate parameters. This is a reference-based index, but any illuminant can be used as the reference.	0 - 100 (the ref. is user defined, but always has a value of 100)	1986	M. Pointer	[23]
Color Rendering Capacity	CRC		**G**			Quantifies color rendering potential based on the number of object colors a light source can theoretically render. The measure is related to the volume of a color solid that is computed in the CIELUV color space.	0.0 - 1.0	1993	X. Hu	[24]
Feeling of Contrast Index	FCI		**G**			Computes the gamut of 4 highly-saturated test-sample colors (red, green, blue, yellow) in CIELAB color space. The area of the gamut is compared to the area of the gamut produced by D65.	D65 is set to 100, values higher and lower are	1993	K. Hashimoto et al. [Matsushita Ltd.]	[25]
Cone Surface Area	CSA		**G**			The base of a cone is formed using the gamut of 8 test-color samples within the CIE 1976 UCS diagram. The height of the cone is determined from the chromaticity of the light source. The area of the cone is employed as a measure of color rendition.	--	1997	S. Fotios	[26]
Percent Deviation from Daylight	mm%Dxx			**S**		The SPD of the test light source is aggregated into 10 nm bins from 420-650 nm and the CCT of the test source is used to compute the equivalent CIE daylight spectrum, denoted by Dxx. The percentage displacement around the Dxx spectrum that contains all of the binned output levels of the light source is then found, with some exclusions for spectral spikes. The percentage displacement necessary to achieve this is denoted by mm%.	0 - 100% (for each phase of daylight)	2004	D. Kirkpatrick [DARPA]	[27]

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Table 6.7 | Indices of Color Rendition (Continued)

Index	Symbol or Abbrev.	Method* R	G	S	M	Concept	Scale of Principal Index	Date	Author(s) [Institution]	Ref.
Full Spectrum Color Index	FSCI			**S**		A mathematical measure of how much a light source's spectrum deviates from an equal-energy spectrum. It is scaled so that the equal energy reference receives a score of 100, a warm white fluorescent receives a score of 50, and a monochromatic source receives a score of zero.	0 - 100	2004	M. Rea et al. [LRC]	[28]
Worthey's Index	--				**M**	This index is conceptualized around the opponent-colors model and includes parameters related to an illuminant's ability to realize red-green and blue-yellow contrasts. It is a theoretical model based on representing color rendition with matrix theory.	--	2004	J. Worthey	[29]
Color Quality Scale	CQS, NIST-CRI	**R**				Improves CRI by maintaining the same computational structure of the CIE Test Color Method, but updated to reflect advances in color science. There are 8 improvements that have strong theoretical underpinnings. However, they are incremental such that there is high correlation between CRI and QCS.	0 - 100	2005	W. Davis, Y. Ohno [NIST]	[30]
Harmony Rendering Index	R_{hr}	**R**			**M**	Like R_f and CPI, this index is concerned with the pleasantness of object coloration. Unlike these other measures, R_{hr} is based on the harmoniousness of test-color sample combinations, including 17 pairs and 5 triads, which are compared under test and reference illuminants. This is a reference-based index that employs the CIECAM02 color appearance model.	D65 and blackbody radiation are set to 100, values higher and lower are possible	2009	F. Szabó et al. [University of Pannonia]	[31]

***Key**

R Reference Based Method: A reference or series of references are defined to have perfect rendering, defined with a maximum value on the index, and test light sources are compared against the reference.

G Gamut Based Method: Based on the gamut created in a 2-dimensional chromaticity diagram or the volume created in a 3-dimensional color space, with reference to the rendering of a defined set of test-color samples. These measures are independent of CCT and therefore allow the comparison of sources that have different source appearances.

S Spectral Bands Method: Based on the idea that creating a spectrum identical to or very similar to a known spectrum that provides very good color rendering, such as an incandescent lamp or daylight, will also result in good color rendering.

M Method Based on Color Appearance Model: These methods employ a color appearance model as a component of the computation, thereby making use of the opponent colors model and advanced color spaces.

$$\rho = 0.547(MV)^3 + 0.4044(MV)^2 + 0.4694(MV) \qquad (6.2)$$

Where:

ρ = luminous reflectance
MV = Munsell value

In the Munsell color solid of Figure 6.22, the lightness dimension is vertical, along the scale of Munsell value, and ranges from black at the bottom to white at the top. Positions within the two dimensional CIE chromaticity diagram are related to Munsell perceived hue and to Munsell perceived chroma (or saturation). The chromaticity diagram represents colors that would be in one plane of the Munsell color solid.

A color with Munsell value 7 is called a light color, yet its reflectance is only 0.42. This is an important consideration for design professionals. Light walls, ceilings, and interior

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Table 6.8 | Colorimetric Properties for Some Lamps

Illuminant	Fig. 6.21 Label	Lamp Power (Watts)	Photopic Lumens	Scotopic Lumens	Luminous Efficacy (lm/Watt)	S/P	CIE 1931 2° (x, y) Chromaticity Coordinates		CIE 1960 2° (u, v) Chromaticity Coordinates	
							x	y	u	v
CIE D65	L	--	--	--	--	2.46	0.313	0.329	0.198	0.312
T8 "830" triphosphor fluorescent	D	32	2950	3746	92	1.27	0.443	0.409	0.252	0.350
T8 "835 triphosphor fluorescent	F	32	2950	4405	92	1.49	0.407	0.393	0.236	0.342
T8 "841" triphosphor fluorescent	G	32	2950	4790	92	1.62	0.385	0.390	0.223	0.339
T8 "850" triphosphor fluorescent	J	32	2950	5797	92	1.97	0.344	0.358	0.208	0.325
T8 "865" triphosphor fluorescent	K	32	2800	6143	87	2.19	0.316	0.345	0.194	0.318
T12 fluorescent for color evaluation, 5000 K	I	40	2200	4440	55	2.02	0.346	0.362	0.208	0.326
T12 fluorescent for color evaluation, 7500 K	M	40	2000	4981	50	2.49	0.300	0.316	0.194	0.306
GLS incandescent	C	60	860	1198	14	1.39	0.451	0.408	0.258	0.350
Clear high pressure sodium	A	100	9500	5686	95	0.60	0.529	0.411	0.308	0.359
Ceramic metal halide, 3000K	E	100	8600	11892	86	1.38	0.429	0.388	0.252	0.342
Ceramic metal halide, 4100K	H	100	8200	14821	82	1.81	0.373	0.371	0.222	0.332
High pressure sodium, high CRI	B	100	7300	6140	73	0.84	0.502	0.416	0.288	0.357

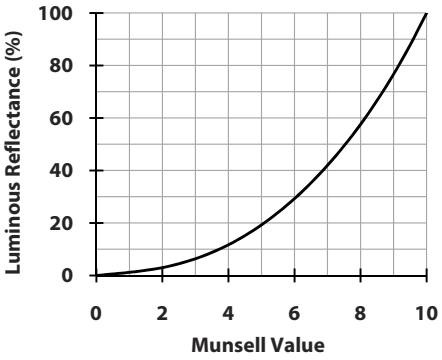


Figure 6.23 | Munsell Value and Luminous Reflectance
Munsell Value for matte surfaces can be related to reflectance using this graph or with Equation 6.1. It is especially useful for determining reflectance values for use in computer models when Munsell Value is known or can be approximated.

furnishings, whether neutral or chromatic, are much more efficient than dark surfaces in distributing optical radiation. Unless all the colors in the color scheme of a room layout are very light, well over 50% of the optical radiation incident upon the surfaces will be absorbed. If value-5 colors are used, as much as 80% of the incident optical radiation will be absorbed.

With practice in the use of a Munsell value scale, particularly the special set of Munsell scales developed for lighting and interior designers, Munsell values can be estimated rather accurately and converted to luminous reflectance by means of Figure 6.23 or Equation 6.2. These reflectances can then be used for lighting calculations, most commonly to set values for surface reflectance within lighting design software.

Since the luminous reflectance of colored objects differs in accordance with the SPD of the light sources, many sets of Munsell scales for judging reflectance have the reflectances of each sample given for three light sources: CIE A at 2856 K, cool white fluorescent at 4300 K, and CIE D65 at 6504 K.

6.4.3 Other Color Specification Systems

6.4.3.1 Color Cards

Color cards are primarily used by the paint industry as communication tools between the paint manufacturer and the consumer or designer. Color cards are organized samples of the available colors, where each color card sample has a corresponding formula for producing the paint.

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CIE 1976 2° (u', v') Chromaticity Coordinates		CCT [13]	CRI [15]	Flattery Index [20]	Color Preference Index [22]	Color Discrimination Index [21]	Color Rendering Capacity [24]	Cone Surface Area [26]	Pointer's Index [23]
u'	v'								
0.198	0.468	6503	100	89	101	96	0.993	0.058	100
0.252	0.524	2929	85	85	102	56	0.522	0.030	76
0.236	0.512	3476	86	86	104	70	0.637	0.038	77
0.223	0.508	3966	84	84	99	74	0.693	0.041	78
0.208	0.488	5070	87	85	106	90	0.835	0.052	80
0.194	0.477	6222	85	84	102	92	0.829	0.056	96
0.208	0.490	5008	90	86	97	84	0.858	0.049	81
0.194	0.460	7420	93	88	101	99	0.994	0.061	98
0.258	0.525	2815	100	89	101	51	0.609	0.028	76
0.308	0.538	1965	16	23	-20	13	0.215	0.009	62
0.252	0.514	2994	87	81	91	65	0.675	0.034	76
0.222	0.498	4166	92	88	100	81	0.853	0.045	80
0.288	0.536	2234	63	61	52	27	0.380	0.016	70

6.4.3.2 CMYK

CMYK (Cyan, Magenta, Yellow, Key (black)). It is a printing process colloquially referred to as four-color or process printing. The CMYK process works by subtractive color mixing and halftoning. The semi-transparent properties of the CMYK inks allow for the perception of full color continuous tone imagery.

6.4.3.3 Pantone Matching System (PMS)

The PMS is a proprietary color space intended to allow designers to specify color matches during the design stage independently from the equipment that will be used to produce the color. The PMS has been widely adopted by graphic designers and the reproduction and printing industries. Based on 14 basic inks, the system can represent more than 1,100 solid colors.

6.4.4 Safety Colors

Safety colors are used to indicate the presence of a hazard or safety facility such as an explosive hazard or a first aid station. These are carefully developed colors that are specified in ANSI Z531-2006 American National Standard for Safety Colors [34]. The background around these safety colors should be kept as free of competing colors as possible, and the number of other colors in the area should be kept to a minimum. These colors should be illuminated by a light source to levels that both will permit positive identification of the color and the hazard or situation that it identifies and will not distort it and thereby obscure the message it conveys.

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The Munsell notations and CIE specifications for safety red, orange, brown, yellow, green, blue, purple, white, gray , and black are given in the ANSI standard cited above. The specifications are based on illumination with CIE Standard Illuminant C, which is a daylight simulator at 6774 K. When lighting safety color surfaces and the surrounding areas it is important to use light sources that do not result in large color shifts. The colors will generally be recognizable under conventional fluorescent lamps, but some high intensity discharge sources will cause unacceptable color shifts. This may be especially problematic in environments with 5 lx and lower, which are not uncommon in industrial spaces. Color tolerance charts showing the safety colors and their tolerance limits are commercially available [35].

6.5 Digital Color Specification

The color specification systems described in this section are not applicable to color in architectural interiors, but are relevant to the realistic display of computer generated graphics to communicate design concepts.

6.5.1 RGB

The RGB (red, green, blue) color model is a generic additive color model that makes use of red, green, and blue primaries, which are mixed in various proportions to reproduce a broad array of colors. The RGB model is used primarily with electronic display systems using technologies such as phosphors, LEDs, liquid crystal displays (LCDs), digital light process-

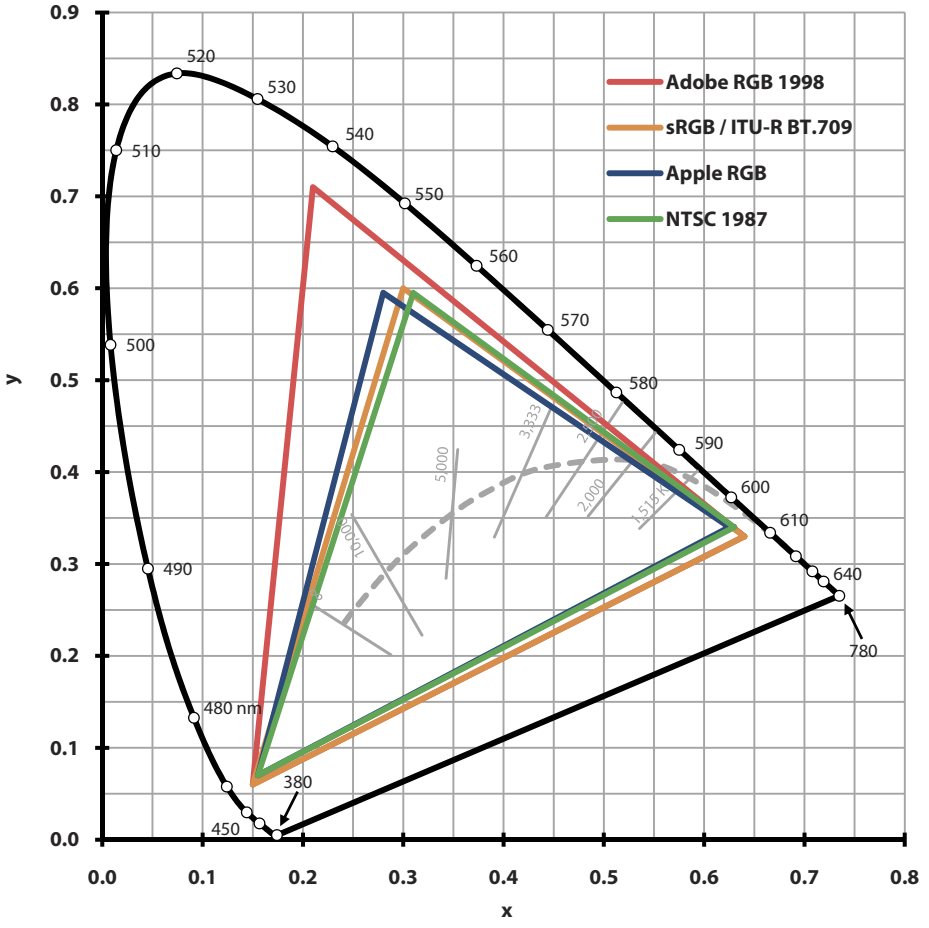


Figure 6.24 | RGB Primary Sets
The CIE 1931 2° chromaticity diagram diagram with primary sets for common display standards.

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ing (DLP), and liquid crystal on silicon (LCoS). RGB is a *device-dependent* color model, so different devices will reproduce a given set of RGB values differently. The use of three primaries is not sufficient to reproduce all colors. Only those within the triangle defined by the chromaticities of the primaries can be reproduced. Figure 6.24 illustrates several primary sets, each establishing its own color triangle and thus demonstrating device dependence.

Device-Dependent When different devices (e.g. laptop display, LCD projector, color printer) reproduce color differently the color specification or color model is said to be device-dependent.

Computer monitors are color additive, RGB devices, while color printers typically use CMYK printing subtractive color mixing. This partially accounts for the difficulty of (inexpensively and easily) matching color between on-screen and printed media. See 6.7 Color Space Conversions.

6.5.2 HSL and HSV

HSL (Hue, Saturation, Lightness) and HSV (Hue, Saturation, Value) are device-dependent systems used to represent colors in a cylindrical-coordinate three-dimensional RGB color space. Figure 6.25 illustrates both.

The HSV space can be visualized as an inverted cone with black at the apex, white at the center of the base, and neutral grays along the axis, which is the value dimension. Hues are positioned around the axis. In some cases the base is a hexagon and red, yellow, green, cyan, blue, and magenta are placed at its vertices. Saturation, or more precisely, chroma, is represented by the distance from the axis on a cross section of the cone. The HSL space can be visualized as a double cone, with black and white at the opposite apexes, and hues positioned as in the HSL system. Saturation is operationally different in the HSL and HSV color spaces.

The HSL and HSV color models are usually used in software as a two-dimensional hue picker, presenting an array of the colors on a particular cross-section (value/lightness) that is chosen by the user.

6.5.3 sRGB

Hewlett-Packard and Microsoft created sRGB (standard Red, Green, Blue) as a *device-independent* RBG color space for digital devices such as monitors, printers, and the Internet [36]. sRGB was designed to handle color in the operating systems, device drivers, the Internet, as well as in peripheral devices such as digital cameras and scanners. It utilizes primaries from high definition television (HDTV), thus creating a color space spanning a wide array of digital technologies. [37] [38] This color space defines and limits the realistic display of computer generated graphics. The sRBG primaries are plotted on Figure 6.24.

Device-Independent When the color specification is universal, such as a paint color specification that could be reproduced by different vendors, it is said to be device independent.

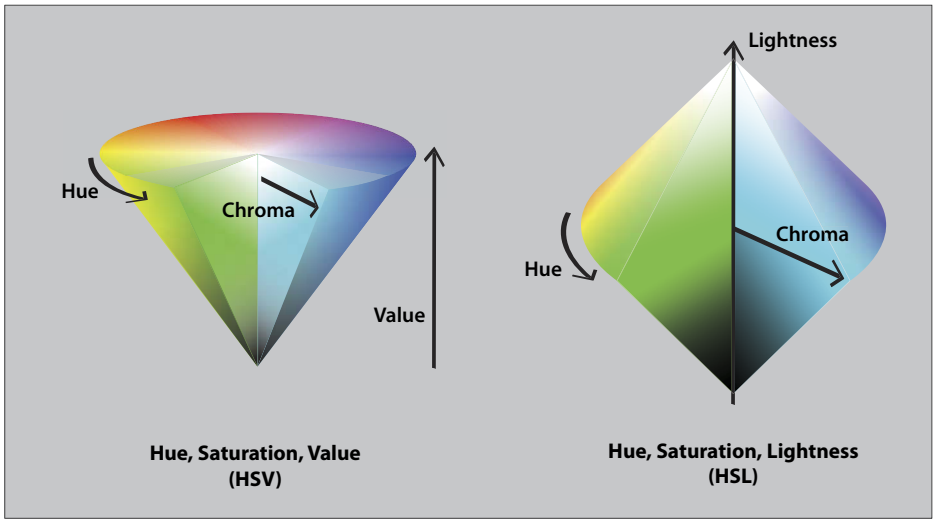


Figure 6.25 | HSL and HSV
Schematic representations of HSV (left) and HSL (right) color spaces. Sometimes "chroma" is labeled as "saturation", which is accurate when illustrating a two-dimensional slice at a constant value, but deceptive for the three-dimensional representations shown here since saturation varies with both chroma and lightness/value.

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6.6 Color Appearance

The term color appearance is used to describe the gestalt effect of the optical radiation spectra entering the visual system, in both space and time, on the resulting perception of color. Color appearance is dependent upon the state of chromatic adaptation, the geometric context for the object being viewed, including the background and surrounding surfaces, the absolute luminance levels within the field of view, and other aspects of the optical radiation stimulus and the cognitive attributes of the observer.

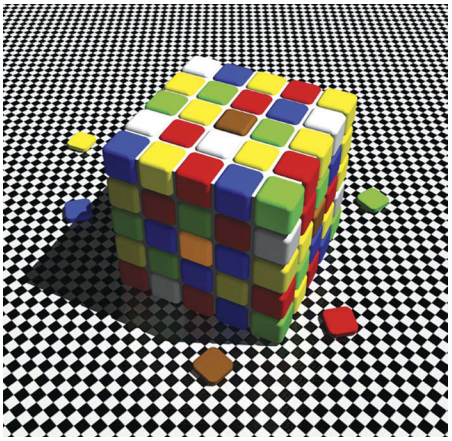


Figure 6.26 | Simultaneous Brightness Contrast
The middle square on the front and top faces have the same chromaticity (x, y) and luminous reflectance factor (Y), yet they appear as different colors.
» Image ©R. Beau Lotto

Figure 6.26 illustrates simultaneous brightness contrast, one type of color appearance phenomena. The central squares on the top and shadowed sides of the cube have the same chromaticity and luminance, yet one appears orange-yellow and the other brown; illustrating how numerical measures can fail to capture human perceptions. Table 6.9 summarizes color appearance phenomena and their relevance to lighting.

6.6.1 Color Appearance Models

Color appearance models (CAMs) endeavor to characterize the multidimensional experience of color by accounting for complex stimulus conditions, perception, and cognition. Color appearance models at least characterize lightness, chroma, and hue. More complex models also characterize brightness and colorfulness.

The current CIE CAM model [14] uses as input: relative tristimulus values of the test stimulus; adaptation luminance; relative tristimulus values of the adaptation luminance; relative luminance of the surround; and whether or not discounting-the-illuminant is likely to take place. From these, the model determines: lightness, brightness, chroma, colorfulness, saturation, and hue. Other CAMs have been defined [39].

6.7 Color Space Conversions

Translating color from one device to another is a common requirement, such as converting RGB video coordinates to a printed CMYK specification, or matching colors of a projected image to those on a laptop screen. The difficulties and details of cross-media matching are numerous [40] [41], but the principal factors that make these conversions difficult are differences in colorimetric characterizations, the chromaticity of the primaries, and the number of primaries.

Color Management Systems (CMS) A system comprised of measurement devices and/or software to control color representation, sometimes across various media, such as from a computer display to printed paper.

Converting between and matching color among different displays and/or media is referred to as device independent color encoding, which is embodied in *color management systems (CMS)*. The most recent International Color Consortium (ICC) specification of a CMS is an ISO Standard and defines a reference medium [42] [43]. A reference medium is required since tristimulus value equality does not guarantee color appearance equality, as with a self-luminous computer screen and a sheet of paper. They appear different even when exhibiting the same tristimulus values. Thus, color appearance models have become a central part of color management systems.

White Point a set of tristimulus values or chromaticity coordinates that serve to define the color white in a digital image or digitally reproduced image.

One task faced by lighting designers may be to realistically model a physical environment on a computer. In this situation it may necessary to convert CIE tristimulus values of building objects to RGB values. The matrices required to perform such a conversion depend upon both the triangle of chromaticity coordinates for the screen phosphors and the specified *white-point* chromaticity. It is also important to know how the visualization software renders RGB values, and to recognize that the RGB values will define the material's reflectance value.

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Table 6.9 | Key Color Appearance Phenomena

Phenomenon	Basic Concept	Relevance to Lighting
Chromatic Adaptation	The sensory process by which the visual system preserves the color appearance of an object under a wide range of light sources. It occurs because the L, M, and S cones have independent sensitivity control. Full chromatic adaptation takes about 2 minutes.	Higher CCT light sources contain proportionally more short wavelength energy than lower CCT light sources. When an environment is illuminated exclusively with just one type of light source the occupants will become desensitized to the differences. The S cones become relatively less sensitive under high CCT light sources and the L cones become relatively less sensitive under low CCT light sources. When multiple types of light sources are used, as with daylight from windows and overhead fluorescent lighting, there is mixed chromatic adaptation and transient chromatic adaptation.
Discounting the Illuminant	Chromatic adaptation is perceived to be complete under a wide range of viewing conditions, yet the sensory mechanisms cannot entirely account for this perception. Discounting the illuminant refers to the cognitive ability of an observer to interpret object color in the way that it is expected to appear based on experience and knowledge about the objects, lighting, and visual environment.	An observer's cognitive ability to discount the illuminant tacitly undermines the tenability of reference-based metrics for color rendering, such as CRI, especially those metrics that are not tied to CCT. This is especially true when considering objects that have an expected color appearance, either from memory or context.
Helmholtz-Kohlrausch effect	It is often erroneously assumed that brightness and luminance are directly related, but this is not so. The perceptions of brightness and lightness depend upon both luminance and chromaticity. See Figure 6.27.	It is possible to increase the perception of brightness at constant luminance by choosing a light source or surface finishes that are more chromatic. This can explain why highly colored environments, such as those illuminated with narrow-emitting LEDs, appear bright despite the fact that measured photometric quantities are low.
Hunt Effect	The colorfulness of chromatic objects increases with luminance (even though chromaticity remains unchanged).	When designing an environment for low light levels highly saturated surface colors will be required in order to create a colorful environment. Conversely, when an environment is designed for high light levels, relatively less saturated surface colors can be used to create an environment that is perceived to be colorful.
Stevens Effect	Brightness or lightness contrast (but not luminance contrast) increases with increasing luminance. Said another way, as luminance increases dark colors will appear darker and light colors will appear lighter.	High contrast is desirable on visual tasks, such as reading print; the Stevens effect provides a rationale for increasing luminance in order to enhance perceived contrast. High contrast is often undesirable within the field of view, such as between windows and walls within working interiors; the Stevens effect provides a rationale for reducing the luminance contrast in such situations.
Purkinje Effect	The peak sensitivity of the visual system shifts toward shorter wavelengths as luminance levels decrease.	Lighting design has historically employed photopic photometric quantities, which are based on a light-adapted visual system. The nighttime lighting of roadways and parking lots are often at levels within the mesopic range, where the Purkinje effect is real and perceptible. See Section 4.12 | An Illuminance Determination System for guidance on how to account for this in setting target illuminances.

Mapping luminance or RGB values into a perceptually-uniform domain is called gamma correction. The goal is to optimize the perceptual performance of the limited resolution of the specification of the red, green, and blue components of a device [44].

Lighting design and analysis software that produces renderings often implicitly assumes a lamp color temperature is 6500 K, corresponding to the default monitor white-point. A lower lamp color temperature can influence the amount of interreflected optical radiation between strongly chromatic surfaces. In addition, the software usually does not model the color shifts due to chromatic adaptation. It is incorrect to simply adjust the color balance of the rendering as is sometimes done.

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Figure 6.27a | Helmholtz-Kohlrausch Effect: Chromaticity-based Quantification
The CIE 1964 10° chromaticity diagram showing loci of constant brightness to luminance ratios.

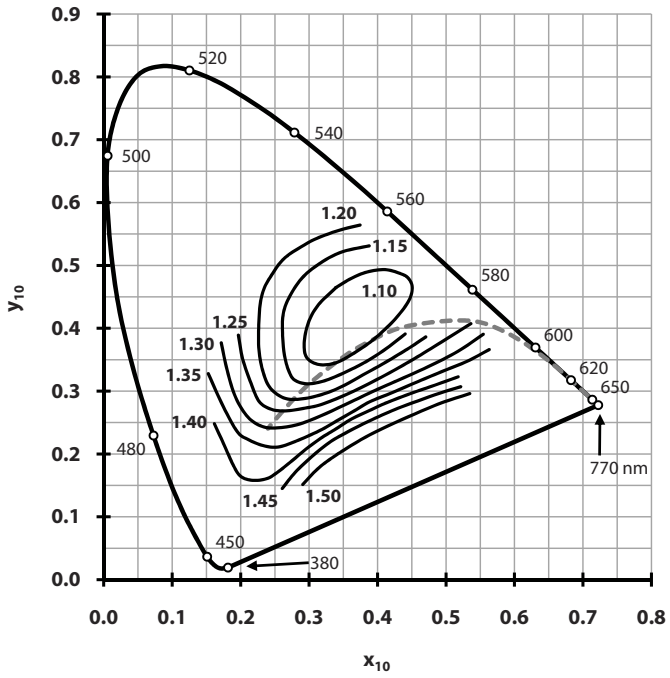


Figure 6.27b | Helmholtz-Kohlrausch Effect: Lighting Design Example
An exemplification of the Helmholtz-Kohlrausch Effect at the Detroit Metropolitan Airport passenger tunnel, which employs saturated LEDs as the sole source of direct, indirect, general and accent lighting. Photometric quantities such as illuminance are low, yet the experience of brightness is not.
» ©SmithGroup.



6.8 References

[1] Billmeyer FW Jr. 1994. Metrology, documentary standards, and color specifications for fluorescent materials. Color Res. Appl. 19(6):413-425.

[2] CIE 38. 1977. Radiometric and photometric characteristics of materials and their measurement. Vienna, Austria: Commission Internationale de l'Éclairage.

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[3] Hubbe MA, Pawlak JJ, Koukoulas AA. (2008) Paper's appearance: a review. BioResources. 3(2):627-665.

[4] Wright WD. 1928-1929. A re-determination of the trichromatic coefficients of the spectral colours. Trans. Opt. Soc. London. 30:141-164.

[5] Guild J. 1931. The colorimetric properties of the spectrum. Philos. Trans. Roy. Soc. London, Series A. 230:149-187.

[6] Hu X, Houser KW. 2006. Large-field color matching functions. Color Res. Appl. 31(1):18-29.

[7] Schanda J. editor. 2007. Colorimetry: understanding the CIE system. Hoboken, NJ: Wiley Interscience. 459 p.

[8] ASTM E308-08. 2008. Standard practice for computing the colors of objects by using the CIE system. West Conshohocken, PA: ASTM International. 34 p.

[9] MacAdam DL. 1942. Visual sensitivities to color differences in daylight. J. Opt. Soc. Am. 32(5):246-274.

[10] ANSI. 2001. ANSI C78.376-2001. American National Standard for electric lamp –specifications for the chromaticity of fluorescent lamps. Rosslyn, VA: National Electrical Manufacturers Association.

[11] MacAdam DL. 1937. Projective transformations of ICI color specifications. J. Opt. Soc. Am. 27(8):294-299.

[12] CIE 15:2004. Colorimetry, 3rd edition. Vienna, Austria: Commission Internationale de l'Éclairage. 79 p.

[13] Wyszecki G, Stiles WS. 1982. Color Science: Concepts and Methods, Quantitative Data and Formulae, 2nd ed. 968 p.

[14] CIE 142:2001. 2001. Improvement to industrial colour-difference evaluation. Vienna, Austria: Commission Internationale de l'Éclairage. 15 p.

[15] CIE 13.3. 1995. Method of measuring and specifying colour rendering properties of light sources. Vienna, Austria: Commission Internationale de l'Éclairage. 20 p.

[16] CIE 13 1974. Method of measuring and specifying colour rendering properties of light sources. Vienna, Austria: Commission Internationale de l'Éclairage.

[17] CIE 13.2 1965. Method of measuring and specifying colour rendering properties of light sources. Vienna, Austria: Commission Internationale de l'Éclairage.

[18] CIE 177. 2007. Colour rendering of white LED light sources. Vienna, Austria: Commission Internationale de l'Éclairage. 14 p.

[19] Guo X, Houser KW. 2004. A review of colour rendering indices and their application to commercial light sources. Lighting Res. Technol. 36(3): 183-199.

[20] Judd DB. 1967. A flattery index for artificial illuminants. Illum. Eng. (USA). 62: 593-98.

[21] Thornton WA. 1972. Color-discrimination index. J. Opt. Soc. Am. 62(2):191-94.

[22] Thornton WA. 1974. A validation of the color preference index. J. Illum. Eng. Soc. 4:48-52.

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[23] Pointer MR. 1986. Measuring colour rendering—a new approach. Lighting Res. Technol. 18(4):175-84.

[24] Xu H. 1993. Colour rendering capacity and luminous efficiency of a spectrum. Lighting Res. Technol. 25(3):131-32.

[25] Fotios SA. 1997. The perception of light sources of different colour properties. PhD thesis. Manchester, United Kingdom: UMIST.

[26] Kirkpatrick DA. 2004. Is solid-state the future of lighting? Third international conference on solid state lighting. Proc. SPIE. 5187:10-21.

[27] Rea M, Deng L, Wolsey R. 2004. NLPIP lighting answers: lighting sources and color. Troy, NY: Rensselaer Polytechnic Institute.

[28] Worthey JA. 2004. Color rendering: a calculation that estimates colorimetric shifts. Color Res. Appl. 29(1):43-56.

[29] Davis W, Ohno Y. 2005. Toward an improved color rendering metric. Fifth international conference on solid state lighting. Proc. SPIE. 5941:1-8.

[30] Hashimoto K, Yano T, Shimizu M, Nayatani, Y. 2007. New method of specifying color-rendering properties of light sources based on feeling of contrast. Color Res. Appl. 32(5):361-371.

[31] Szabo F, Bodrogi P, Schanda J. 2009. A colour harmony rendering index based on predictions of colour harmony impression. Lighting Res. Technol. 41(2):165-182.

[32] ASTM D1535-08 Standard practice for specifying color by the Munsell system. West Conshohocken, PA: ASTM International. 45 p.

[33] X-Rite, Inc. [homepage on the Internet]. Grand Rapids (MI): X-Rite, Inc.; c2010 [cited 2010 Jun 30]. Available from: http://www.xrite.com/home.aspx

[34] ANSI Z535.1-2006. 2006. American National Standard for safety colors. Rosslyn, VA: National Electrical Manufacturers Association.

[35] Hale Color Charts Int'l. [homepage on the Internet]. Naples (FL): Hale Color Charts Int'l. [cited 2009 Jun 4] Available from: www.halecolorcharts.com.

[36] Stokes M, Anderson M, Chandrasekar S, Motta R. 1996. A standard default color space for the Internet-sRGB, version 1.10. [Internet]. [cited 2009 Jun 23]. Available from: http://www.w3.org/Graphics/Color/sRGB

[37] ITU-R BT.709-5. 2002. Parameter values for the HDTV standards for production and international programme exchange. Geneva, Switzerland: International Telecommunication Union.

[38] IEC 61966-2-1. 1999. Multimedia systems and equipment, colour measurement and management, part 2-1: colour management, default RGB colour space, sRGB, 1st ed. Geneva, Switzerland: International Electrotechnical Commission.

[39] Fairchild, MD. Color appearance models, 2nd ed. West Sussex, England: John Wiley & Sons, Ltd. 408p.

[40] Green P, MacDonald L. editors. 2002. Colour engineering: achieving eevice independent colour. Wiley series in display technologies. Chichester, England: John Wiley & Sons, Ltd. 282 p.

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[41] Pharr M, Humphreys G. 2004. Physically based rendering: from theory to implementation. The Morgan Kaufmann series in interactive 3D technology. San Francisco, CA: Elsevier. 1042 p.

[42] ISO 15076-1:2005. Image technology colour management–architecture, profile format and data structure–part 1: based on ICC.1:2004-10. Geneva, Switzerland: ISO Central Secretariat.

[43] Berns RS. 2000. Billmeyer and Saltzman's principles of color technology, 3rd ed. New York, NY: Wiley Interscience. 247 p.

[44] Poynton C. 1998. The rehabilitation of gamma. in: Rogowitz BE, Pappas TN editors. Human vision and electronic imaging III. proceedings of SPIE/IS&T conference 3299. San Jose, CA. Jan. 26–30, 1998. Bellingham, Washington: SPIE.

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7 | LIGHT SOURCES
TECHNICAL CHARACTERISTICS

If I find 10,000 ways something won't work, I haven't failed. I am not discouraged, because every wrong attempt discarded is another step forward.

Thomas Alva Edison, 18th and 19th century inventor, scientist, and businessman

This chapter is organized around the major families of light sources: daylight, filament, fluorescent, high intensity discharge (HID), and solid state lighting (SSL). It provides technical characteristics including the principles of operation, construction, identification, and operating characteristics for the most common sources and auxiliary gear now available. 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS emphasizes common design criteria related to source selection. Chapters 7 and 13 are together intended to facilitate the choice and specification of light sources. Fundamental information concerning the generation of optical radiation is given in 1 | PHYSICS AND OPTICS OF RADIANT POWER. Techniques for the measurement of optical radiation are provided in 9 | MEASUREMENT OF LIGHT: PHOTOMETRY.

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7.1 Daylight

Daylight is the most sustainable source of light for building interiors. The application of daylight as a primary source of illumination for buildings has expanded in recent years, with the increased focus on high performance and green building design. Implementation of daylighting in architectural spaces, however, is a challenging task due to its variability in both quantity and direction across time of day, season and weather conditions [1]. This section addresses the general nature of daylight as a light source, while Chapters 14 | DESIGNING DAYLIGHTING and 16 | LIGHTING CONTROLS address the architectural design and control integration aspects involved in daylighting a building.

Daylight is distinguished as a light source by its unique changing spectra and distribution. The daily and seasonal movements of the sun with respect to a particular geographic location produces a predictable pattern in both the amount and direction of the available daylight. Superimposed on this predictable pattern is variation caused by changes in the weather, temperature, and particulate matter in the air. The source of all daylight originates with the sun, however in daylighting design, the sun and sky are generally considered as distinct sources because they have very different characteristics, as described below.

7.1.1 The Sun

The solar disk is roughly one-half degree in diameter, with a luminance prior to atmospheric attenuation of approximately 1.6×10^9 cd/m^2 [2]. This extreme luminance and the sun's output in the non-visible portion of the electromagnetic spectrum are capable of causing permanent physical damage to the eye if viewed directly. If allowed to enter a building, the primary concern is glare caused either by a direct view of the sun, or by the high luminance patterns it creates.

The sun traverses an arc across the sky throughout the course of a day, with the position of this arc varying with time of year and site latitude [3]. The apparent motion of the sun along this

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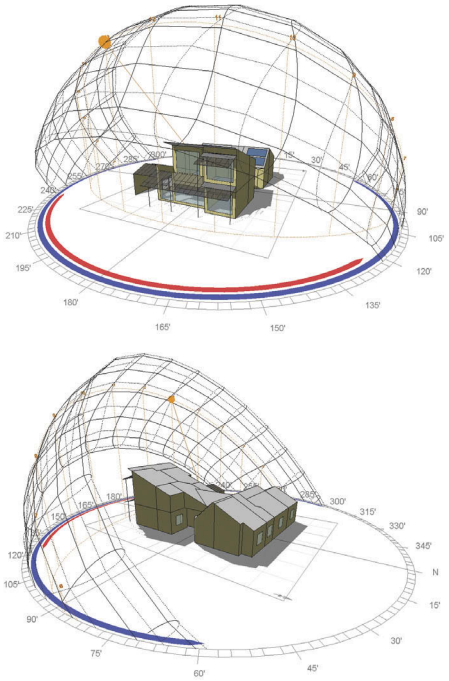


Figure 7.1 | Apparent Motion of the Sun
Representative sun paths across the year. Solar position is relative to the center of the large circle surrounding the building. The arcs represent the 21st day of each month, while the loops represent solar positions at the top of each hour (in solar time). The shape of these single hour loops is the effect of the Equation of Time (Equation 7.2). The lowest sun path occurs at the winter solstice, and the highest path at the summer solstice. Rendered shadows in these figures permit the evaluation of sunlight penetration through daylight apertures into spaces. Note that the software tool used to generate these images (Ecotect™) places the zero degree solar azimuth at north rather than south.

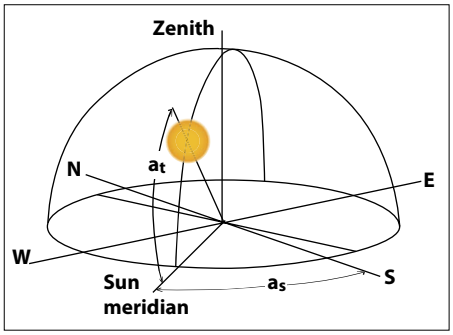


Figure 7.2 | Solar Position
Solar altitude (a_t) and solar azimuth (a_s) define the sun's position in the sky.

path is 15° per hour. Its highest point above the horizon occurs at solar noon, which coincides with the orientation of the North or South Pole, depending on site location. See Figure 7.1.

Because the sun is roughly 93 million miles away, the sun's rays are essentially collimated upon reaching the earth. Due to the angular size of the sun, the edges of a sunlight beam that passes through an aperture become blurred, in what is known as a shadow penumbra, and this blurred region increases in size as the distance from the aperture increases.

Solar illuminance measured on a plane normal to the sun's direction is a function of both solar altitude and sky clearness, and can reach values as high as 100,000 lux. Since the earth's orbit is elliptical, the value at the outer reaches of the earth's atmosphere varies by approximately ±3.2% from its yearly average, peaking around January 3rd and reaching a minimum on or about July 4th. Given its magnitude, the sun is a significant source of daylight, but only if it is appropriately controlled and distributed within a space. The sun can also be a significant source of glare and heat gain, which is why many daylight systems attempt to block direct sunlight and transmit the diffuse daylight from the sky and ground.

The ever-changing position of the sun in the sky presents a major challenge when attempting to redirect, control or eliminate direct sunlight. The sun's position is expressed in terms of two angles: the solar altitude, a_t (the vertical angle of the sun above the horizon), and the solar azimuth, a_s (the horizontal angle of the sun measured from a polar south direction with positive angles in a westward direction). See Figure 7.2. Equations to compute the sun's position are provided in 7.1.5 Solar Position.

7.1.2 The Sky

A clear sky is made luminous through Rayleigh scattering of sunlight by air molecules, small particles of water vapor, and particulate matter in the atmosphere. Shorter wavelength light is scattered more than longer wavelengths, giving the sky its blue color. When clouds are present, they reflect and diffuse sunlight with minimal influence on spectrum. For daylight purposes, the sky is considered to be a luminous hemisphere, providing light from multiple directions with a luminance distribution that varies with solar position and atmospheric conditions.

The highly diffuse nature of daylight from the sky is quite the opposite of direct sunlight, which is highly directional. For daylight striking a horizontal plane such as the ground or the roof of a building, an unobstructed sky covers the entire field of view. For a vertical surface such as a window, the sky encompasses one-half of all possible incident light directions, with the ground covering the other half.

Multiple sky luminance distribution models have been developed to study daylight performance, and are applied in lighting and daylighting software tools. IES has developed standard skies for clear, partly cloudy, and overcast conditions [4]. More complex models (see 7.1.6.1 Perez and CIE Skies) are designed to simulate conditions based on weather data and describe a much wider range of sky conditions for studying and comparing annual system performance at a site for which weather data are available. The following paragraphs provide a general description of the IES sky models for which equations are provided in the formulary.

Under a clear sky, the circumsolar region is the brightest, with a significantly lower luminance directly opposite the sun in azimuth, and approximately 90 degrees from the sun in a vertical plane. The horizon is relatively bright due to greater atmospheric scattering at low altitude angles. Figure 7.3 illustrates the luminances provided by a representative clear sky.

A standard overcast sky completely obscures the sun, is azimuthally symmetric, and is roughly 2.5 times brighter at zenith than at the horizon, as illustrated in Figure 7.4. Because of its symmetry, the vertical illuminance on a building façade is independent of orientation under an overcast sky.

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A wide range of sky conditions exist between a totally clear and overcast sky. The standard partly cloudy sky model is an average of these. Figure 7.5 shows the luminance distribution of the sky dome for a standard partly cloudy sky. The more advanced Perez and CIE models provide sky conditions that obscure the sun to varying degrees, while also addressing the sky luminance distribution under these conditions.

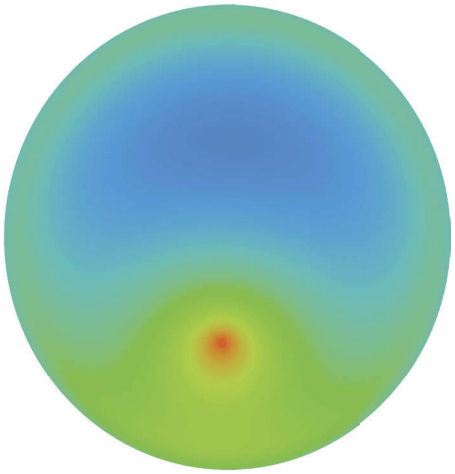
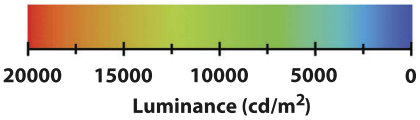


Figure 7.3 | Clear Sky Luminance Map
A standard clear sky has its highest luminance in the circumsolar region, which is clearly visible in this luminance map for a solar altitude of 50°. Directly opposite the sun, a clear sky has a relatively low luminance. The sky is somewhat brighter near the horizon due to particle scattering. See luminance scale below.



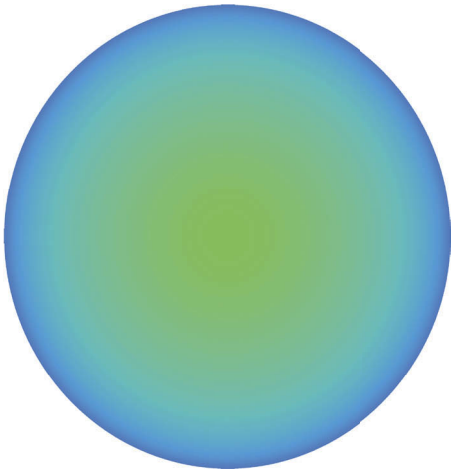
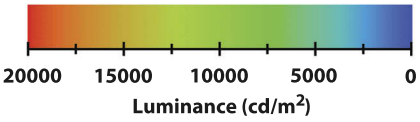


Figure 7.4 | Overcast Sky Luminance Map
A standard overcast sky is azimuthally symmetric, almost 3 times as bright at zenith than at the horizon, and brighter than a clear sky in the direction facing away from the sun. The 50° altitude solar position is completely blocked. See luminance scale below.



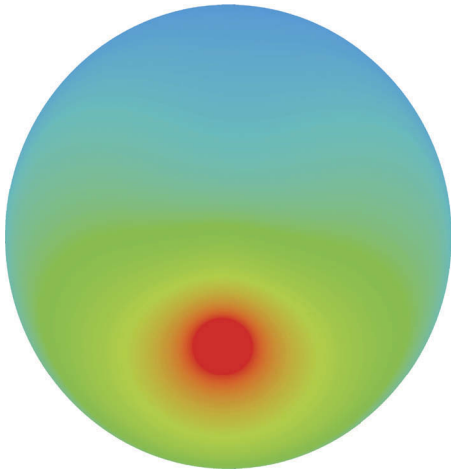
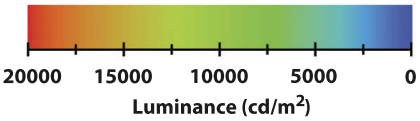


Figure 7.5 | Partly Cloudy Sky Luminance Map
A standard partly cloudy sky has a relatively high sky luminance in all directions with a bright and broad circumsolar region as shown in this 50° altitude example. Across the sky dome, these luminances represent what might be experienced by a thin high cloud layer.



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7.1.3 Externally Reflected Daylight

While the sun and sky are the primary sources of daylight, externally reflected light from the ground and adjacent structures or objects also contributes luminous flux to daylight apertures. For a vertical window on a flat site, the ground encompasses the lower half of the field of view. Like skylight, ground light is usually diffuse, with its luminance a function of the ground reflectance, the sky conditions, and shadowing and reflections provided by surrounding objects.

Light reflected from the ground provides an important daylight contribution, since it is directed through vertical apertures to the ceiling and walls. The fraction of the total incident daylight on a vertical façade that arrives from the ground can range from below 10% to as high as 70-80% at a ground reflectance of 20%. The lowest fractions occur when direct sunlight strikes the facade, while the highest occur on a facade facing away from the sun on a clear day, when the sky is deep blue and the ground is sunlit. Under an overcast sky, the ground contribution is generally around 20%.

Table 7.1 | Reflectance of Ground Materials

Material	Reflectance (percent)
Brick	
• Light buff	48
• Dark buff	40
• Dark red glazed	30
Concrete	40
Asphalt (free from dirt)	7
Grass (dark green)	6
Gravel	13
Slate (dark clay)	8
Snow	
• New	74
• Old	64
Vegetation (mean)	25

Ground reflectance can vary significantly, as shown in Table 7.1. Light-colored ground surfaces such as sand and snow will result in higher ground contributions.

Objects such as trees, neighboring buildings, and other portions of the same building can limit the view of the ground or sky seen from a daylight aperture. In these situations, daylight from portions of the sky or ground is replaced by light reflected from the obstructing object, which may either increase or decrease the daylight delivered to a building interior.

7.1.4 Spectrum

Daylight spectra are continuous and have nearly equal energy per wavelength. Because the spectral distribution of daylight changes with solar position as well as sky conditions, the Commission Internationale de l'Éclairage (CIE) has adopted standard spectral radiant power distributions for daylight, as illustrated in Figure 7.6 [5]. These SPDs are used as the reference sources for the evaluation of CRI for light sources with CCT of 5000 K or higher. Figure 7.6 is based on 10 nm averages, which provides a relatively smooth curve. When measurements are taken at 1 nm intervals, the curve contains some sharp absorption bands as seen in Figure 1.7.

Of the solar energy received at the earth's surface, approximately 45% is visible radiation under a clear sky. The remainder is in the ultraviolet (≈5%) and infrared (≈50%) regions. The amount of total and visible energy received varies with the atmospheric conditions and the distance that light must travel through it, which varies with site elevation (for example, less attenuation occurs in Denver than in Miami) and with solar altitude.

The luminous efficacy of daylight varies with sky conditions. The overall global average across a year is generally in the range of 105-110 lumens per watt. Solar beam efficacy is relatively low at roughly 70-95 lumens per watt, while the light from the sky is generally on the order of 115-120 lumens per watt for an overcast sky and 120-160 or more lumens per watt for a clear sky [6]. Spectrally selective glazings can increase the efficacy of daylight that enters a building by excluding a greater fraction of the non-visible wavelengths.

The resulting impact of daylight efficacy is quite different than that of efficacy for electric light. The watts associated with daylight entering a building are realized as heat gain within a building, whereas with electric lighting these watts also must be spent to power the light source. If thermal losses are low and interior daylight levels or system losses are not excessive, this can lead to an energy advantage for daylighting.

7.1.4.1 CCT

Daylight is cool in color temperature, with high angle noon sunlight generally around 5000 K. The daylight received from a clear blue sky has a significantly higher color temperature, and depends on the orientation relative to the sun, with values exceeding 20000 K facing away from the sun. The CCT for daylight provided by an overcast sky is generally in the range of 5500 K. Only near sunrise and sunset does direct sunlight

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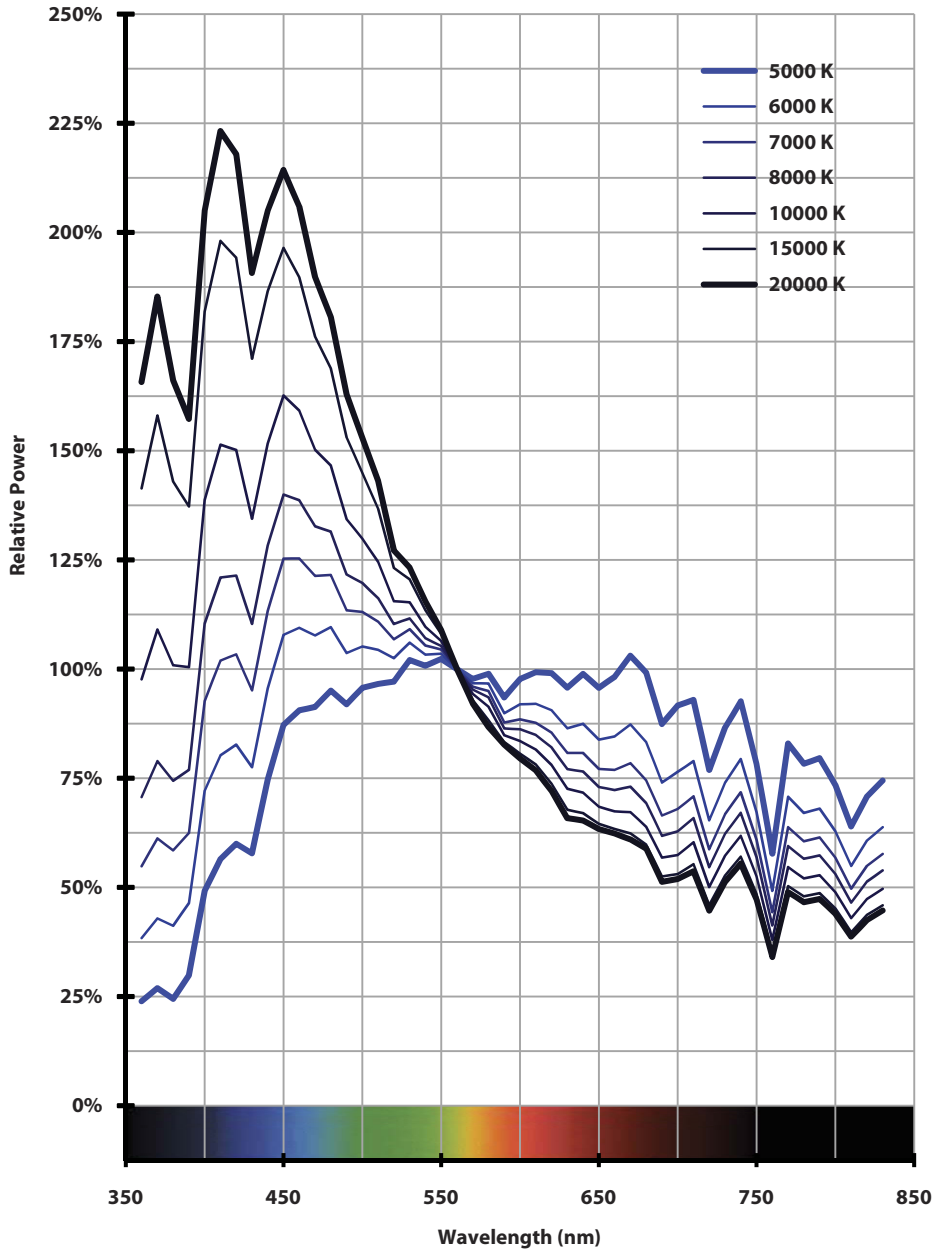


Figure 7.6 | Daylight SPDs
Standard CIE spectral power distributions for different daylight CCT's, normalized at 560 nm, using 10 nm bandwidth data.

become warm on the CCT scale, when it can fall as low as 2000 K. At these times, the shorter wavelengths are removed by atmospheric scattering of the sunlight beam, lowering the CCT and creating colorful orange and red sunrises and sunsets. In general, the CCT of daylight incident on an aperture will be 5000 K or higher most of the time, and is a function of the amount of light received from the sun, sky, and ground, as well as the sky conditions and aperture orientation. Glazing material that is not spectrally neutral will alter the makeup of the transmitted light, and change the CCT of daylight within a space.

7.1.4.2 Color Rendering

Daylight's continuous and relatively uniform output across the visible spectrum delivers relatively consistent and high quality color rendering. Colors tend to take on their "natural" hue under daylight, although certain daylight conditions can create very high CCTs, which will alter the color appearance of materials due to the relatively large blue component. Since standardized daylight spectra serve as the reference source for determining CRI for light sources above 5000 K, the CRI of daylight is generally near

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100. However, like with CCT, the spectral transmittance of glazing materials can alter the color rendering characteristics of daylight.

7.1.5 Solar Position

The position of the sun is specified by two angles, the solar altitude, a_t, and solar azimuth, a_s (see Figure 7.2). The solar altitude is the vertical angle of the sun's position with respect to the horizon, while the solar azimuth denotes the sun's position in a horizontal plane measured from south (note that some sources measure solar azimuth from north). Both of these angles are a function of the site latitude, solar time and solar declination (the tilt of the earth's axis with respect to the sun, which is a function of the calendar day).

7.1.5.1 Site Location

A site's location is one input in determining solar position, and is specified by both its latitude, ℓ, and longitude, L. These values can be determined for most sites using an atlas or the Internet.

Conventions for expressing latitudes used in equations found in this Handbook are:

Positive = northern hemisphere
Negative = southern hemisphere

Conventions used in expressing longitudes are:

Positive = west of prime meridian (Greenwich, United Kingdom)
Negative = east of prime meridian

7.1.5.2 Solar Time

To determine the sun's position, it is first necessary to determine the solar time, which is based on the local time and site location. A 24-hour clock is used to express time. Three adjustments must be considered in converting local time to solar time.

1. If daylight savings time is in effect, one hour must be subtracted from the local clock time to arrive at standard time, t_s.

$$t_s = t_{local} - 1 \tag{7.1}$$

Where:

t_s = standard time
t_{local} = local time

2. The Equation of Time (ET), which accounts for the earth's elliptical orbit about the sun and the tilt of the earth's axis relative to its plane of orbit, adjusts the time between -14 and +16 minutes over the year (see Equation 7.2 and Figure 7.7) [7].

$$ET = 0.1644 \sin\left(\frac{4\pi(J-81.6)}{365.25}\right) - 0.1273 \sin\left(\frac{2\pi(J-2.5)}{365.25}\right) \tag{7.2}$$

Where:

ET = Equation of Time correction, in decimal hours (for example, 1:30 p.m. = 13.5)
J = Julian day, a number between 1 and 365

While this equation should suffice for most applications, a more accurate and less simplified equation is provided by Meeus [8].

3. The longitude correction accounts for the site's longitude relative to a time zone's standard meridian (its center longitude). Time zones are nominally 15 degrees wide, therefore solar noon at the east and west boundaries of a time zone occur approxi-

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mately one-half hour earlier and one-half hour later than at the standard meridian, and intermediate positions receive correspondingly smaller corrections based on their position within the time zone.

Solar time, t, is computed from standard time, t_s, using the following equation, where the rightmost term is the longitude correction.

$$t = t_s + ET + \frac{12 \times (SM - L)}{\pi} \quad (7.3)$$

Where:

t = solar time in decimal hours
t_s = standard time in decimal hours
ET = time from Equation 7.2 in decimal hours
SM = standard meridian for the time zone in radians.
L = site longitude in radians

To apply SM and L in degrees, use

$$t = t_s + ET + \frac{12 \times (SM - L)}{180} \quad (7.4)$$

Where:

t = solar time in decimal hours
t_s = standard time in decimal hours
ET = time from Equation 7.2 in decimal hours
SM = standard meridian for the time zone in degrees.
L = site longitude in degrees

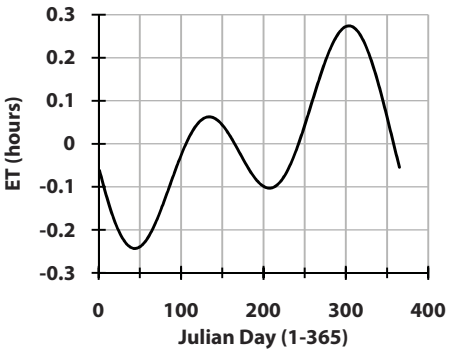


Figure 7.7 | Equation of Time (ET)
Plot of the equation of time correction as a function of Julian day.

7.1.5.3 Solar Angles

The solar azimuth and altitude define the sun's position and are determined from solar time and site latitude through a series of equations. Graphs for determining solar angles based on solar time and Julian day (1-365) are provided in Figure 7.8 for a range of site latitudes.

To calculate the solar position, the solar declination, δ, must first be determined.

$$\delta = 0.4093 \sin\left(\frac{2\pi(J - 81)}{368}\right) \quad (7.5)$$

Where:

δ = solar declination in radians
J = Julian date

The solar altitude, a_t, the angle of the sun above the horizon, is then given by

$$a_t = \arcsin\left(\sin \ell \sin \delta - \cos \ell \cos \delta \cos \frac{\pi t}{12}\right) \quad (7.6)$$

Where:

a_t = solar altitude in radians
ℓ = site latitude in radians
δ = solar declination in radians
t = solar time in decimal hours

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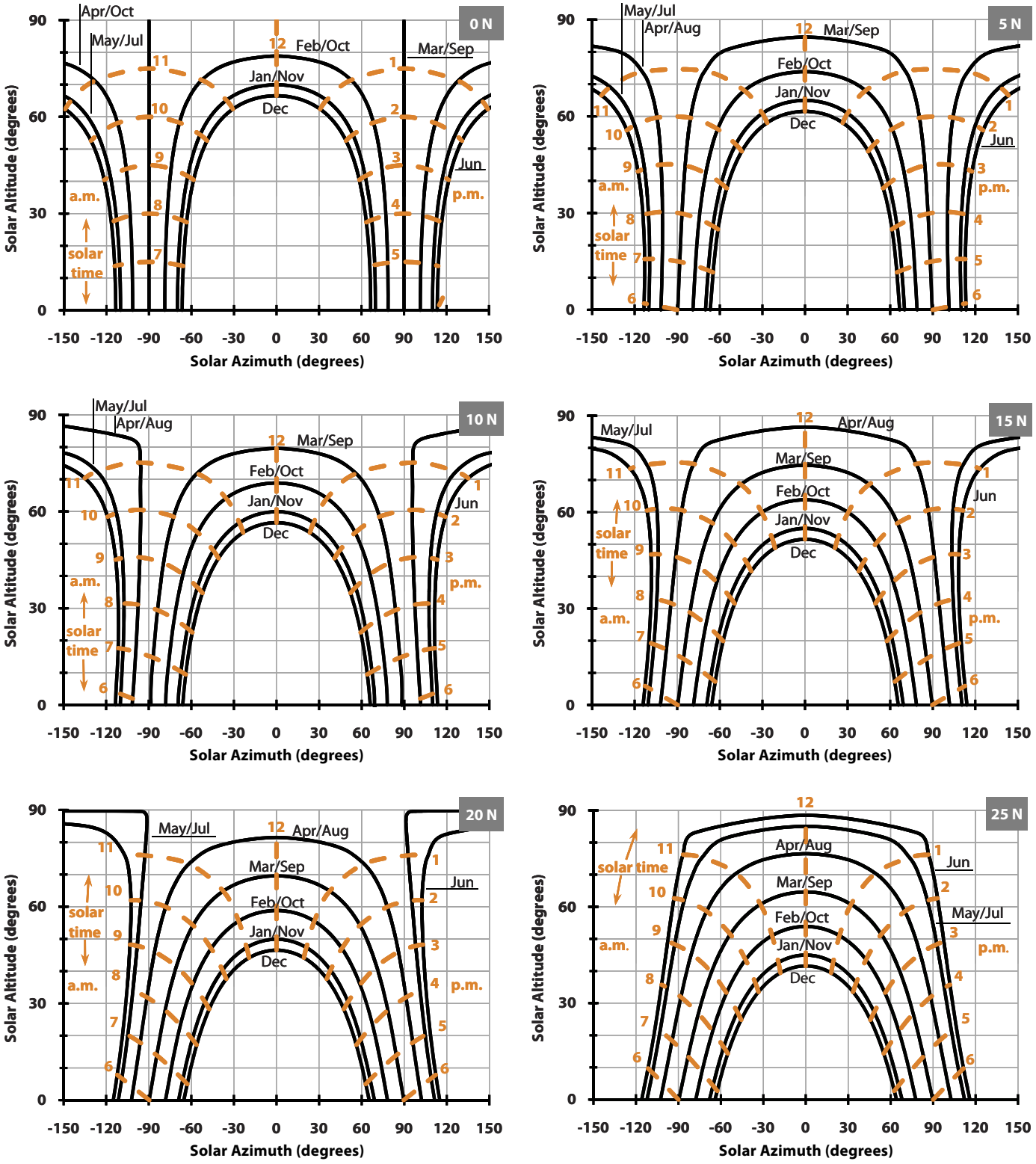


Figure 7.8 | Solar Position
Solar position defined with azimuth and altitude angles for site latitudes from 0 N to 55 N.

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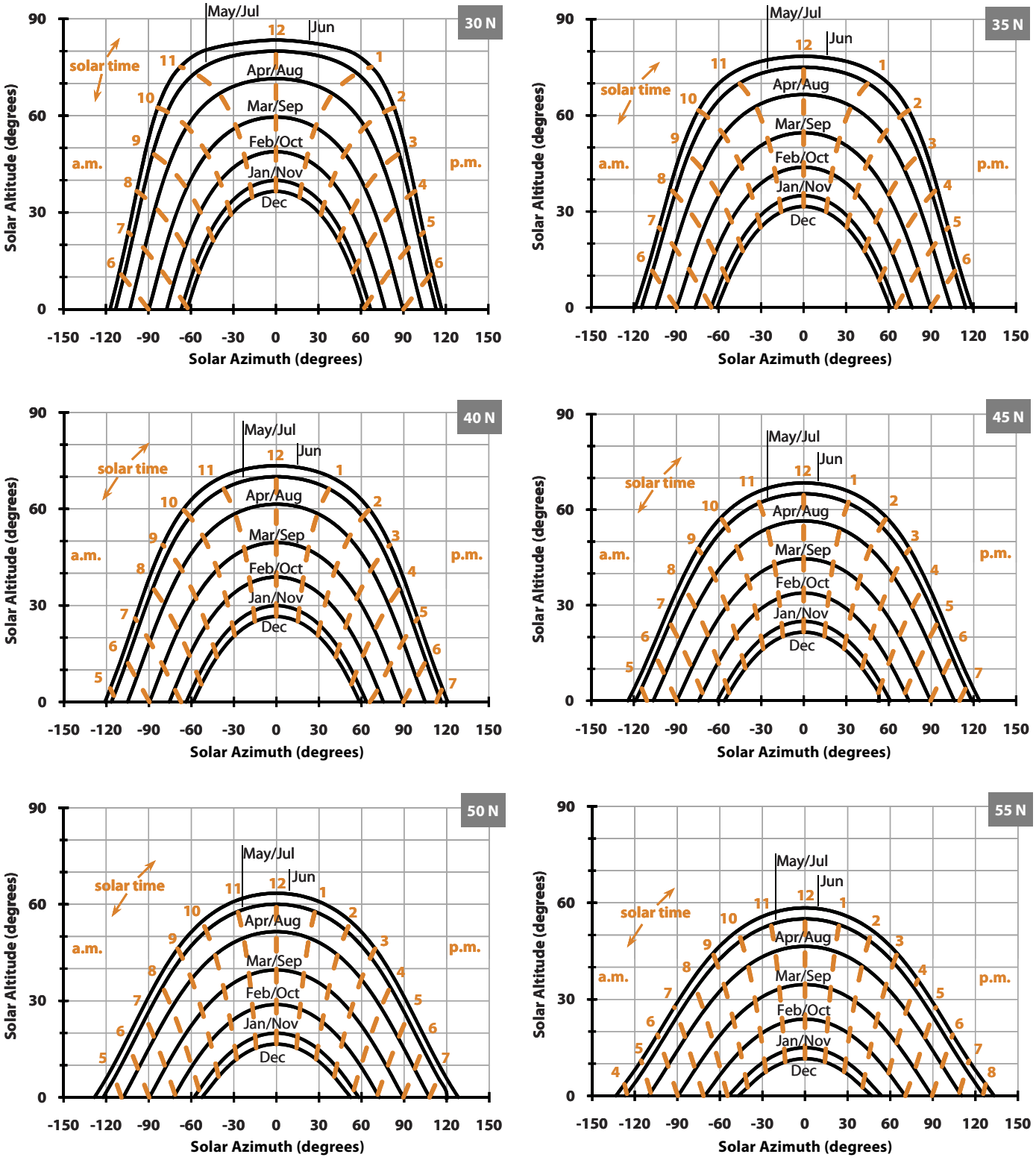


Figure 7.8 | Solar Position (continued)

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If the sun is above the horizon, this equation returns an angle between 0 and π/2. The solar altitude is negative when the sun is below the horizon.

The solar azimuth, a_s, the horizontal angle of the sun's position measured from south, is determined as follows.

$$a_s = \arctan\left[\frac{-\cos\delta\sin\frac{\pi t}{12}}{-\left(\cos\ell\sin\delta+\sin\ell\cos\delta\cos\frac{\pi t}{12}\right)}\right] \tag{7.7}$$

Where:

a_s = solar azimuth angle in radians
δ = solar declination in radians
ℓ = site latitude in radians
t = solar time in decimal hours

The solar azimuth can range from -π to +π, with negative angles east of south and positive angles west of south. To achieve the full range of required angles, the arctan function used in the above equation must be capable of evaluating the sign of both the numerator and denominator to place the angle in the appropriate quadrant and assign it the correct value.

7.1.5.4 Solar Angles Relative to a Vertical Surface

In analyzing daylight systems, it is often necessary to determine the incident angle, a_i, at which sunlight strikes an aperture as shown in Figure 7.9. For a vertical aperture, such as a window, this angle is based on the solar elevation azimuth, a_z, the azimuth angle of the sun's relative to a façade's elevation azimuth as illustrated in Figure 7.10.

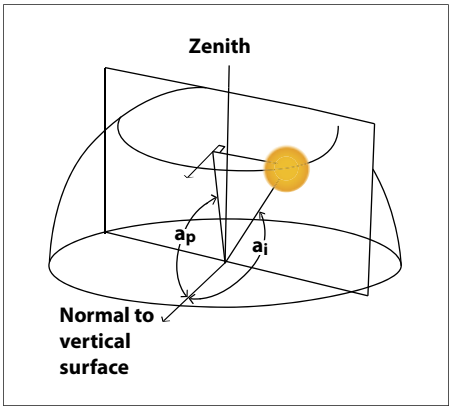


Figure 7.9 | Incident and Profile Angles
The incident and profile angles for sunlight striking a vertical surface.

$$a_z = a_s - a_e \tag{7.8}$$

Where:

a_z = solar elevation azimuth in radians,
a_s = solar azimuth in radians,
a_e = elevation azimuth in radians.

Positive angles are measured in a clockwise direction, with both a_e and a_s referenced from south.

The incident angle for a vertical surface is the angle between a vector normal to the surface and the direction to the sun, as shown in Figure 7.9, and is equal to:

$$a_i = \arccos(\cos a_t \cos a_z) \tag{7.9}$$

Where:

a_i = incident angle in radians,
a_t = solar altitude in radians,
a_z = solar elevation azimuth in radians.

The profile angle, a_p, is the apparent altitude of the sun relative to a vertical surface of interest (Figure 7.9) and is calculated by Equation 7.10. It can be used to evaluate sunlight penetration distance or the shading impact of an overhang or light shelf.

$$a_p = \arctan\left(\frac{\sin a_t}{\cos a_i}\right) = \arctan\left(\frac{\tan a_t}{\cos a_z}\right) \tag{7.10}$$

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Where:

a_p = profile angle in radians,
a_t = solar altitude in radians,
a_i = incident angle in radians,
a_z = solar elevation azimuth in radians.

7.1.6 Daylight Availability

Lighting calculations for daylighting are considerably more complex than for electric lighting. Determination of the incident illuminance on windows and skylights, or the daylight distribution within a space, must take into account the solar position relative to the daylight aperture as well as the sky conditions.

The phrase "daylight availability" refers to the amount of light provided from the sun, sky and ground at a specific location, orientation, time, date, and sky condition. Measurements of daylight illuminance and sky luminance by researchers working all over the world have resulted in very similar mean values for the sun and sky contributions [9]. Formulae to estimate the available daylight illuminance have been derived from these values. Because these are best fits to average values, they are unlikely to agree with instantaneous values, and it is not unusual for instantaneous values to be more than twice or less than half of these mean design values.

Calculation of daylight availability at a site begins with a determination of solar position. For a particular sky condition, standard equations can then provide either the daylight illuminance for a complete full or half-sky on a horizontal or vertical plane, or the complete luminance distribution of the sky. Software tools generally apply sky luminance patterns to determine the available daylight onto daylight apertures and can address complex situations involving a partial view of the sky. Equations are provided in 7.9 Formulary: Daylight Availability from IES Standard Skies to compute the available horizontal and vertical illuminance under the standard clear, partly cloudy and overcast skies, as well as the direct normal solar illuminance and sky luminance distributions under these skies. Sample results from these sky models are provided in Figure 7.11 for the direct (solar) contribution onto horizontal and vertical surfaces, and in Figure 7.12 for the sky contributions to these surfaces. These exterior daylight illuminance values have historically been used in simple hand calculation techniques, such as the Lumen Method for Toplighting (See Formulary) and the Lumen Method of Sidelighting [10], but are also valuable for assessing how daylight availability from the sun and sky vary with orientation and solar position under these general sky conditions.

7.1.6.1 Perez and CIE Skies

Weather files are frequently used to model site specific thermal and solar conditions in building energy simulations. Perez conducted full-sky luminance scans and developed a series of equations that produce representative sky conditions based on measured solar and global insolation conditions [11] [12]. These sky models, which are often referred to as Perez skies, have been shown to perform reasonably well [6]. Similarly, the CIE developed a series of 15 skies [13] that can be used to model sky conditions based on measured illuminance and zenith luminance data. By simulating sky conditions from site-specific weather data, typically TMY2, TMY3 (Typical Meteorological Year data sets), EPW (Energy Plus Weather file), or CWEC (Canadian Weather for Energy Calculation files) [14] [15] [16] [17], daylight system performance and the lighting energy savings provided by photosensor-based lighting control systems can be modeled across a year. A stochastic model to transform these hourly daylight values into one-minute variable data has been shown to further improve the correlation with real world time varying conditions [18].

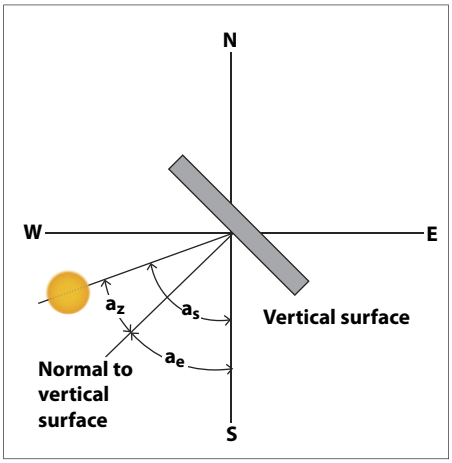


Figure 7.10 | Azimuth Angles
The solar azimuth, a_s, is a measure of the sun's azimuth position relative to south. The solar elevation azimuth, a_z, is the sun's azimuth position relative to a building's elevation azimuth, a_e, as shown.

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Figure 7.11 | Direct Solar Illuminance from Standard Sky Models
Direct illuminance from the sun onto a horizontal surface (E_{dh}) and onto a vertical surface (E_{dv}) at different solar elevation azimuth angles using the standard clear and partly cloudy sky models. The solar contribution under an overcast sky is zero.

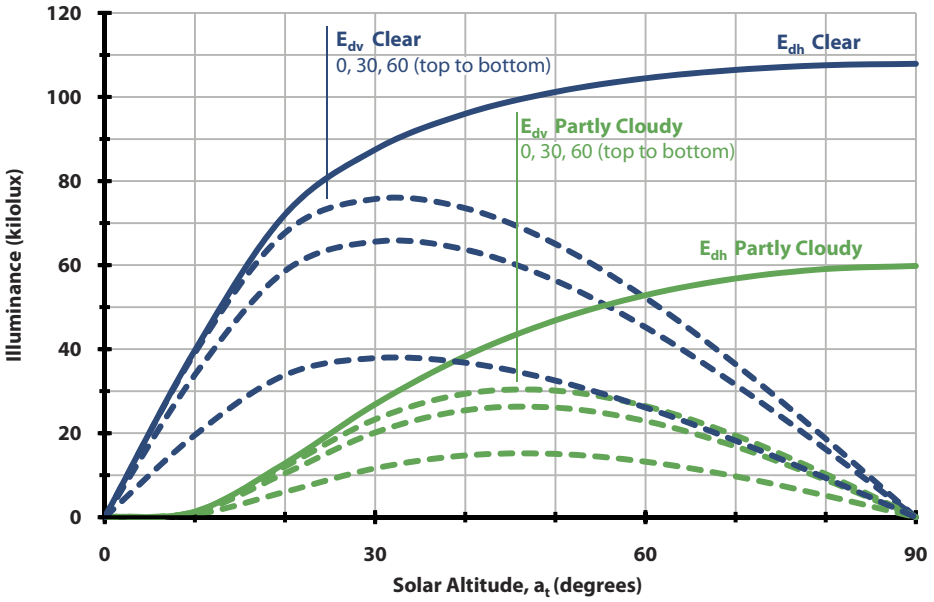
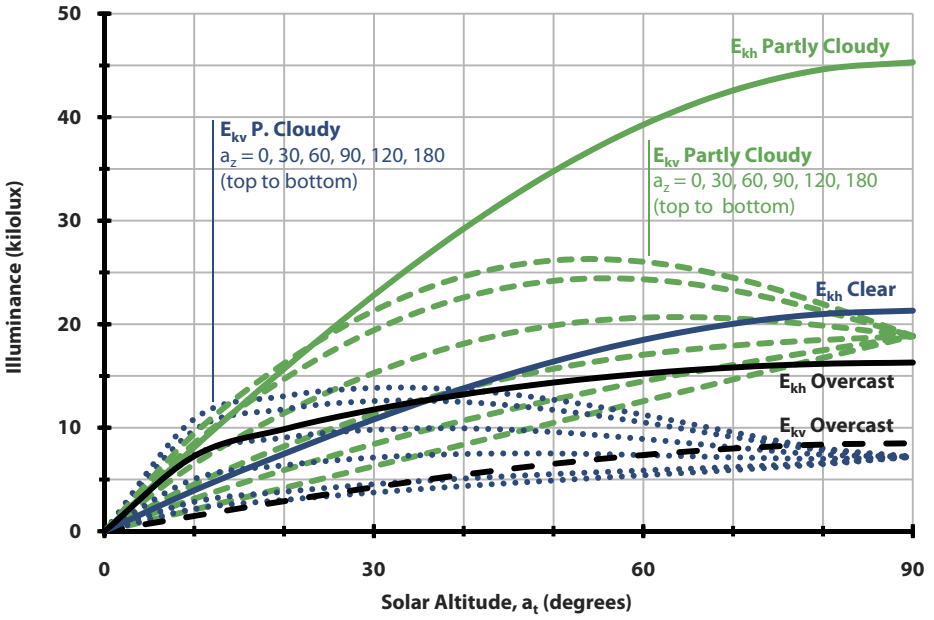


Figure 7.12 | Sky Illuminance from Standard Sky Models
Sky illuminance provided onto a horizontal surfae (E_{kh}) and onto a vertical surface (E_{kv}) at different solar elevation azimuth angles using the standard clear, partly cloudy and overcast sky models.



7.2 Filament Lamps

Filament lamps consist of a wire filament mounted within a glass bulb that contains a gas or a vacuum. Optical radiation is emitted when the filament is heated to incandescence by the passage of electrical current. End of life is most commonly due to tungsten evaporation, which leads to failure of the filament.

7.2.1 General Principles of Operation

Electric current passes through a thin filament of tungsten wire, heating it until it emits optical radiation. The efficacy of light production depends on the temperature of the filament: the higher the temperature, the greater the portion of optical radiation emitted in the visible region. The major factors that affect filament temperature are: the filament

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material, microstructure, and geometry; the composition of the atmosphere, and its pressure; and the magnitude of electrical current. All else equal, lamp life is inversely related to filament temperature. It is therefore important in the design of a lamp to keep the filament temperature as high as is consistent with satisfactory life.

7.2.2 Construction

The basic components are a filament, bulb, gas fill, and base, as illustrated in Figure 7.13. When the gas fill includes a halogen, usually bromine, the lamp is referred to as a tungsten halogen lamp. When a special coating is applied to a tungsten halogen capsule to redirect infrared radiation back to the filament, it is then known as a halogen infrared lamp.

7.2.2.1 Filament

Early incandescent lamps used carbon, osmium, and tantalum filaments, but tungsten has the desirable properties of a high melting point, low vapor pressure, high strength, and suitable radiating characteristics and electrical resistance. Its melting point of 3382° C permits high operating temperatures and high efficacies in comparison to other potential filament materials. Drawn tungsten wire has high strength and ductility, allowing the uniformity necessary for present-day lamp tolerances. In some lamp designs tungsten is alloyed with other metals, such as rhenium, and thoriated tungsten wire is used in filaments for rough service applications.

Less than 10% of the total radiation from an incandescent source is in the visible region of the spectrum. As the temperature of a tungsten filament is raised, the proportion of radiation in the visible region increases, and thus luminous efficacy increases. The luminous efficacy of uncoiled tungsten wire at its melting point is approximately 53 lumens per watt. In order to obtain long life, it is necessary to operate a filament at a temperature well below the melting point, resulting in lower efficacies.

In tungsten filament lamps the hot resistance is 12 to 16 times greater than the cold resistance, as summarized in Figure 7.14. The comparatively low cold resistance results in an initial in-rush of current, which may be important in the design and adjustment of circuit breakers, in the design of lighting-circuit switch contacts, and in dimmer design. See Table 7.2. The in-rush lasts for only a fraction of a second and is negligible as an additional energy load.

Filament forms, sizes, and support construction vary widely with different types of lamps. Figure 7.15 summarizes typical constructions. Filament forms are designated by a letter or

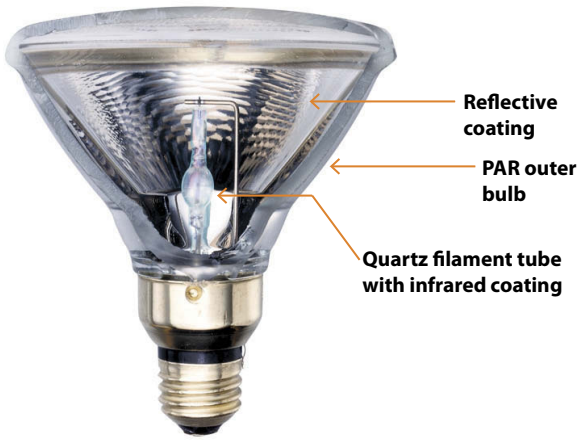


Figure 7.13 | Halogen Infrared Filament Lamp Construction
Components of a PAR38 halogen infrared filament lamp.
» Image courtesy of General Electric Company

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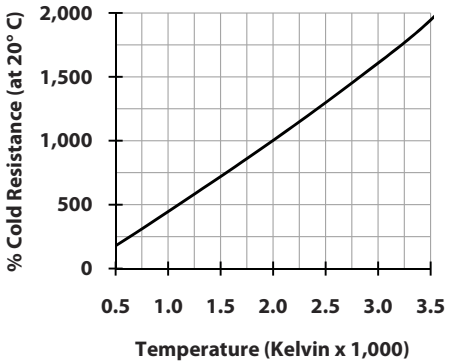


Figure 7.14 | Resistance vs. Temperature
Variation of tungsten filament hot resistance with temperature, as a percentage of cold resistance.

letters followed by an arbitrary number. The most commonly used letters are: S (straight), meaning the wire is uncoiled; C (coiled), meaning the wire is wound into a helical coil; and CC (coiled coil), meaning the coil is itself wound into a helical coil. Coiling the filament increases its luminous efficacy and forming a coiled coil further increases efficacy (see 7.2.2.4 Gas Fill and the Tungsten Halogen Cycle). More filament supports are required in lamps designed for rough service and vibration service than for GLS lamps (see 7.2.7.1 General Lighting Service (GLS)), which conducts heat away from the filament and decreases efficacy. Filament designs are determined by service requirements: planar filaments such as C-13 are often employed in film projectors; axial filaments such as C-8 and CC-8 are often employed within lamps that have axially symmetric reflectors, such as PAR lamps.

7.2.2.2 Bulb

General lighting service (GLS) filament lamps have one bulb; it is the outer envelope and is made of soda lime (soft) glass. Higher wattage lamps may use heat resisting (hard) glass made of borosilicate, or a specialized hard glass such as fused silica (quartz), high-silica, or aluminosilicate. Hard glass is needed for lamps that have small bulbs and high wattages, or to prevent glass breakage due to moisture or other environmental factors.

Tungsten halogen and halogen infrared lamps may have one or two bulbs. When a bulb-within-a-bulb construction is used, the inner bulb is known as a capsule. It is typically made of quartz or hard glass rather than soft glass in order to withstand the higher bulb-wall temperatures required for the halogen cycle, which is described in the next section. When a quartz capsule is accessible, it should not be handled with bare hands because

Table 7.2 | In-rush Current

Filament Lamp Type	Power (Watts)	Voltage (Volts)	Normal Current (Amperes)	Theoretical In-Rush: Basis, Hot-to-Cold Resistance (Amperes)[a]	Time for Current to Return to Normal Value (Seconds)
General Lighting Service (GLS) Filament Lamps	15	120	0.125	2.30	0.05
	25	120	0.208	3.98	0.06
	40	120	0.333	7.00	0.07
	50	120	0.417	8.34	0.07
	60	120	0.500	10.20	0.08
	75	120	0.625	13.10	0.09
	100	120	0.835	17.90	0.10
	150	120	1.250	26.10	0.12
	200	120	1.670	39.50	0.13
	300	120	2.500	53.00	0.13
	500	120	4.170	89.50	0.15
	750	120	6.250	113.00	0.17
	1000	120	8.300	195.00	0.18
	1500	120	12.500	290.00	0.20
	2000	120	16.700	378.00	0.23
Halogen Lamps with C-8 Filament	300	120	2.50	62.00	b
	500	120	4.17	102.00	b
	1000	240	4.17	100.00	b
	1500	240	6.24	147.00	b
	1500	277	5.42	129.00	b

a. The current will reach the peak value within the first peak of the supplied voltage. Thus the time approaches zero if the instantaneous supplied voltage is at peak, or it could be as much as 0.006 seconds.
b. Not established. Estimated time is 5 to 20 cycles.

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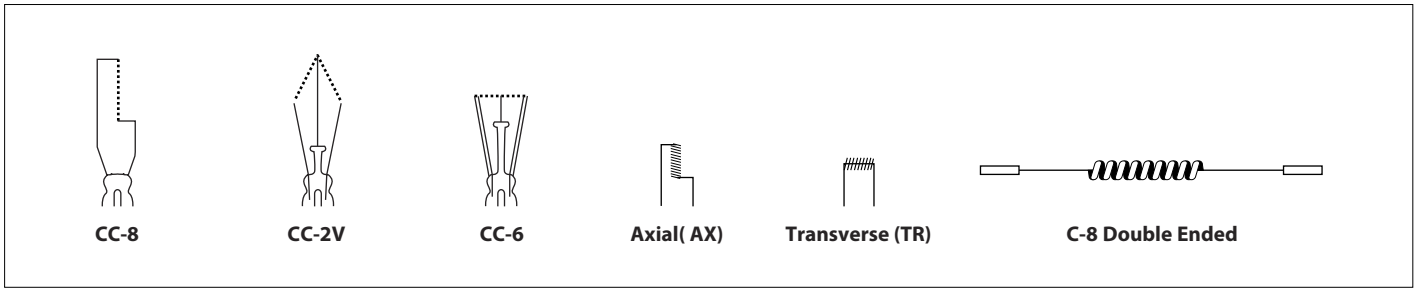


Figure 7.15 | Filaments
Typical filament lamp constructions. Not to scale.
» Images courtesy of Osram Sylvania

the oils in human skin coupled with the heat of operation may lead to devitrification and non-passive failure. If a quartz capsule is handled by accident, it should be cleaned with rubbing alcohol or mineral spirits. The tungsten halogen or halogen infrared capsule is commonly placed within an outer glass bulb, as with PAR lamps. Typical bulb shapes and their ANSI designations are given in Figure 7.16. The bulb may provide protection of the filament, optical diffusion, shaping of the luminous intensity distribution, and spectral filtering. In the case of halogen infrared lamps, the halogen capsule is used for redirection of infrared radiation.

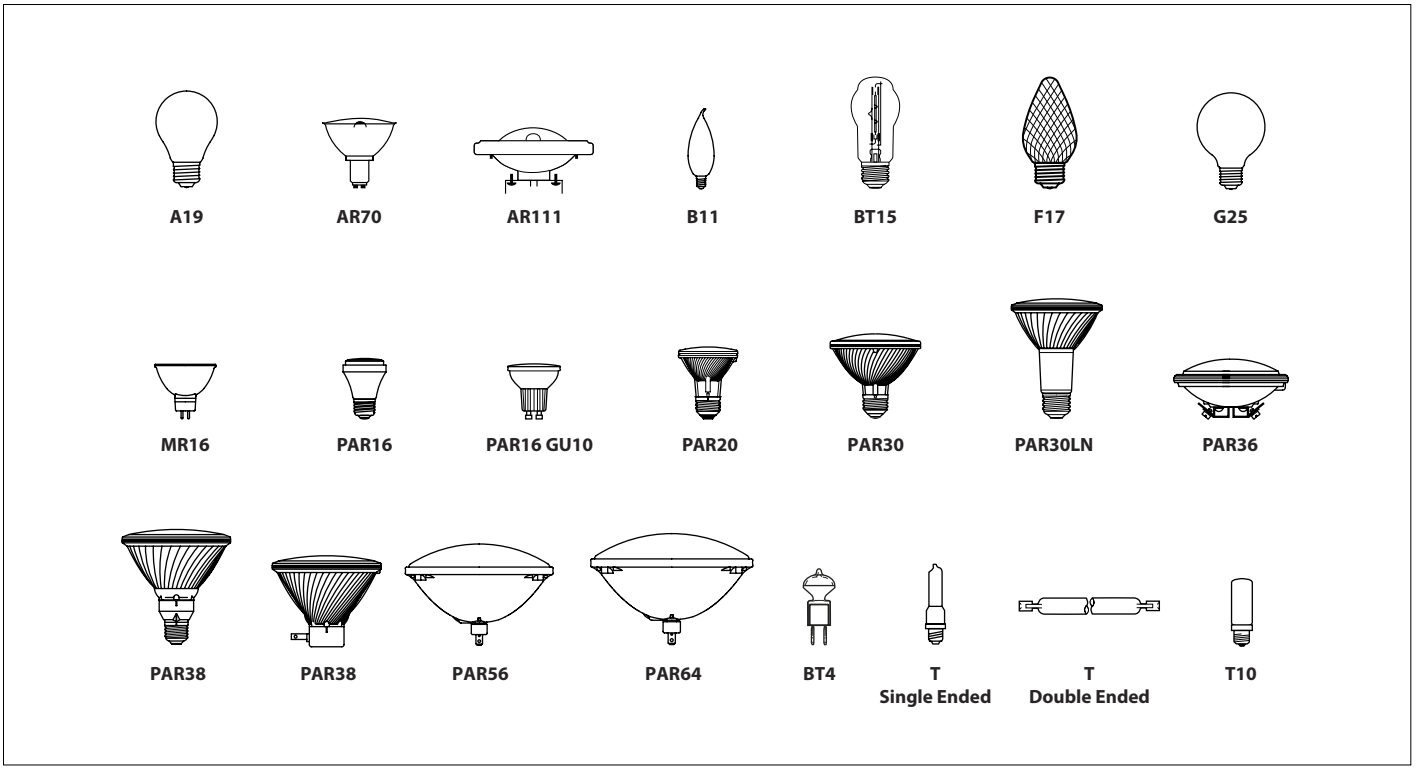
Protection of the filament: Tungsten will quickly evaporate if heated to incandescence in free air. The bulb creates a hermetically sealed environment that is either a vacuum for GLS lamps below about 25W, or an atmosphere of gas.

Diffusion: Frosting may be applied to the inner surface of a bulb to diffuse the extremely high filament luminance. This produces moderate diffusion with very little reduction in output while mostly eliminating striations and shadows from internal lamp components. Finely powdered white silica is typically employed.

Shaping of the luminous intensity distribution: The luminous intensity distribution may be shaped with reflection and/or refraction. When reflection is employed a portion of the inner surface of the bulb is coated with aluminum or silver and the lamp shape is used to direct light out of the uncoated bulb wall. Silver has the advantage of higher reflectance and therefore higher efficiency. The most common type of reflectorized lamps have parabolic glass envelopes, although other shapes are available, including elliptical reflector lamps, and A-shaped lamps with half-coated bulbs, known as silver-bowled-reflector lamps. For parabolic reflector lamps the dimpling or prismatic pattern on the face is used as a refractive optic: clear lenses are used for narrow beam distributions with an increase in dimpling with beam width. See 7.2.7.2 Reflector Lamps.

Spectral filtering: Filament lamps are available with inside- and outside-spray-coated, outside-ceramic, transparent-plastic-coated, and doped-glass bulbs. Daylight lamps have bluish glass bulbs that absorb some of the long wavelengths produced by the filament. The transmitted light is of a higher correlated color temperature than standard incandescent. Bulb glass doped with neodymium selectively filters some of the yellow optical radiation generated by the filament, as shown in Figure 7.17. Filament lamps with spectrally selective filters have a lower CRI than standard incandescent lamps. This is a consequence of the way CRI is defined, but does not necessarily mean that such lamps exhibit poorer color rendition. See 6.3 Color Rendition and 7.2.3 Spectrum. Notably, filament lamps with blue-glass or doped with neodymium are considered by many to provide premium color rendition despite CRI values in the high 70s [19] [20] [21] [22]. Spectral filtering reduces luminous efficacy.

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A-Arbitrary spherical tapered to narrow neck
AR-Aluminized Reflector
AT-Arbitrary tubular
B-Bulged or bullet shape, blunt tip
BA-Bulged with angular (bent) tip
BD-Bulged with dimple in crown
BR-Bulged reflector
BT-Bulged tubular
C-Conical
CA-Candle shape with bent tip
CC-Two conical shapes blended together
E-Elliptical
ED-Elliptical with dimple in the crown
ER-Elliptical reflector
F-Flame shape, decorative
FE-Flat elliptical
G-Globe shape
GT-Globe/tubular combination
K-Similar to M but with conical transition
M-Mushroom shape with rounded transitions
MR-Multifaceted reflector
P-Pear shape
PS-Pear shape with straight neck
PAR-Parabolic aluminized reflector
R-Reflector
RB-Bulged reflector
RD-Reflector with dimple in crown
REC-PAR type lamp with rectangular face
RM-Reflector, mushroom shape
RP-Reflector, pear shape
S-Straight-sided shape (compare with CA and BA)
ST-Straight-tipped shape
T-Tubular shape
TL-Tubular shape with lens in crown
T/C-Tubular circular
TU-Tubular U-shape
2D-Two-dimensional

Figure 7.16 | Typical Bulb Shapes and their ANSI Designations
Not to scale. Not every ANSI designation, as key-listed here to a descriptive phrase or word, is illustrated.
» Images courtesy of Osram Sylvania

Redirection of infrared radiation: The capsule for halogen infrared lamps is designed to redirect infrared radiation back to the filament, which leads to a higher filament temperature at the same electrical current, thus increasing luminous efficacy. Halogen infrared capsules are constructed with a multilayer coating that allows visible optical radiation to pass through while reflecting infrared and absorbing ultraviolet radiation. Such capsules are typically, although not always, placed inside an outer envelope. The capsule shape and filament location must be precisely engineered and manufactured for the reflected IR to be focused on the filament.

7.2.2.3 Base

The functions of the base are to: make the electrical connection, support the lamp, and in some cases provide optical positioning within a luminaire. Common bases for tungsten halogen and halogen infrared lamps are given in Figure 7.18. Most GLS lamps employ a screw base. Bipost and prefocus bases ensure proper filament location in relation to luminaire optical elements. Lamp wattage is also a factor in determining base type.

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7.2.2.4 Gas Fill and the Tungsten Halogen Cycle

The gas fill is designed to: minimize conductive losses of input energy, suppress arcing between lead-in wires, and not react with the internal parts of the lamp. In the case of tungsten halogen and halogen infrared lamps, the gas fill is also designed to eliminate tungsten deposits on the wall of the capsule.

The tungsten filament of an incandescent lamp is surrounded by a thin sheath of heated gas to which some of the input energy is dissipated via convection. When the filament is coiled into a tight helix the sheath surrounds the entire coil such that the heat loss is no longer determined by the diameter of the wire, but by the diameter of the coil. Coiling thus reduces the loss. The energy loss is also dependent upon the atomic weight of the gas surrounding the filament. Larger atoms have lower heat conductivity. Inert gasses are employed because they do not react with the filament or with the other internal components of the lamp. The modern 120 V GLS incandescent lamp has a fill of about 95% argon and 5% nitrogen. The nitrogen is necessary to suppress arcing whereas the argon, being a heavier atom, has lower heat conductivity thus increasing efficacy. Krypton gas has lower heat conductivity than argon, and xenon lower still. The larger atoms are also more effective at retarding tungsten evaporation; they can be employed to extend life at the same efficacy or maintain the same rated life with increased efficacy. Of the four inert gasses employed in the gas fill, xenon is the most expensive, followed in order by krypton, argon, and nitrogen. Where the increase in cost is justified by the increased efficacy or life, krypton or xenon is employed.

Tungsten halogen lamps get their name from the chemical reaction that happens between evaporated tungsten and halogen atoms, which are a component of the gas fill. Halogens are electronegative elements that include fluorine, chlorine, bromine, and iodine. Bromine is most commonly employed in tungsten halogen lamps. The tungsten halogen cycle starts with the tungsten filament operating at incandescence, evaporating tungsten off the filament. Normally the evaporated tungsten particles would collect on the bulb wall, resulting in bulb blackening, common with GLS incandescent lamps and most evident near end-of-life. In tungsten halogen lamps the evaporated tungsten combines with the halogen and then circulates within the gas fill. Unlike tungsten only, at high temperatures

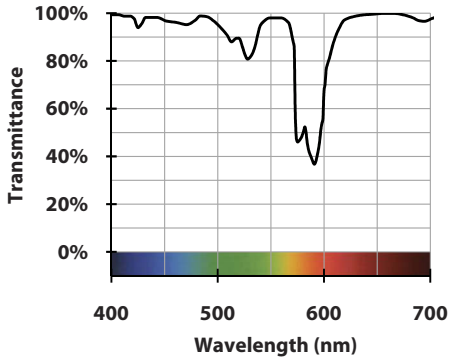


Figure 7.17| Neodymium Glass Transmittance

STD for neodymium glass showing the sharp dip in transmittance in the yellow part of the spectrum. See also Figure 7.20 | Filament Lamp SPDs.

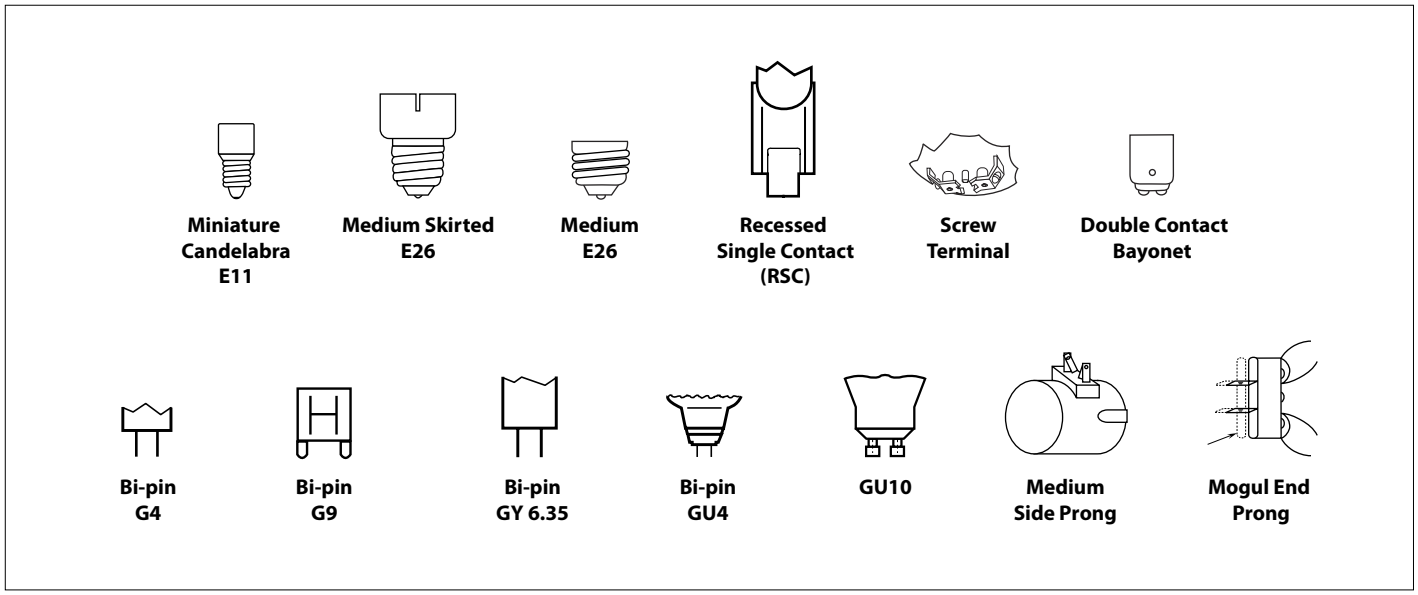


Figure 7.18 | Typical Filament Lamp Bases

Common lamp bases for tungsten halogen and halogen infrared lamps. Not to scale. ANSI designations are shown where available.

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tungsten-iodide or tungsten-bromide does not condense on the bulb wall and so blackening does not occur and the molecule is free to (eventually) encounter the hot filament. Here the heat is sufficient to break down the compound into tungsten, which is redeposited to the filament, and halogen, which is freed to continue its role in this cycle. Since the tungsten does not redeposit at the same point of evaporation, the tungsten halogen lamp still has a finite life. See 7.2.5.7 Lamp Life and Failure Mechanism.

The halogen cycle only occurs if the temperature is sufficient to maintain the halides in their gas phase, which corresponds to a minimum temperature of 260° C at the bulb wall. At lower temperatures the evaporated tungsten will deposit on the bulb wall. Dimmed tungsten halogen lamps should periodically be run at full power, inducing the tungsten halogen cycle to clean the tungsten off the bulb wall, thereby maintaining lamp efficacy over time.

Loading The loading is the energy density of optical radiation on the bulb wall. As the loading is increased, more lumens are produced per unit area, and bulb luminance increases. The bulb material is selected, in part to have the strength to handle the desired loading for the lamp design.

The requirement of a high bulb wall temperature for the halogen cycle has the corollary effect of requiring smaller bulbs. At equal wattage, smaller bulbs have a higher *loading* of optical radiation, and higher bulb-wall temperatures. This led first to the development of small low-voltage reflector lamps and later in the incorporation of tungsten halogen capsules in various reflector envelopes such as PAR and MR. Tungsten halogen and halogen infrared capsules are today housed in A, G, BT, F and other envelopes as replacements for conventional GLS incandescent lamps. See Figure 7.16 for bulb shapes. The small size of the capsule makes it more economical to incorporate larger molecular weight atoms in the gas fill. Some capsules are also pressurized, which further retards the evaporation of tungsten, thus allowing for longer life and/or an increase in efficacy. These variables of lamp engineering—gas fill, gas fill pressure, operating temperature—are responsible for the fact that tungsten halogen and halogen infrared lamps have longer lives and/or greater efficacy than standard filament lamps. The halogen cycle is itself not responsible for an increase in life; it is responsible for keeping the bulb wall clean of tungsten and maintaining lumen output.

7.2.3 Spectrum

Filament lamps produce proportionally more long-wavelength optical radiation than short. Most of the radiation is in the infrared part of the spectrum, as illustrated in Figure 7.19. The SPD for a neodymium doped incandescent lamp is shown with a standard

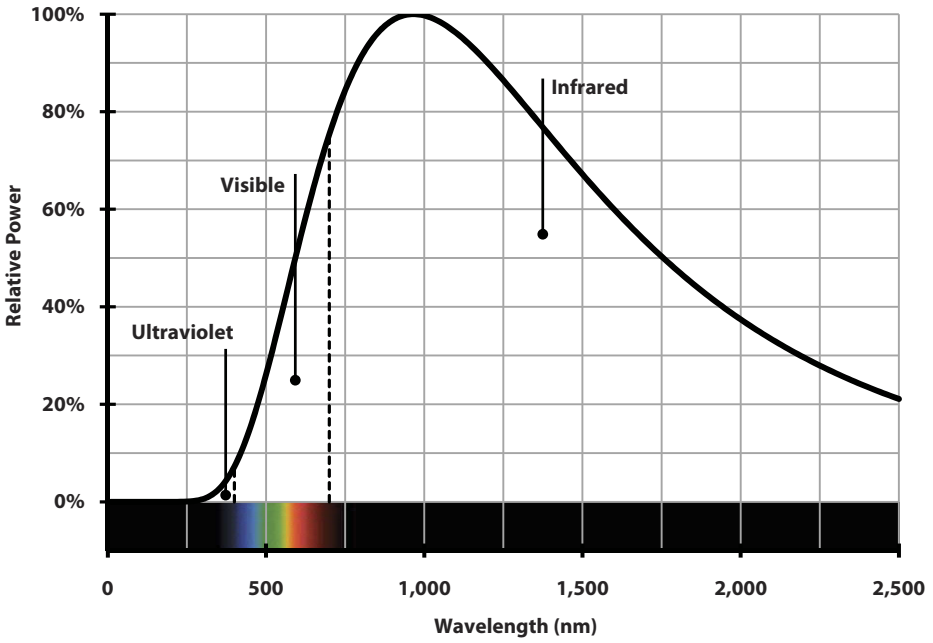


Figure 7.19 | Filament Lamp Optical Radiation
Spectral power distribution for tungsten at 3000 K in the ultraviolet, visible, and infrared regions of the spectrum.

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incandescent lamp in Figure 7.20. Figure 7.21 illustrates SPDs in the visible region from tungsten filaments of equal input wattage but different temperatures. Within the visible spectrum, there is proportionally more long-wavelength power as CCT decreases, which explains why the dimming of filament lamps makes them appear warmer.

7.2.4 Luminous Intensity Distribution

The filament may be shaped to slightly modify the distribution emitted from the bulb, but major optical redirection is best achieved with reflection and/or refraction. Reflectors may be incorporated into a filament lamp, as with PAR, MR, and AR shaped bulbs. PAR lamps also incorporate a refractive optical element at the face of the lamp. Luminous intensity distributions are available from nearly-isoradiant, to wide flood, to very narrow spot. Figure 7.22 illustrates how beam angle is defined for reflector lamps.

7.2.5 Operating Characteristics

If the voltage applied to the filament is varied, there is a change in the filament temperature, resistance, current, power, lumen output, efficacy, and life. These characteristics are interrelated; not one of them can be changed without affecting the others. Some are input variables while others are output measures. For example, increasing current (an input variable) will increase lumen output (an output measure). These interrelationships are plotted on Figure 7.23.

7.2.5.1 Voltage

Filament lamps are available in line-, low-, high- and specialty-voltage designs. In comparison to line-voltage lamps, low-voltage lamps have the advantages of greater resistance to vibration and shock because of their larger diameter filaments, a more compact filament that allows better beam control, and higher efficacy. Typical low-voltage lamps operate at 12 and 24 V. Voltage is supplied through a step-down transformer. Low voltage lamps tend to be either small capsules, such as T4, or small reflector types, such as MR16. High voltage lamps for 220 and 300 V operation are available, but they represent a very

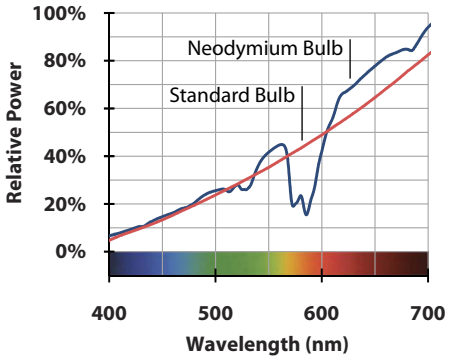


Figure 7.20 | Filament Lamp SPDs
SPDs for a standard filament GLS incandescent lamp and for an incandescent lamp with a neodymium bulb.

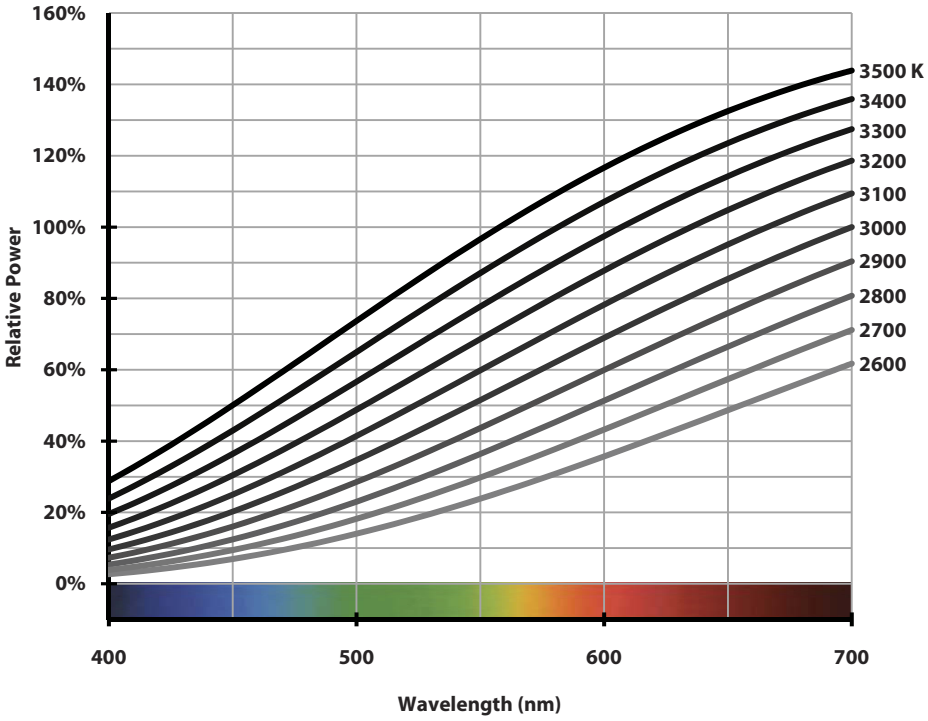
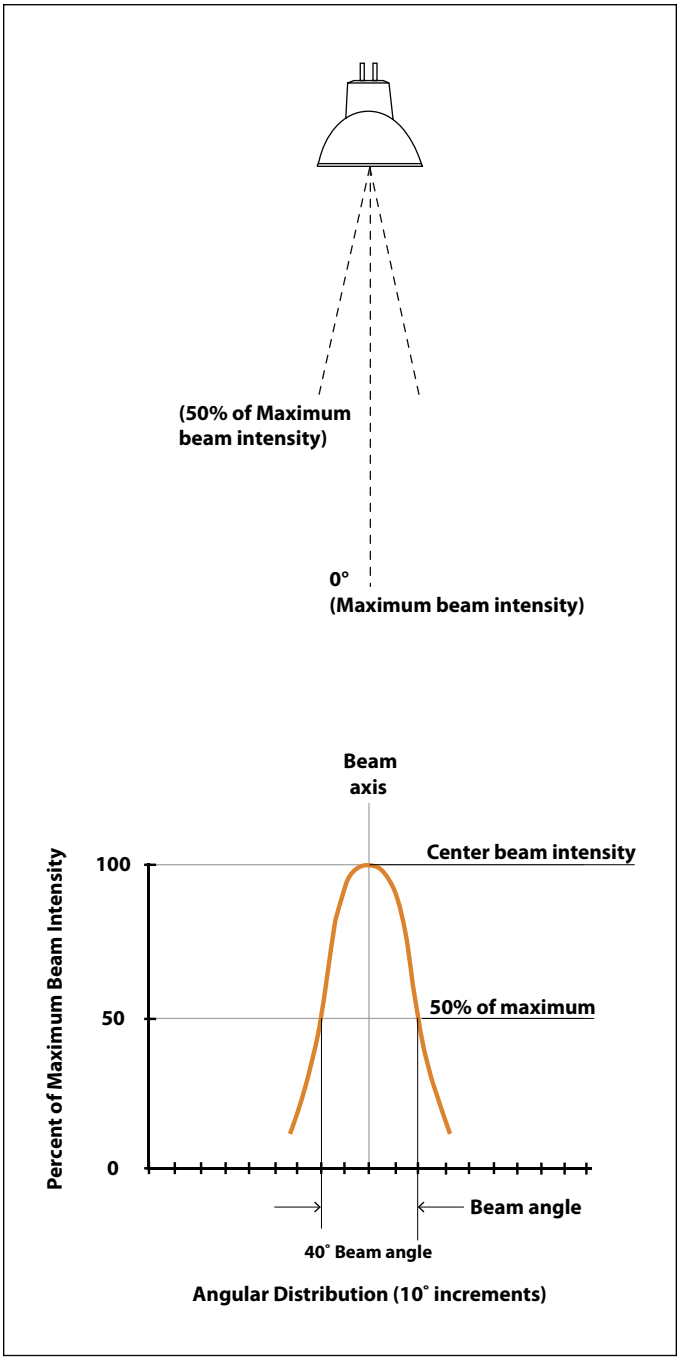


Figure 7.21 | Filament Lamp SPDs as a Function of Temperature
SPDs in the visible region from tungsten filaments of equal wattage but different temperatures.

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Figure 7.22 | Beam Angle
The beam angle is the angle within which the lamp produces 50% of maximum luminous intensity.



small portion of the lamp demand in North America. High voltage lamps have filaments of small diameter and longer length and require more supports than corresponding 120 V lamps. Therefore they are less rugged and less efficient. For specialty applications, lamps with other voltage ratings, such as 84 and 200 V, are also available.

130 V lamps are also available, and in the past have been intended for use on 120 V circuits. This had the effect of operating the lamp in a continuously dimmed state, thus extending life, but at a lower luminous efficacy. The U.S. DOE rulemaking for 2012 standards will likely eliminate this practice as it relates to PAR 20, 30, and 38 lamps. See 13.12.2 Legislation for 130V PAR Filament Lamps

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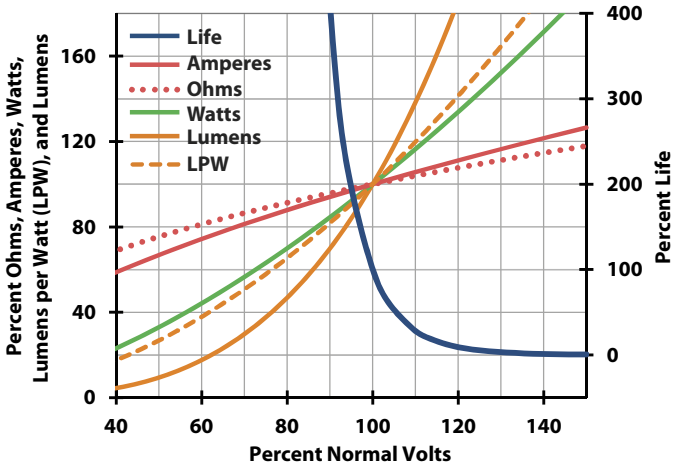


Figure 7.23 | Filament Lamp Operating Characterisitics vs. Voltage
Effect of voltage and current variation on the operating characteristics of incandescent filament lamps.

7.2.5.2 Dimming

Dimmers serve several purposes: energy reduction; variable illuminance; and aesthetic lighting effects. Filament lamps can be dimmed by reducing the voltage or by rapid on/off switching. With either method, less power is dissipated and less light is produced with a lower color temperature. Since lower temperature operation decreases tungsten evaporation, life is increased but at the expense of luminous efficacy. Dimming tungsten halogen and halogen infrared lamps has a deleterious effect on lumen maintenance because the halogen cycle no longer operates when the bulb wall temperature falls below 260° C, leading to bulb wall blackening (see 7.2.2.4 Gas Fill and the Tungsten Halogen Cycle). This can be partially reversed by periodically operating the lamp at full light output, which helps clean the bulb wall of tungsten deposits.

Thyrisor A three-state solid state semiconductor device that is employed as a bistable switch when integrated into a dimming circuit.

Most dimmers for filament lamps are electronic, using *thyristor* and transistor circuits that have low power dissipation. Thyristors operate as high-speed switches that rapidly turn the voltage to the lamp on and off. The rapid on/off switching, or 'chopping', lowers time-averaged power consumed by the lamp, thus lowering the filament temperature while reducing energy consumption. This is different than lowering the voltage delivered to the lamp. This switching can cause electromagnetic interference with other electrical equipment as well as audible buzzing in the lamp filament. Magnetic coils functioning as inductors and known as chokes can be used as filters to reduce these effects. With many wall-box dimmers, however, lamp buzzing cannot be completely eliminated because a larger choke is needed than space allows. For these cases, remotely mounted, properly sized lamp debuzzing coils or additional chokes are recommended.

7.2.5.3 Luminous Efficacy

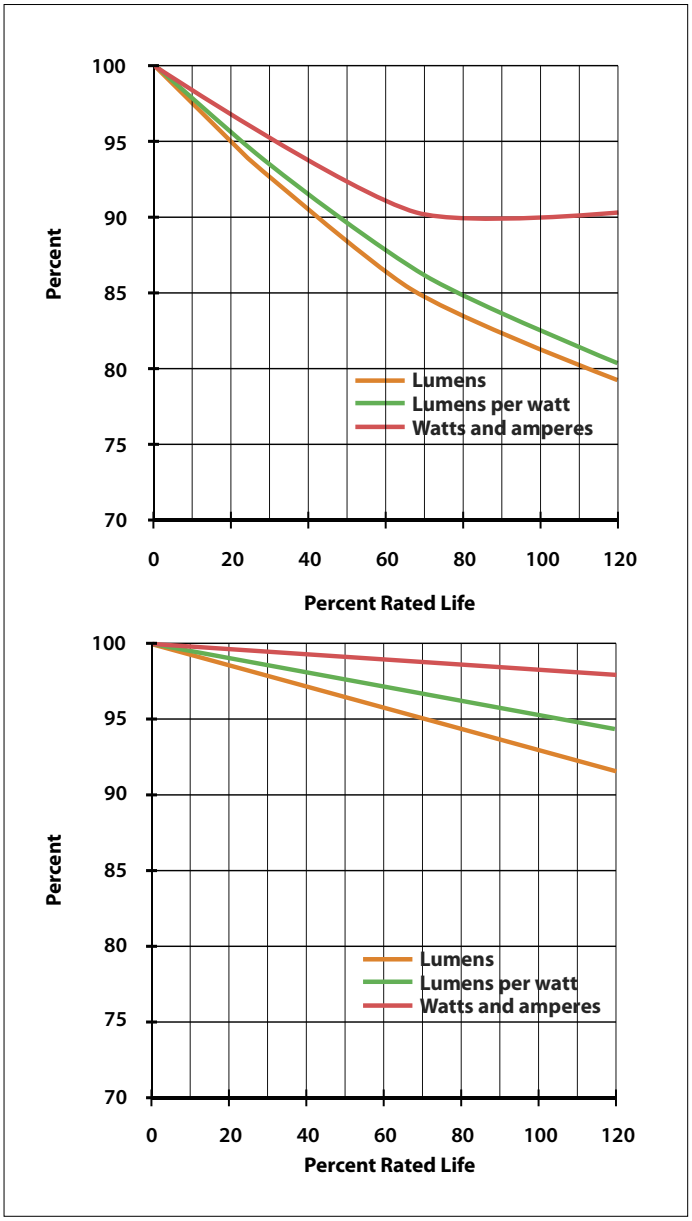
A typical T60 shaped halogen infrared lamp (as of this writing) has an efficacy in excess of 22 lumens per watt. The typical efficacy (as of this writing) for a PAR38 halogen infrared lamp is about 24 lumens per watt. The most efficacious commercially available halogen infrared lamps (as of this writing) are double-ended cylindrical bulbs that achieve efficacies in excess of 34 lumens per watt.

7.2.5.4 Lumen Maintenance

Over time incandescent filaments evaporate and shrink, which increases their resistance thereby reducing current, power and lumens. A further depreciation in lumens is caused by the absorption of light due to the deposition of evaporated tungsten on the bulb wall. Tungsten halogen and halogen infrared lamps have significantly less lumen depreciation due to the halogen cycle. Figure 7.24 shows changes in light output and efficacy for typical incandescent, tungsten halogen, and halogen infrared lamps.

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Figure 7.24 | Lamp Lumen Depreciation for Filament Lamps
Typical operating characteristics as a function of burning time: (a) general tungsten halogen lamps and (b) tungsten halogen and halogen infrared lamps. Note the differences in scales.



7.2.5.5 Ultraviolet Radiation

When operated at full output filament lamps generate some ultraviolet (UV) radiation. The higher the filament temperature, the greater is the amount of UV generated by the filament. The amount of UV that escapes the bulb is determined by the capsule and/or outer envelope materials. Fused quartz and most high-silica glass transmit most of the UV radiated by the filament, while high-silica and aluminosilicate glasses absorb UV radiation. Some tungsten halogen lamps transmit more UV radiation than standard incandescent lamps due to their higher filament temperatures and quartz envelopes. Halogen infrared lamps, however, emit less ultraviolet radiation despite their higher filament temperature, as the capsule absorbs ultraviolet radiation. If the lamp does not filter UV radiation then a UV-absorbing lens or cover glass should be employed. A tempered lens will also provide protection in case of lamp breakage. In applications where the reduction of UV radiation is critical, additional filtering as with a supplementary lens or cover glass might be required.

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7.2.5.6 Special Considerations

Tungsten halogen and halogen infrared lamps are not equipped with filament supports since they would reduce luminous efficacy by conducting heat away from the filament. It is also desirable to remove filament supports since they introduce non-uniformity and striations in the beam. However, without such supports tungsten halogen and halogen infrared lamps are susceptible to premature failure from rough handling or vibration. As with all lamps, these lamps should be installed when power is off. Rotational torque during installation or relamping causes the filament to move. In energized sockets the inrush current shocks the moving filament and some of the filament turns may be shorted, leading to failure. For directional lamps that cannot be extinguished during aiming, they should be aimed with slow, smooth movements.

7.2.5.7 Lamp Life and Failure Mechanism

Many factors inherent in the manufacturing process make it impossible for every lamp to achieve the rated life associated with the product. For this reason, lamp life is rated as the average of a large group. A range of typical mortality curves representing the performance of high quality lamps is illustrated in Figure 7.25.

For laboratory test operation normal tungsten filament evaporation determines lamp life. Lamp life may also be determined by filament notching, which is the appearance of step-like or saw-tooth irregularities on all or part of the tungsten filament surface. These notches reduce the filament wire diameter at these points. Faster spot evaporation due to high temperatures at the notch and reduced filament strength become the dominant factors influencing lamp life. Predicted lamp life can be reduced by as much as one-half. Among the factors producing filament notching is direct current (DC) operation.

7.2.6 Nomenclature

The typical nomenclature for filament lamps follows a pattern of: Wattage/Shape/Diameter/Technology/Optical. For example, 55PAR38/IRC/Hal/SP10 indicates a 55-watt lamp with a parabolic aluminized reflector (PAR) outer bulb, which has a diameter of 38/8" (4 ¾"), employs halogen infrared technology (IRC/Hal), and has a spot distribution with a beam angle of 10 degrees. The specific nomenclature varies from one manufacturer to the next, but follows a similar format. Not all lamp types require all categories to be listed. The diameter designation may be in units of 1/8" or mm, which must be inferred from context. For example, an AR111 is an aluminized reflector lamp with a diameter of 111 mm and a T60 lamp is a "T" shaped lamp with a diameter of 60 mm. The "T" (tubular) is a straight sided version of the ubiquitous "A" (arbitrary) shaped bulb. Refer to Figure 7.16.

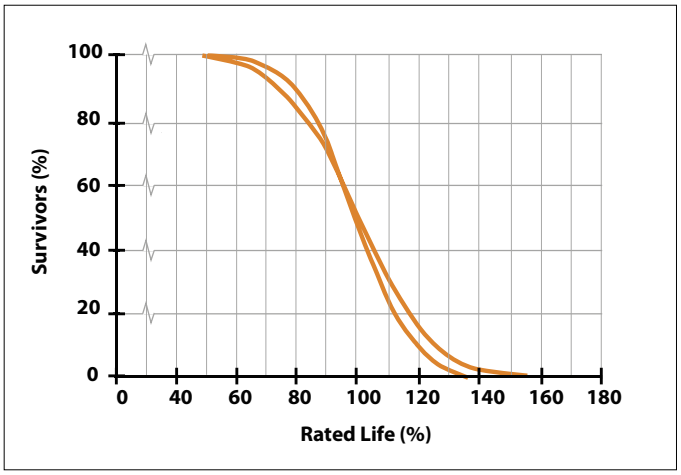


Figure 7.25 | Mortality Curves
Range of typical mortality curves based on averages for a statistically large group of incandescent filament lamps.

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7.2.7 Types

There are no sharp dividing lines among groups of filament lamps. Figure 7.26 [23] provides a general taxonomy, but it is not all-inclusive. The sources most suitable for application in the built environment are outlined below. Even so, filament sources should seldom be used in permanent installations, and preferably only in situations where they are not the sole source of light or operated continuously for long periods.

7.2.7.1 General Lighting Service (GLS)

Standard filament GLS lamps are rarely appropriate for functional lighting and should be reserved for special situations, such as where low-wattage bare lamps are needed for decorative appearance and effect. If filament lamps must be used for functional lighting, tungsten halogen or halogen infrared are the appropriate choices. Common shapes include the T60, BT, and TB.

7.2.7.2 Reflector Lamps

Halogen infrared reflector lamps include the PAR and MR shapes. PAR is an acronym for parabolic aluminized reflector. Some advanced PAR lamps are now reflectorized with silver due to its higher reflectance, but they are still known as PAR lamps. PAR lamps are made of precisely formed cast glass with aluminum or silver deposited on the inner surface. A halogen infrared capsule is fitted at the focal point of the parabola, such that rays are reflected parallel to one another. A refractive optical component attached to the face of the reflector disperses the beam of parallel reflected rays, as well as the rays that directly strike it from the filament. Different refractive optical components control whether or not the beam is narrow (spot) or wide (flood). A wide range of beam angles (see Figure 7.22 Beam Angle) are available from Very Narrow Spot (VNSP ≤ 7°), through Narrow Spot (NSP 8 to 10°), Spot (SP 11 to 14°), Wide Spot (WSP 15 to 18°), Very Wide Spot (VWSP 19 to 23°), Narrow Flood (NFL 24 to 32°), Flood (FL 33 to 44°), Wide Flood (NSP 45 to 55°), and Very Wide Flood (VWF ≥ 56°). A wide range of wattages are available, in PAR20, PAR30, and PAR38 diameters, and with different maximum overall lengths. PAR lamps are most commonly designed for line voltage (120 V) operation.

MR is an acronym for multifaceted reflector. The most common type, MR16 lamps, have a 2” diameter reflector that surrounds a small tungsten halogen or halogen infrared capsule. Because of the possibility of non-passive failure, MR16 lamps with exposed capsules are only intended to be used with luminaires that incorporate a tempered glass lens. MR16 lamps with integral lenses are available for use in open luminaires. Most MR16 lamps are designed for 12V operation and therefore require a transformer. Some MR16 lamps are also available with screw-bases; in these cases the transformer is built into the lamp itself. The screw-based MR16 lamps are intended as a retrofit product and are considerably larger than the standard MR16 lamps that make use of a 2-pin or turn-and-lock base.

Other 12 V tungsten halogen lamps include the PAR36, AR70, and AR111. None of these lamps employ a halogen infrared capsule, and their luminous efficacy is accordingly lower. However, these lamps employ a filament cap that serves two purposes: 1) it eliminates the light emitted directly from the filament, thus leading to a highly controlled and crisp-edged beam; 2) it blocks a view of the filament, providing much less glare from most viewing angles. The lack of spill light and glare makes them suitable for high contrast focal lighting. These lamps are used in limited situations where beam control, luminous intensity, and dimming are more important than luminous efficacy. By limiting unwanted stray light they may provide energy effective solutions.

7.2.7.3 Double-Ended Lamps

The T3 halogen infrared lamp has a tubular shape with a 3/8” diameter. This lamp is available for 120, 130, 240, and 277 V operation. Its linear filament and small bulb diam-

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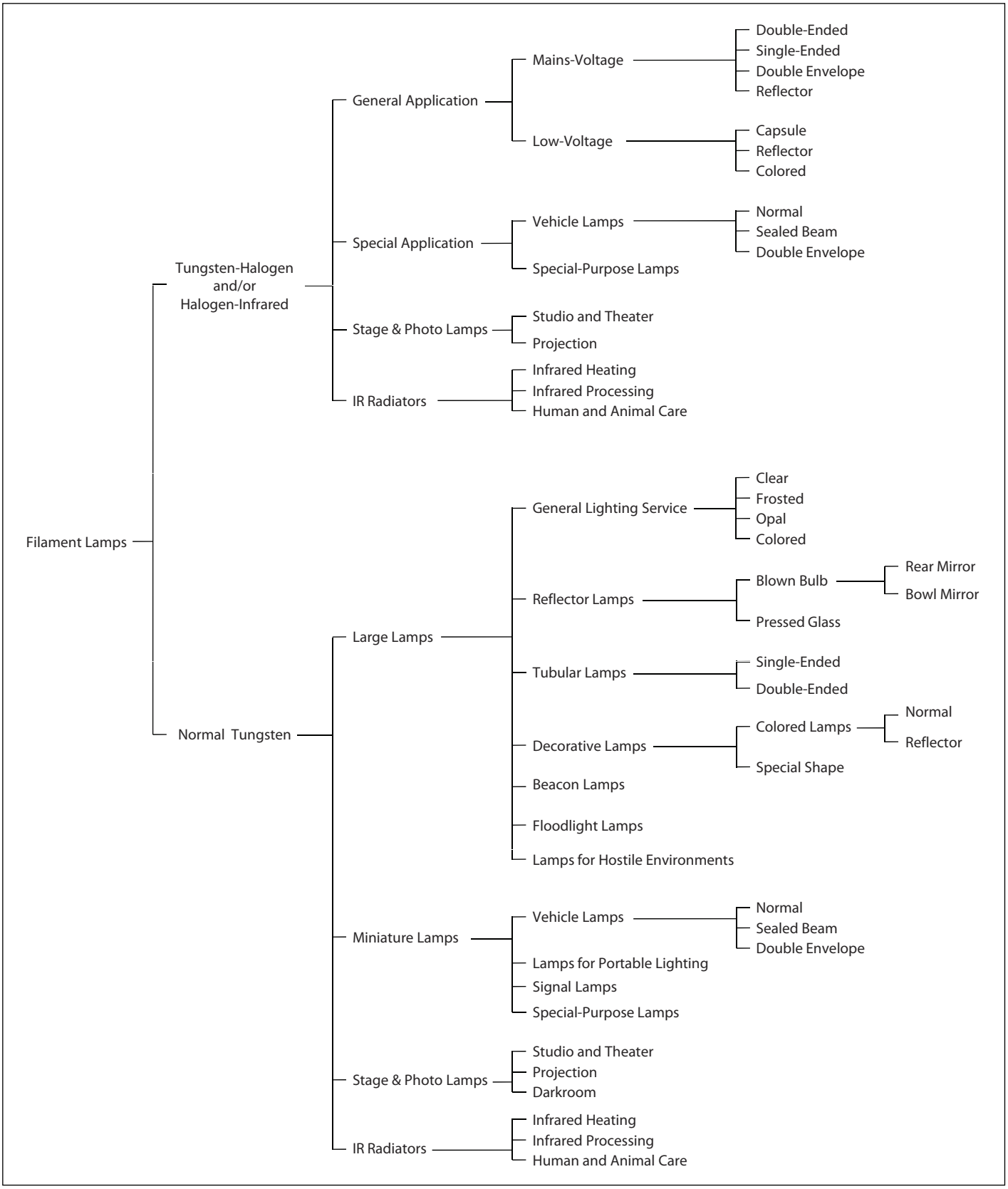


Figure 7.26 | Taxonomy of Filament Lamps
A summary of the major categories of filament lamps, after [23].

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eter makes it well suited for highly efficient linear reflectors used in surface washing and grazing applications. These lamps should be used sparingly, but may be appropriate in applications that require punch and that will only be used for relatively few hours per week.

7.3 Fluorescent

Fluorescent lamps are the most widespread and versatile of the discharge lamps. They are employed almost universally in offices, educational facilities, healthcare, and other commercial applications, while finding widespread use in industrial, retail, institutional, and residential lighting. This is because fluorescent lamps are available in a wide variety of lumen outputs, shapes, and colors, while having desirable characteristics that include good to excellent life, luminous efficacy, lumen maintenance, and color rendering.

7.3.1 General Principles of Operation

The fluorescent lamp is a low-pressure gas discharge source, in which light is produced predominantly by fluorescent powders, also known as phosphors, that are activated by UV energy generated by a mercury arc. See also 1.4.1 Atomic Structure and Optical Radiation. The electrodes (see 7.3.2.2 Electrodes) of most fluorescent lamps are pre-heated prior to ignition, causing them to emit electrons, which collide with mercury atoms contained within the discharge tube. Collisions may happen with such force to free electrons from mercury atoms, a process known as ionization, which is necessary to maintain the arc. Collisions at lower force may elevate an electron of the mercury atom to a higher energy level, which is known as excitation. When the electron of an excited mercury atom returns to its rest state, a photon is released. In a low-pressure mercury discharge most of these photons are in the ultraviolet (UV) region of the spectrum. Phosphors on the inside of the tube convert the UV radiation into visible optical radiation. This process is illustrated schematically in Figure 7.27.

Because the mercury discharge has a negative volt-ampere relationship, fluorescent lamps must be operated in series with a current-limiting device, commonly called a ballast. A ballast limits the current to the value for which the lamp is designed, provides the required starting and operating lamp voltages, and may provide dimming control.

7.3.2 Construction

The basic components are the bulb, electrodes, gas fill, phosphor, and base. The ballast may be an auxiliary component or integrated within the lamp itself. See 7.3.6.5 Ballasts.

7.3.2.1 Bulb

The tube of a normal linear fluorescent lamp is made of soda-lime glass doped with iron oxide to limit the emission of UV radiation. Low sodium content glass is also used for very highly loaded lamps, such as compact fluorescent lamps (CFLs). Tube length and

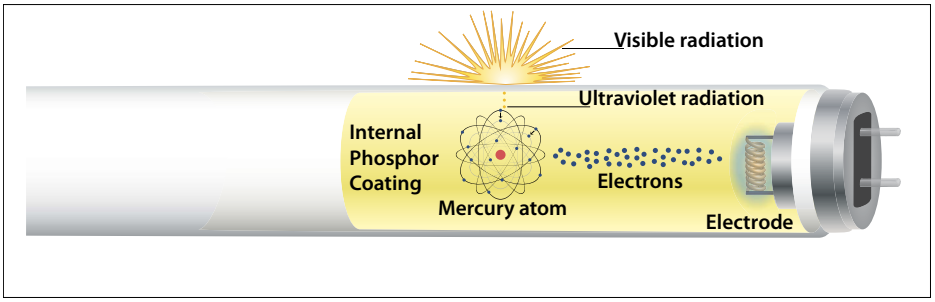


Figure 7.27 | Fluorescent Lamp Operation
Schematic illustration of the process of creating optical radiation with a fluorescent lamp.

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diameter have been standardized (see 7.3.4 Nomenclature). Diameter is determined first by the desired loading on the phosphors; higher loadings increase lumen output per unit area, and are associated with smaller tube diameters. Length is dictated first by the luminous flux to be produced by the lamp. All else being equal, higher lumen output requires more surface area of phosphor and therefore longer tubes. The diameter and length also dictate the voltage across the discharge tube, and hence lamp voltage. Reducing the diameter increases the required lamp voltage, and increasing the length increases the required lamp voltage. It is also possible to adjust lamp voltage by altering the gas fill (see 7.3.2.3 Gas Fill). Single ended fluorescent lamps, such as CFLs, have multiple shaped tubes joined together to form a continuous arc path. This is done to increase the ratio of lumen output to overall size. Some bubs are designed to approach the size of a GLS incandescent lamp.

7.3.2.2 Electrodes

Two electrodes are hermetically sealed at opposite ends of the bulb. They conduct electrical power into the lamp and provide the electrons necessary to maintain the arc discharge. Constructions vary, but all are made of tungsten coated with a mixture of alkaline earth oxides, which readily emit electrons when heated to a temperature of about 800° C. The tungsten is coiled into shapes similar to those used in incandescent lamps, although triple coils are common, as are structures made by winding one tungsten wire around another and then double-coiling the resulting wire, a structure known as 'wound round' or 'intertwined'. Coiling and winding are done to hold as much emitter material as possible.

Electrodes may be preheated, continuously heated, or 'cold', states which are controlled by the ballast. In the 'cold' mode, high voltage is used to start the fluorescent lamp instantly, causing electrons to bombard the electrodes at high velocity. Such collisions heat the electrodes and facilitate the emission of electrons via thermionic emission. Ion bombardment also occurs, which causes sputtering of the electron emissive material leading to end blackening and reduce electrode life. In some lamp designs electrode life is the principal cause of lamp failure, and thus, the instant start associated with the 'cold' mode may lead to premature lamp failure. Preheating is gentler on the electrodes. It causes them to emit electrons that facilitate starting with less loss of electron emissive material. Once the lamp is operating, the ballast may continue to heat the electrodes or switch them off. Since the temperature necessary for continued electron emission is maintained by electrons from the discharge that bombard the electrodes, and because energy can be conserved, it is most common to employ ballasts that switch off the heating.

7.3.2.3 Gas Fill

The inside volume of the tube is a near-vacuum containing a mixture of saturated mercury vapor and an inert buffer gas.

The inert buffer gas controls the speed of the free electrons in the discharge, which is important because: 1) it prolongs the life of the electrodes by reducing sputtering that results from high velocity ion bombardment; 2) it balances the fraction of ionization versus excitation that results from collisions between electrons and vaporized mercury. If the electron and ion speeds are too high, the result is excessive sputtering and too little mercury excitation. The inert gas also facilitates starting, especially at low temperatures. Buffer gasses include argon, neon, xenon, and krypton. For a given tube length and diameter, lamp voltage decreases as the atomic weight of the buffer gas increases. This is one of the principal variables in creating, for example, 28 or 30 W T8 lamps that operate on ballasts originally intended to drive 32W T8 lamps.

During normal operation mercury is present in the tube in both liquid and vapor forms. Mercury condenses on the coolest part of the bulb, which for linear lamps will normally be at the bottom-middle of the tube. The mercury vapor pressure is strongly dependent

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upon temperature. The fraction of radiant energy emitted in the UV bands is strongly dependent upon the vapor pressure, and since luminous flux output is strongly dependent upon the generation of UV by the mercury, it is highly sensitive to ambient temperature. Figure 7.28 illustrates lumen output as a function of bulb wall temperature.

A mercury amalgam may be employed to reduce temperature dependence. An amalgam is a chemical compound consisting of mercury and one or more metals, such as the bismuth-indium-mercury amalgam commonly employed with CFLs. The amalgam stabilizes and controls the mercury vapor pressure in the discharge by absorbing or releasing mercury, thus keeping mercury pressure in the discharge close to its optimal value as the lamp temperature changes. An amalgam lamp can produce more than 90 percent of its maximum light output over a wide temperature range, as illustrated in Figure 7.29. A downside is that amalgam lamps can take longer to reach full light output when turned on, usually in the order of several minutes in a room-temperature ambient environment.

Figure 7.28 | Lumen Outpus vs. Bulb Wall Temperature
Typical fluorescent lamp temperature characteristics for nonamalgam lamps. Exact shape of curves will depend on lamp and ballast type; however, all nonamalgam fluorescent lamps have curves of the same general shape, since this depends on mercury vapor pressure.

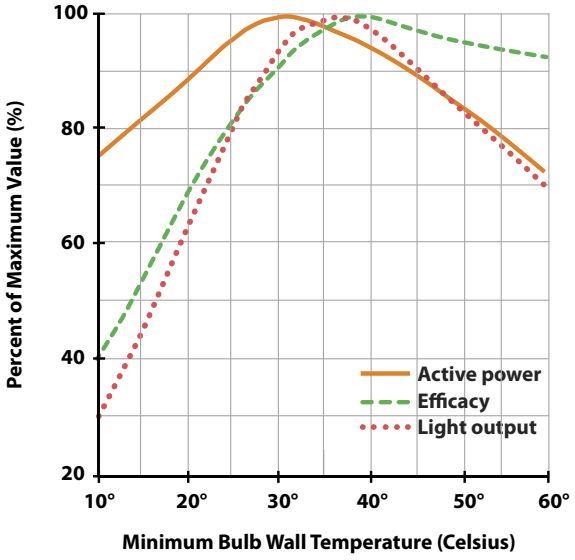
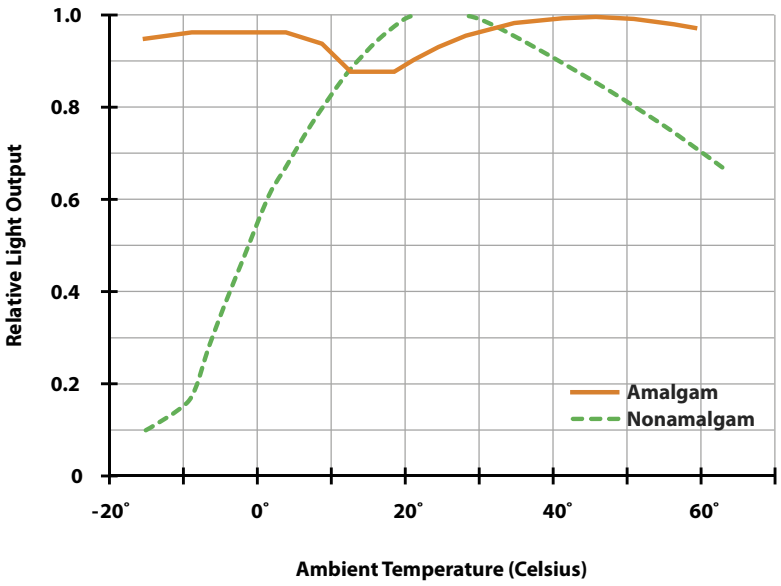


Figure 7.29 | Amalgam and Non-Amalgam CFLs
Comparison of relative light output vs. ambient temperature for two compact fluorescent lamp designs, with and without amalgam. Both are for base-up operation.



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7.3.2.4 Phosphors

Approximately 97% of the fluorescent lamp spectrum is determined by the phosphor, with the balance due to direct emission from the low-pressure mercury discharge into visible optical radiation. The choice of phosphors fixes the lamps CCT and CRI, and is strongly related to luminous efficacy and lumen maintenance. Table 7.3 lists some commercially important phosphors. Although several naturally occurring minerals exhibit fluorescence, those listed in Table 7.3 are a product of modern chemical engineering. The requirements of modern light sources demand highly purified compounds combined with a small amount of another compound that serves as an *activator*. Luminous efficacy is also dependent upon the physical characteristics of the phosphor and how it is applied to the bulb wall. It needs to be thick enough to efficiently convert UV into visible optical radiation, yet as thin as possible to prevent the outer layers from absorbing the optical radiation emitted by the inner layers. In modern lamps the average thickness of the phosphor layer is about three layers of crystals.

Activator A dopant added to a phosphor that contributes to the emission of optical radiation.

7.3.2.5 Bases

The base physically supports the lamp and provides a means of electrical connection. Typical bases for linear and compact fluorescent lamps are shown in Figure 7.30, which also includes ANSI designations.

Preheat and rapid start linear fluorescent lamps have four electrical connections, two at each end of the tube; which allows a circuit path for electrode heating prior to lamp ignition. Such medium bipin linear fluorescent lamps may also be operated in an instant start mode, which is governed by the ballast. Linear fluorescent lamps designed for only instant-start operation have just two connections, one pin at each end. Many sockets are available for fluorescent lamps with bipin bases, including those with straight-slot entry and quarter-turn sockets that click and lock the lamp in place. Spring-loaded plunger sockets are available for single pin and bipin based fluorescent lamps. In the case of circular lamps, a single four-pin connection (G10q) is employed.

Table 7.3 | Important Fluorescent Lamp Phosphors

Compound	Commercial Name	Activator	Main Emission Peak (nm)	Color of Fluorescence
Halos				
• Calcium halophosphate	Apatite	antimony & manganese	--	white
Triphosphors				
• Strontium chlorapatite	--	europium	447	blue
• Barium magnesium aluminate	BAM	europium	447	blue
• Sr, Ca, Ba chlorapatite	--	europium	453	blue
• Cerium terbium magnesium aluminate	CAT	--	541	green
• Cerium gadolinium magnesium borate	CBT	terbium	542	green
• Yttrium oxide	YOX, YEO	europium	610	red-orange
Specialty Phosphors				
• Barium disilicate	BSP	lead	350	UV
• Zinc silicate	Willemite	manganese	525	green
• Yittrium phosphate vanadate	--	europium	620	red
• Lithium pentaaluminate	--	iron	743	IR

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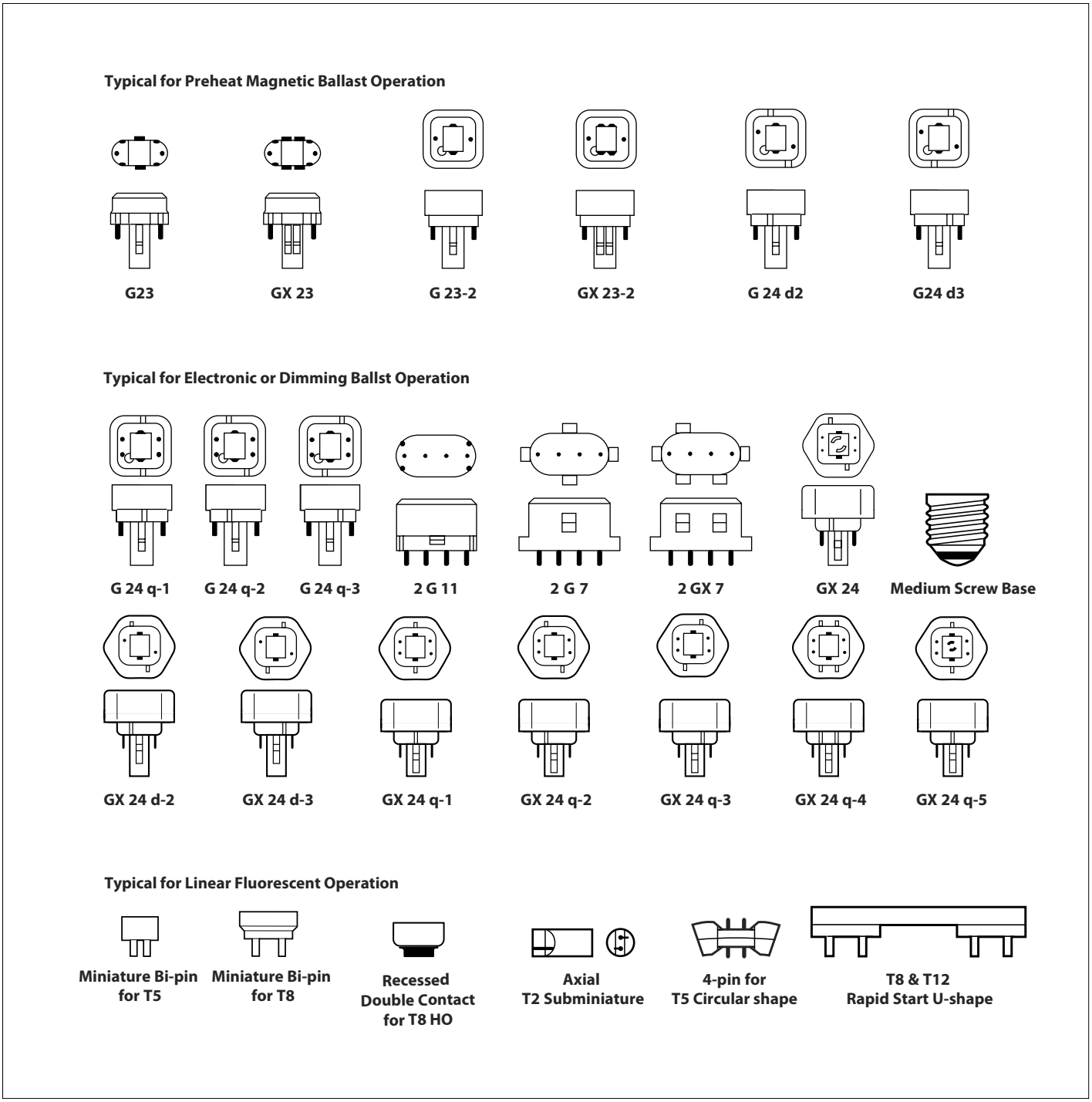


Figure 7.30 | Fluorescent Lamp Bases
Typical bases for linear and compact fluorescent lamps. Not to scale. ANSI designations are shown.
» Images courtesy of Osram Sylvania

Single-ended compact fluorescent lamps of different wattages have unique base designs to help ensure their use with the correct ballast. They may have two or four pins. The two-pin varieties have starting components mounted in the base, including an integral glow-switch starter and noise reduction filter capacitor. These lamps are not dimmable. The four-pin bases are smaller (at equal wattage) and such lamps can be used with dimming ballasts. Compact fluorescent lamps may also have a medium screw base for compatibility with sockets

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originally intended for use with GLS incandescent lamps. Such compact fluorescent lamps have an integral ballast. Note that as pin configuration change, so too will power factor (PF) and total harmonic distortion (THD). This is not directly due to the pin configurations, but is rather due to the different ballast circuitry associated with the different pin configurations.

7.3.2.6 Other Fluorescent Lamp Components

When a fluorescent lamp is extinguished some of the vaporized mercury condenses on the bulb wall, where it may momentarily melt the glass and then become entrapped when the glass cools. Such entrapped mercury will no longer be available to the discharge, and thus mercury entrapment is one possible failure mechanism (see 7.3.6.3 Lamp Life and Failure Mechanism). In the past, lamps were dosed with extra mercury to provide satisfactory life. This is no longer an acceptable practice because of the increased awareness of the detrimental effects of mercury and associated legislation that places upper limits on hazardous materials in consumer products. Modern fluorescent lamps employ barrier layers between the glass and phosphor that minimize the absorption of mercury when the lamp is extinguished, and reduce interactions between the mercury and glass during operation. The barrier also protects the phosphor from the sodium in the glass, significantly improving lumen maintenance. Finally, the barrier acts as a reflector of UV, and thus reduces the amount of phosphor required for maximum luminous efficacy. Materials employed for the barrier layer include alumina, gamma alumina, and alpha alumina, but may also be an oxide formed from the group consisting of magnesium, aluminum, titanium, zirconium, and rare earth elements.

Other coatings are employed as starting aids. A thin layer of tin or indium oxide may be applied between the tube wall and phosphor. This layer helps with cold weather starting, and is also employed in reduced-wattage lamps that are designed to operate on standard-wattage ballasts. Most fluorescent lamps, especially linear types, have a water-repellent coating of silicone applied to their exterior to help prevent starting problems in environments that have high humidity.

7.3.3 Spectrum

Many different white and colored fluorescent lamps are available, each having its own characteristic SPD, examples of which are shown in Figure 7.31. Typical CCT, and CRI are included for each SPD. Popular “white-light” triphosphor fluorescent lamps use three highly efficient narrow-band, rare-earth activated phosphors with emission peaks in the short-, middle-, and long-wavelength regions of the visible spectrum. Triphosphor lamps have high color rendering and improved lumen maintenance and efficacy, in comparison to fluorescent lamps that employ halophosphate phosphors. A variety of lamp types is available that radiate in particular wavelength regions for specific purposes, such as plant growth and medical therapy. Various colored lamps, such as red, blue, green, and gold, are obtained by phosphor selection, and in some cases, subtractive filtration.

7.3.4 Nomenclature

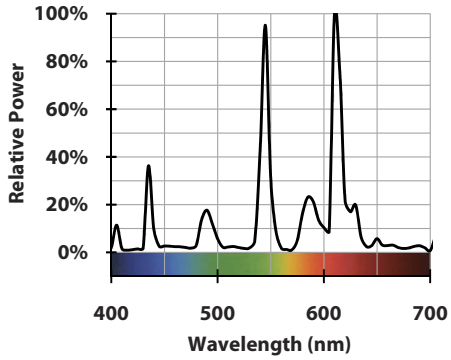
Fluorescent lamp nomenclature tends to follow a standard pattern, as summarized in Table 7.4. This is only one example; often manufacturers will adopt variations. The bulb is typically designated by a letter indicating the shape, followed by a number indicating the maximum diameter in eighths of an inch. Hence T8 indicates a tubular bulb, 8/8 in., or 1 in. (26 mm), in diameter. Numerical codes are included to indicate the CCT and CRI, followed by optional modifiers that may indicate features such as extended life (for example: XL, XXL), reduced wattage (for example: EW, ES), or high lumen output (for example: HL, HO).

7.3.5 Types

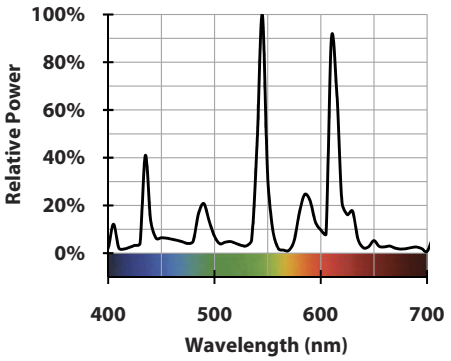
Most fluorescent lamps can be categorized as linear or compact. Standard tube diameters have been adopted for linear lamps: T1 (3.2 mm), T2 (6.4 mm), T5 (16 mm), T6 (19 mm),

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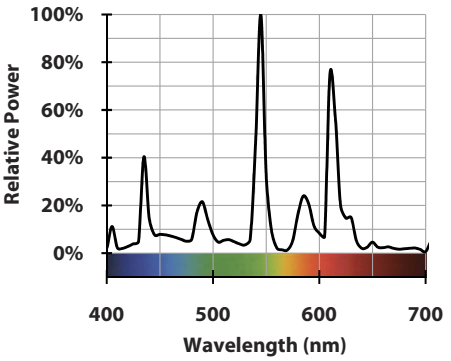
Tri-Phosphor 830
CCT: 3000 K
CRI: 80 - 89



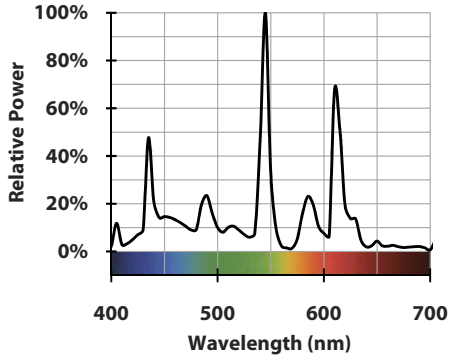
Tri-Phosphor 835
CCT: 3500 K
CRI: 80 - 89



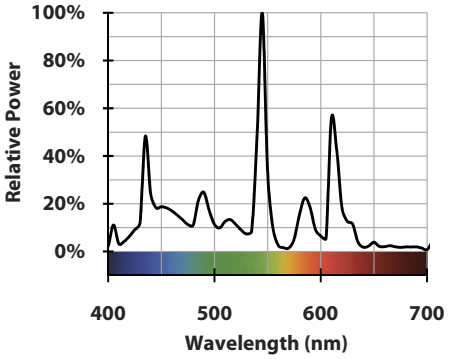
Tri-Phosphor 841
CCT: 4100 K
CRI: 80 - 89



Tri-Phosphor 850
CCT: 5000 K
CRI: 80 - 89



Tri-Phosphor 865
CCT: 6500 K
CRI: 80 - 89



Broadband Color Matching
-CCT: 5000 K
CRI: 90+

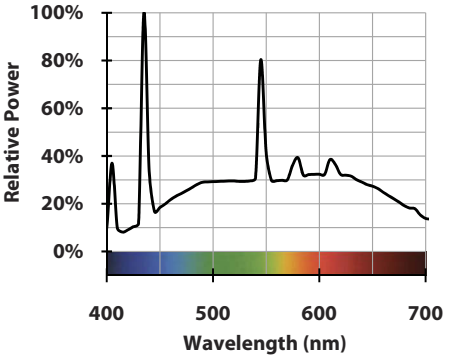


Figure 7.31 | Fluorescent Lamp SPDs
Approximate spectral power distributions for various types of linear fluorescent lamps.

T8 (26 mm), T10 (32 mm), T12 (38 mm), and T17 (54 mm). The most common nominal lengths for straight fluorescent lamps are 24 to 48 in. (1200 mm) for T12 and T8 lamps and 21 to 46 in. (1150 mm) for T5 lamps; the complete range includes lengths from 6 in. (150 mm) to 8 ft. (2400 mm). The nominal length includes the thickness of the standard lampholders and is the back-to-back dimension of the lampholders with a seated lamp. Compact fluorescent lamps are either screw-based (a.k.a. integrated, retrofit), pin-based (a.k.a. dedicated socket), or have a special twist and lock pin base with an integral ballast (a.k.a. GU24). Other types of fluorescent lamps include circular fluorescent lamps, cold cathode, and inductive discharge. The most common fluorescent lamp types are summarized below.

7.3.5.1 Standard Output Linear T12 Lamps

Under the terms of the National Energy Policy Act of 1992 (EPACT) and similar legislation in Canada many of the full wattage T12 lamps can no longer be manufactured due to their relative low efficacy and/or poor color characteristics. The energy legislation allows the use of reduced wattage T12 lamps, such as the 34 W 48 in. lamps, which are promoted as energy-saving lamps. While such lamps consume less energy than those with higher wattage, they are not necessarily more efficacious. The T12, 34 W, 48 in. lamps are filled with an argon-krypton gas mixture, rather than argon only, and dissipate approximately 34 W per lamp with a corresponding reduction in lumen output. These reduced wattage lamps can directly replace their full-wattage T12 counterparts except in applications where the lamp temperature is too cold or the ballast is unsuitable. A typical unsuitable application is a retrofit for “shoplight”

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Table 7.4 | Fluorescent Lamp Nomenclature

	F (a)	32 (b)	T8 (c)	835 (d)	XL (e)
(a)	Lamp type. "F" is employed for fluorescent lamps. "FB" or "FU" is employed for U-bent lamps, "FS" or "FL" may be used for twin-tube lamps, "FD" for double twin-tube, "FT" for triple twin-tube, and "FQ" for quad twin-tube.				
(b)	Wattage for preheat and rapid start lamps; or lamp length (in.) for slimline and some HO lamps.				
(c)	Diameter of tube in eights of an inch. "T8" is a 1-in. (26 mm) diameter tube, and "T5" is a 5/8" (16 mm) diameter tube.				
(d)	Lamp color. The first numeral, in this example "8", represents the first digit of the CRI (between 80 and 89); the next two numerals, "35", represent the first two digits of the CCT (approximately 3500 K). The numerals may be preceded by "RE" for rare earth or they may be manufacturer specific letter codes. For halophosphate lamps the color might be represented as in these examples: "CW" for cool white or "WW" for warm white.				
(e)	Optional modifiers. "XL" or "XLL" represents extra life and extra long life, "HO" and "HL" represent high output and high lumen. Other modifiers are possible.				

luminaires, which are residential grade fixtures, often used in a workshop, that typically contains a low power factor ballast. Suitability should be verified with the ballast manufacturer before retrofitting. Dimming ballasts for reduced wattage T12 lamps are not available.

Lamp-ballast circuits that employ standard output 48 in. T12 lamps are of comparatively low system efficacy. They should generally be replaced with lighting systems that employ more efficient technologies, such as (but not exclusive to) systems that employ electronic ballasts and T5 or T8 lamps.

7.3.5.2 Slimline Lamps

Slimline lamps are similar to standard output T12 lamps in their energy loading. They use a single pin base instead of the double or bi-pin base, are instant start (see 7.3.6.5 Ballasts), and do not require a lamp starter. Slimline lamps are available in several lengths up to 2440 mm (96 in.) and in T6, T8, and T12 diameters.

7.3.5.3 High Output T8 and T12 Lamps

These are rapid start (see 7.3.6.5 Ballasts) lamps designed for higher current operation than standard output lamps. This family of lamps is commonly applied where the standard lamp does not provide sufficient lumen output per lamp length. Both diameters are available in 1220 mm (48 in.), 1830 mm (72 in.) and 2440 mm (96 in.) lengths and are particularly suitable for outdoor applications. They use a recessed double contact base. The standard T12 high output lamps are affected by EPACT legislation; reduced wattage versions are available which meet the legislative requirements.

7.3.5.4 Very High Output T12 Lamps

The 1500 mA fluorescent lamp is of rapid start design and has the highest current density commonly available. It is physically, but not electrically, interchangeable with the 800 mA high output T12 lamp and is used when a lower current lamp will not meet lumen output requirements. The standard lamps are affected by EPACT legislation; reduced wattage versions are available which meet the legislative requirements.

7.3.5.5 Linear T8 Lamps

The relatively small diameter of T8 lamps, in comparison to the T12 cross section that it was originally designed to replace, allows for the economical use of higher quality rare-

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earth phosphors. They are available in many varieties of wattage, length, lumen output, rated life, CCT, and CRI. T8 lamps dominate the market for general lighting.

The standard 48" (1219 mm) T8 lamp is designed to consume approximately 32 W. At the time of writing, versions are available that consume 25, 28, and 30 W. The lower wattage lamps are designed to be compatible with standard ballasts. T8 lamps are available in lengths similar to T12 with compatible bases and sockets, but they have different electrical requirements and require a different ballast. In retrofit situations the ballast must be replaced. See also 13.13.2 High Performance T8 Lamps and Ballasts.

T8 lamps have less embodied energy than T12 lamps because they use fewer raw materials, have reduced packaging, are lighter weight, and less fuel is required for transportation. See also 13.11 Sustainability and 19 | SUSTAINABILITY.

7.3.5.6 Linear T5 Lamps

T5 fluorescent lamps are a family of smaller diameter straight tube lamps employing triphosphor technology. Available in metric lengths and mini bipin bases, the T5 shape provides a higher source luminance than T8 and better optical control. The lamps provide optimum light output at an ambient temperature of 35° C (95° F) rather than the more typical 25° C (77° F) of T8 lamps, allowing for the design of more compact luminaires. Also available are high output versions that provide approximately twice the lumens and wattage at the same length as the standard versions. T5 lamps are designed to operate solely on electronic ballasts. Their metric lengths, special lampholder and ballast requirements, and higher source luminance make them unsuitable for most retrofit applications. T5 lamps are typically used in shallower luminaires than those used for T8 lamps. Luminaire optical efficiency is generally better because of the smaller lamp size. Note that not all T5 lamps are dimmable and the lamp and ballast manufacturers should be consulted to determine dimming compatibility.

T5 lamps have less embodied energy than T8 lamps because they use fewer raw materials, have smaller packaging, are lighter weight, and less fuel is required for transportation. See also 13.11 Sustainability and 19 | SUSTAINABILITY.

7.3.5.7 Pin-based and Screw-Based Compact Fluorescent Lamps

The compact fluorescent lamp family includes a variety of multi-tube, single-based lamps. T4 and T5 tubes are typically used, and there are many techniques of adding, bending, and connecting the tubes to obtain the physical size and lumen output desired. Because of the high power density in these lamps, high performance phosphors are used extensively in order to attain the desired lumen output, lumen maintenance, and color rendering. They were initially designed to physically replace conventional 25 to 100-watt GLS incandescent lamps, but this lamp family now includes sizes that replace linear fluorescent lamps in smaller luminaires. In comparison to filament lamps, compact fluorescent lamps have greater lumens per watt and provide longer lamp life.

As of this writing compact fluorescent lamp wattages range from 5 to 55 W, and rated lumen output ranges from 250 to 4800 lumens. Overall lamp length varies from 100 to 570 mm (3.93 to 22.4 in.), depending on lamp wattage and construction.

Sockets may have 2-pin or 4-pin configurations, or be designed to accept a screw base. Screw-based lamps have an integral ballast, and thus, have a larger overall size than the pin-based versions of the same wattage. The 4-pin versions are generally paired with electronic ballasts that may be dimmable or on/off. The 2-pin versions may also be paired with an electronic ballasts, but they cannot be dimmed. Some screw-based lamps have partial dimming.

7.3.5.8 GU24 Compact Fluorescent Lamps

GU24 is a type of base comprised of two bayonets of a specific shape and spacing, which are compatible with a specially designed twist and lock socket. Compact fluorescent lamps

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that employ a GU24 base have an integral ballast and they are therefore electrically compatible with any luminaire that employs a GU24 socket. The benefit is that a luminaire designed for the explicit use of a GU24 compact fluorescent lamp will not be limited to a single wattage lamp. They are not yet available in the broad range of lamp wattages available in the screw-based configurations. GU24 lamps are available from 7 to 25 W corresponding to 300 to 1750 lumens. Available shapes are intended to be comparable to the incandescent A, flame, globe, and reflector lamps. Some have partial dimming. It is expected that the majority of Energy Star® qualified luminaires will use the GU24 connection.

7.3.5.9 Inductive Discharge Fluorescent Lamps

Inductive discharge fluorescent lamps are low pressure gas discharge fluorescent lamps that operate without the need of electrodes. They use an electromagnetic (EM) field, instead of an electric current passing through electrodes, to excite the gas in a bulb. Because there are no electrodes to fail, they are sometimes called electrodeless lamps, and they have rated lifetimes up to 100,000 hours. Power from the high frequency generator, typically 200-300 KHz in one type and 2.65 MHz in another, couples directly to the mercury vapor discharge. The discharge itself acts as the secondary part of a transformer, the primary part being an antenna. As with standard fluorescent lamps, light is given off by a phosphor coating excited by ultraviolet radiation from the discharge. The discharge vessel and ballast/driver are part of a tuned system. Individual components may be exchanged, but at the moment, the lamp/ballast combination should be from the same manufacturer. Lamps are available in power ranges from 23 W to 165 W. These lamps are finding greater use in hard to reach locations and where lamp or fixture maintenance might be especially difficult.

Like all electronic devices, inductive discharge fluorescent lamps generate EM waves. Electromagnetic interference (EMI) occurs when unwanted EM signals, which can travel through wiring or radiate through the air, interfere with desirable signals from other devices. In the United States, the Federal Communications Commission (FCC) regulates EM emissions in the communication frequencies of 450 kHz to over 960 MHz. Canada also regulates EM emissions over these frequencies through Industry Canada. Manufacturers must comply with FCC regulations to sell products in the United States. However, manufacturer compliance does not assure that EMI will not occur in unregulated frequencies. The International Electrotechnical Commission's (IEC) International Special Committee on Radio Interference, Subcommittee F, develops standards for EMI from lighting devices.

7.3.5.10 Cold Cathode Fluorescent Lamps

Cold cathode fluorescent lamps often are used in decorative, sign lighting, and other architectural applications. Due to the high energy losses associated with electrode operation, they are not as efficacious as the more widespread hot cathode lamps for lengths up to 2.44 m (8 ft.). The lamps can be custom manufactured in special shapes and sizes. They are frequently manufactured with small diameter tubing so they can be bent into various shapes and sizes. Cold cathode lamps with color phosphors can replace neon tubes in many applications where exposed sources are acceptable or desirable. Cold cathode lamps have immediate starting, even under cold conditions, and long life unaffected by the number of starts. Compact cold cathode lamps are also available.

7.3.5.11 UV Lamps

A low pressure mercury discharge generates UV radiation that in an ordinary fluorescent lamp is converted to visible optical radiation by phosphors. UV lamps that make use of the low-pressure mercury discharge fall into two categories: 1) those that create UV-C for sterilization and germicidal applications, and 2) those that create UV-A for special illumination effects as sometimes used in theatres and discotheques (a.k.a. blacklights). UV-C lamps do not use a phosphor. They employ a bulb that transmits UV-C, such as quartz, or a vitreous material with a high percentage of silicon dioxide. These lamps are used to purify water and

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surfaces, harden paints, adhesives and plastics, expose printing plates, and assist with some inspection tasks. UV-A lamps employ a phosphor that converts short wavelength UV-C and UV-B, which is present in the low-pressure mercury discharge, to longer wavelength UV-A. See also 3.6 Germicidal UV Radiation and 13.9 Damage and Physical Harm.

7.3.6 Operating and Other Characteristics

Relevant characteristics for fluorescent lamps include: luminous efficacy, lumen maintenance, lamp life and failure mechanism, system efficacy, ballasts, dimming, thermal characteristics, disposal and recycling, non-visible optical radiation, intensity distribution and source luminance, and flicker.

7.3.6.1 Luminous Efficacy

Three main energy conversions occur in a fluorescent lamp: 1) electrical energy is converted into kinetic energy by accelerating charged particles; 2) kinetic energy is converted to electromagnetic radiation, particularly UV, during particle collisions; 3) UV is converted to visible by the lamp phosphor. During each conversion some energy is dissipated as heat and only a small percentage of the input is converted into visible radiation. Figure 7.32 shows the approximate energy distribution in a typical triphosphor fluorescent lamp.

The geometric design and operating conditions influence efficacy. At constant current, as the lamp diameter increases, efficacy increases, reaches a maximum, and then decreases. This occurs because: 1) in lamps of small diameter, an excessive amount of energy is lost by recombination of electrons with ions at the bulb wall; 2) in lamps of large diameter, losses due to imprisonment of radiation become correspondingly larger. The optimum bulb diameter maximizes efficacy by balancing these factors. The length of the lamp also influences efficacy; the greater the length, the higher the efficacy. This is due to two separate energy losses within the lamp: 1) the energy absorbed by the electrodes, which do not generate any appreciable light; 2) the energy losses associated with the generation of light. The electrode losses are essentially constant, whereas the loss associated with light generation depends on lamp length. As lamp length increases, electrode loss decreases relative to the total loss.

The operating voltage of a lamp, like its efficacy, is a function of its length. The operating voltage is that supplied to the lamp by the ballast. It is not the building system line voltage that is supplied to the ballast.

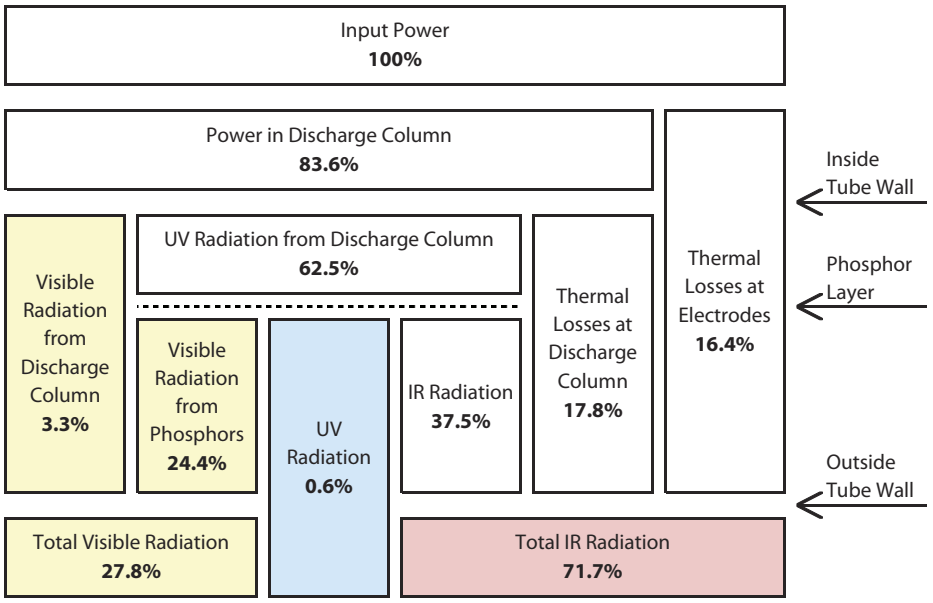


Figure 7.32 | Power Balance for a Typical Linear T8 Triphosphor Fluorescent Lamp
The percentages are fractions of nominal lamp power in units of watts. The figure is organized from top (input power) to bottom (output power).

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7.3.6.2 Lumen Maintenance

The light output of fluorescent lamps decreases with accumulated operating time because of photochemical degradation of the phosphor coating and glass tube and the accumulation of light-absorbing deposits within the lamp. The rate of phosphor degradation increases with arc power and decreases with increased coating density. Lamp lumen depreciation (LLD) curves for different fluorescent lamps are shown in Figure 7.33. Note that luminous efficacy and system efficacy degrade over time in concert with LLD, since input power is relatively constant over the life of a fluorescent lamp. Rare earth phosphors are more stable than halophosphates, allowing for higher wall loadings. The exceptional LLD of modern T5 and T8 lamps is a result of employing rare earth phosphors in concert with protective coatings that are designed to reduce phosphor degradation.

The deposit of electrode coating material causes end darkening. The electrode coating may be sputtered during starting, evaporated during normal lamp operation, and is dependent upon the starting and operating conditions that are governed by the ballast. The deposits reduce UV radiation into the phosphors, thereby reducing light output near the ends.

7.3.6.3 Lamp Life and Failure Mechanism

Reducing power to a fluorescent lamp does not increase lamp life as it does for filament lamps. End of life is most typically due to electrode failure or mercury depletion. A lamp may also fail due to a bad or missing ground connection.

Electrode Failure

Some of the emissive coating on the electrodes is eroded from the filaments each time the lamp is started. Emissive coating is also lost by evaporation during normal lamp operation. Electrodes are designed to minimize both of these effects. When the coating is completely removed from one or both electrodes, or when the remaining coating becomes nonemissive, the lamp has reached end of life.

The loss of electron emissive material can be accelerated by several factors: 1) excessive switching, 2) insufficient preheating of the electrodes, 3) line voltage variations, and 4) sharp peaks in the lamp current.

Because some of the emissive coating is lost from the electrodes during each start, the frequency of starting hot cathode lamps may influence lamp life. The rated average life

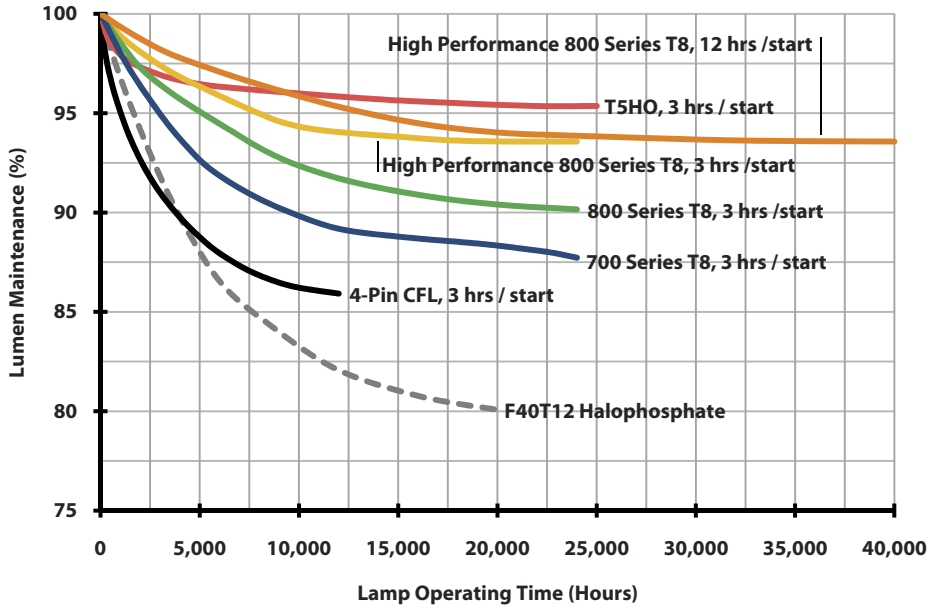


Figure 7.33 | Fluorescent Lamp Lumen Depreciation (LLD)
Curves are based on the hours-per-start listed and specification grade electronic ballasts.

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of fluorescent lamps is usually based on three hours of operation per start. The estimated effect of burning cycles on lamp life varies with the lamp/ballast combination and with the lamp manufacturer. Cold cathode lamps are not appreciably affected by starting frequency.

Insufficient preheating of the electrodes is associated with the ballast. Some electronic ballasts have been designed to instant start rapid-start T8 and T12 lamps (See 7.3.6.5 Ballasts). These lamp/ballast combinations have the advantage of consuming less energy because they do not heat the electrodes initially or during lamp operation. This may come at the expense of lamp life, particularly in applications with frequent switching as with occupancy sensors.

If line voltage is too high, it can cause instant starting of lamps in preheat and rapid-start circuits. If it is too low, slow starting of rapid-start or instant-start lamps, or the recycling of starters in preheat circuits, can result. All of these conditions adversely affect lamp life. The peak current ratio is the quotient of the peak value of the lamp current to the root mean square (RMS) value. For most fluorescent lamps the maximum permissible peak factor is about 1.7, otherwise life may be affected. Magnetic ballasts have a peak factor close to this value, whereas electronic ballasts have a peak factor close to 1.0. Electronic ballasts are also better at governing the voltage across the lamp as line voltage fluctuates. These are two of the reasons why fluorescent lamps operated on electronic ballasts have longer average lives than those operated on traditional magnetic ballasts (see 7.3.6.5 Ballasts).

Mercury Depletion
Mercury consumption is determined by the quantity of mercury which is bound on lamp components during operation, and is thus no longer available for operation of the lamp. Lamp failure can occur when there is no longer a sufficient quantity of mercury to sustain the arc (see 7.3.2.6 Other Fluorescent Lamp Components).

7.3.6.4 System Efficacy

System efficacy is equal to the lumens generated by the lamp when operated with a specific ballast or auxiliary gear, divided by the input watts into that same ballast or auxiliary gear. System efficacy is more relevant to lighting design than luminous efficacy (see 7.3.6.1 Luminous Efficacy). System efficacy applies to all lamps that require a ballast or auxiliary gear, including inductive discharge, HID, cold cathode, and LEDs.

7.3.6.5 Ballasts

Fluorescent lamps, like all discharge lamps, have negative resistance characteristics and therefore must be operated with a ballast, which is a current limiting device. The ballast also controls the starting of the lamp, the electrical conditions during operation (e.g. power factor, harmonics), and is a key component of system efficacy. The current limiting component of a ballast can be a resistor, capacitor, inductor (a.k.a. 'choke'), or an electronic circuit. High frequency electronic ballasts should be employed for new specifications because they have several important advantages over the magnetic types: improved lamp and system efficacy of approximately 10%, no flicker or stroboscopic effects, integrated starting circuitry, increased lamp life, excellent ability to regulate lamp lumen output, integrated power factor (PF) correction, quiet operation, comparatively light weight, many options for input voltage, and some can be used with direct current (DC). Regarding lamp life, some manufacturers provide plots of lamp life as a function of ballast starting method and lamp type, and as a function of the operating cycle. These plots show that the lamp/ballast combination may affect lamp life by 50% or more. The lamp and ballast manufacturers should be consulted when making a specification decision.

Typical parts of an electronic ballast include: electromagnetic interference (EMI) filter; rectifier; preconditioner; high frequency oscillator (inverter); current limiting device; and integrated circuit (IC) control. The EMI filter limits feedback into the power system and protects the internal ballast components from line voltage fluctuations. The rectifier converts AC line voltage into rectified DC voltage. The preconditioner provides a constant

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DC voltage to power a high frequency oscillator, which inverts the preconditioned DC into 20 to 60 kHz AC voltage. The preconditioner may also minimize power line harmonics, contribute to the starting sequence, and provide power factor correction. The IC control board is the brain of the ballast that regulates operation of all ballast components, while sensing and satisfying the power requirements of the lamps that are connected. Electronic ballasts have circuitry for shaping the cold-starting of the connected lamps and the continuous restarting operation, and may have circuitry for sensing and acting on dimming commands. While electronic ballasts use ICs, which are reliable and long-lived, it is still necessary to use large individual components because of the voltage and power involved and the need to limit lamp current.

The starting mode of the ballast circuit may be preheat, rapid start, programmed start (a.k.a program start, programmed rapid start), or instant start. The preheat system requires an external starter or switch and a few second delay to start. Rapid start types essentially give immediate starting with nearly full lumen output and tend to yield rated lamp life. They do so with a short period of electrode heating, followed by the application of a higher voltage to initiate the arc. Instant start ballast forgo electrode and apply a high voltage to create an instant start. Such circuits produce instant lumen output and are traditionally associated with lamps that have single pin base designs. Electronic instant start ballasts are available to operate T8 rapid start lamps; this pairing suffers the possibility of reduced lamp life when lamps are started frequently, such as when controlled by occupancy or motion sensors. Programmed start electronic ballasts are designed to minimize damage to the electrodes during starting. They are designed to maintain rated lamp life, compared to instant start ballasts, when lamps are started frequently. Because of the wide variability in performance characteristics, manufacturers' literature should be referenced when making specification decisions.

Inductors and capacitors put the alternating current (AC) current wave out of phase with the voltage wave. Current through a capacitor is said to lead the applied voltage, and that through an inductor is said to lag. Out of phase conditions are characterized with power factor, which is defined as the ratio of input wattage to the product of root mean square (RMS) voltage and RMS current. It represents the amount of current and voltage that the customer is actually using as a fraction of what the utility must supply. High power factor is defined as being above 90%. A ballast with low power factor draws more current from the power supply, therefore larger supply conductors or more circuits may be necessary. Low power factor ballasts are more common with compact fluorescent systems than for 4-ft and 8-ft fluorescent systems. Some utilities require high power factor equipment or have established penalty clauses in their rate schedule for installations with low power factor.

Ballast factor (BF) is equal to the quotient of the relative lumen output of a lamp (or lamps) operated on the ballast, by the lumen output of the same lamp (or lamps) when operated with a reference ballast. Reference ballasts are discussed in detail for each fluorescent lamp type in applicable ANSI lamp standards. A BF of 1.0 means the ballast will drive the lamp(s) at rated lumen output. If the BF is greater than 1.0, the lamp will produce more than rated lumens. Conversely, if the BF is less than 1.0, the lamp will produce less than rated lumens. Lumen output is equal to the product of the lamp(s) rated lumens and BF. Ballasts are available with BFs greater than or less than 1.0. Fluorescent lamp ballasts can be loosely characterized as high BF (≈1.15), standard BF (≈0.88), and low BF (≈0.75). Commercially, there are many options available within the range of about 0.70 to 1.35. There is not a direct relationship between BF and system efficacy, which tends to be comparable for high, standard, and low BF ballasts. BF can be used to tune lumen output, which is particularly useful when endeavoring to balance luminaire layout with quantity of light and connected power, or in retrofit applications.

Ballast efficacy factor (BEF) was developed solely for regulatory purposes and is unrelated to ballast efficiency. It is computed as ballast factor in percent, divided by the total input

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power in watts. In the United States and Canada, government regulations set limits on the BEF of some ballasts for 1.22 m (4-ft) and 2.44 m (8-ft) fluorescent lamps, as summarized in Table 7.5. Specifically excluded are dimming ballasts, ballasts intended for cold weather starting (as for outdoor signage), and some ballasts that are designed for residential use.

Line current harmonics are those components of the line current that oscillate at low integer multiples of the fundamental frequency of the power supply. In North America, the fundamental frequency is 60 Hz, the second harmonic is 120 Hz, the third harmonic is 180 Hz, and so forth. If corrections are not implemented, solid state electronic components can cause

Table 7.5 | U.S. and Canadian Standards for Ballast Efficacy Factor

Applicable for the operation of:	Ballast Input Voltage (V)	Total Nominal Lamp Power (W)	Minimum Ballast Efficacy Factor (BEF)	
			Level 1	Level 2
New installation ballasts			--	3-Feb-95
Replacement ballasts			1-Apr-05	1-Apr-10
One F40T12 or one F40T10	120	40	1.805	2.29
	277	40	1.805	2.29
	347	40	1.75	2.22
One F34T12	120	34	1.805	2.61
	277	34	1.805	2.61
	347	34	1.75	2.53
Two F40T12 or two F40T10	120	80	1.06	1.17
	277	80	1.05	1.17
	347	80	1.02	1.12
Two F34T12	120	68	1.06	1.35
	277	68	1.05	1.35
	347	68	1.02	1.29
Two F96T12/IS	120	150	0.57	0.63
	277	150	0.57	0.63
	347	150	0.53	0.62
Two F96T12/ES	120	120	0.57	0.77
	277	120	0.57	0.77
	347	120	0.53	0.76
Two 110W F96T12HO	120	220	0.39	0.39
	277	220	0.39	0.39
	347	220	0.38	0.38
Two F96T12HO/ES	120	190	0.39	0.42
	277	190	0.39	0.42
	347	190	0.38	0.41
Two F32T8	120	64	1.25	1.25
	277	64	1.23	1.23
	347	64	1.20	1.20

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substantial line-current harmonics. This can be especially problematic in three-phase installations if the third-harmonic current is large, since the third-harmonic and its multiples add to the neutral wire, while the fundamental currents tend to cancel one another. If the third harmonic is 33.3% of the fundamental, then the total third harmonic on the neutral wire will be equal to the fundamental in the phase wires. This can cause problems, including overheating, if the neutral wire is not sized accordingly. For these reasons ANSI C82.11 Consolidated-2002 [24] places limits on the harmonic content in the line current for electronic ballasts.

7.3.6.6 Dimming

Continuous dimming is achieved by reducing the lamp current. Concurrently, it is necessary to supply the full starting voltage and to maintain the restrike voltage necessary at each 60-Hz half cycle, which becomes increasingly important as lamp lumen output is lowered. If the ballast circuit does not maintain the restrike voltage the lamp(s) will extinguish. It is also necessary to provide cathode heating in order to maintain the required electron emissions from the electrodes at all levels of lumen output.

The requisite electrical conditions are created by a dimming ballast, which receives a signal from a controller such as a wall switch, daylight photocell, computer interface, and/or handheld remote control. Most commercially available dimming ballasts are electronic, though magnetic dimming ballasts may still be encountered in existing construction. The dimming ballast must be able to communicate with the connected control devices, which forms the basis for a controls protocol. Control protocols can be either analog or digital. Analog control equipment includes 0-10V DC, two-wire phase control, three-wire phase control, and infrared control. Digital control makes use of a five conductor system with separate wires for power and digital control. It provides a higher degree of control capability, including the ability to individually address and group ballasts, reconfigure zones and scenes without rewiring, digitally monitor use, and detect and diagnose faults within the lighting circuits. Table 7.6 summarizes the major fluorescent lamp dimming systems that make use of electronic ballasts.

Stepped dimming can be achieved in one of two ways: 1. by switching off one or more lamps in a multi-lamp lamp luminaires; 2. with stepped-dim ballasts. Consider a three-lamp luminaire. In the switching method, a one-lamp ballast or tandem wiring may be used for the inboard lamp and a two-lamp ballast for the outboard lamp. By separately switching the ballasts, zero, one, two, or three lamps may be turned on, corresponding to dimmed steps. Switching may be controlled by a wall switch, occupancy sensor, daylight photocell, time clock, or some combination. In the stepped-dim method, all three lamps would be connected to one step-dimming ballast, designed to operate all three lamps at predefined light levels, such as 33%, 66%, and 100%. Step dim ballasts are available for one to three lamps, and with two or three steps, plus off.

7.3.6.7 Thermal Characteristics

Lumen output for fluorescent lamps is temperature dependent. T5 lamps are designed to achieve rated lumen output at a higher temperature than T8 lamps (see 7.3.5.6 Linear T5 Lamps). Amalgam lamps are designed to maintain lumen output over a wider range of temperatures in comparison to non-amalgam lamps (see 7.3.2.3 Gas Fill). Cold weather starting can be facilitated with special lamp designs (see 7.3.2.6 Other Fluorescent Lamp Components) and control gear (see 7.3.6.5 Ballasts). This temperature dependency places constraints on the design and/or specification of luminaires, which is a central factor in governing the local thermal environment experienced by the lamp(s).

7.3.6.8 Intensity Distribution and Source Luminance

The emission of optical radiation from phosphors is diffuse. The specific intensity distribution of a fluorescent lamp is therefore dependent upon the geometry of the tube, which may be straight, curved, bent in half, or bent many times to form a more compact shape. Unlike tungsten filaments, which can approach point sources, fluorescent lamps emit

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Table 7.6 | Fluorescent Lamp Dimming

Dimming Method	Dimming Range	Wiring	Typical Controls
Digital	1%-117% dimming ballasts are available	Five wire Class 1 cable is recommended. The line, neutral, and ground must be Class 1 rated. The two control wires may be Class 1 or 2. If they are Class 2 then they must be run separately from the power wires. Some codes required a separate Class 2 conduit.	Building energy management system; lighting automation system; occupant override through PC and/or local preset controls; daylight photocells; occupancy sensors.
0-10 V	3%-100% ballasts are available for T8 lamps; 1%-100% ballasts are available for T5HO lamps	The line, neutral, and ground are run through the conduit carrying line voltage wires. The two control wires (often a twisted pair) are Class 2 and are not permitted in the same conduit. Some codes require a separate Class 2 conduit.	Building energy management systems; lighting automation system; local preset controls; daylight photocells; occupancy sensors.
Two-wire phase Control	5%-100% available for T8 lamps; 1%-100% available for T5HO lamps	Power and control make use of the same line-voltage wires. The ballast is wired in the same way as a conventional non-dim ballast.	Local controls accessible to occupants.
Three wire phase control	1%-100% available	All wires are Class 1. Relative to the two-wire phase control ballast, there is an additional control wire that is routed in the same conduit as the other wires.	Building energy management systems; lighting automation system; local preset control; daylight photocells; occupancy sensors.
Infrared control	1%-100% available	No additional wires are required outside of the luminaire. The dimming device is either integral to the ballast or a separate interface within the luminaire.	Infrared transmitter.

optical radiation from a comparatively large area. Smaller lamps and smaller diameter linear lamps permit better luminaire optics. At equal lumen output, a lamp with a smaller surface area will have higher luminance.

7.3.6.9 Flicker

Discharge light sources operated on alternating current will flicker. The degree to which flicker is perceived, if at all, depends on the frequency of the alternating current delivered to the lamp, the persistence of optical radiation generated by the lamp, and viewing conditions.

The flicker index [25] is a relative measure of the cyclic variation in output of various sources at a given power frequency. It takes into account the waveform of the light output as well as its amplitude. It is calculated by dividing the area above the line of average light output by the total area under the light output curve for a single curve, as shown in Figure 7.34. The flicker index has a range of 0 to 1.0, with 0 for steady light output. Area 2 in Figure 7.34 may be close to zero if light output varies as periodic spikes, leading to a flicker index close to 1.0. Higher values indicate an increased possibility of noticeable flicker and stroboscopic effect. The flicker index is not suitable for evaluating non-visual biological responses to flicker that may occur when flicker is visually imperceptible; see [26] and [27] for reviews.

When a fluorescent lamp is operated on a magnetic ballast with a 60 Hz power input frequency, the resulting 120 Hz variation coupled with phosphor persistence makes the fluctuating light output too rapid for most people to perceive. This assumes, however, that the power input is free of electrical noise from other equipment, which can result in frequencies that manifest themselves as visible flicker. Under noise-free operating conditions, the flicker index for typical fluorescent lamps operated with electromagnetic ballasts ranges from 0.01 to approximately 0.1. The index is much lower when high frequency electronic ballasts are employed due to the high frequency operation in the range of 20 kHz and above.

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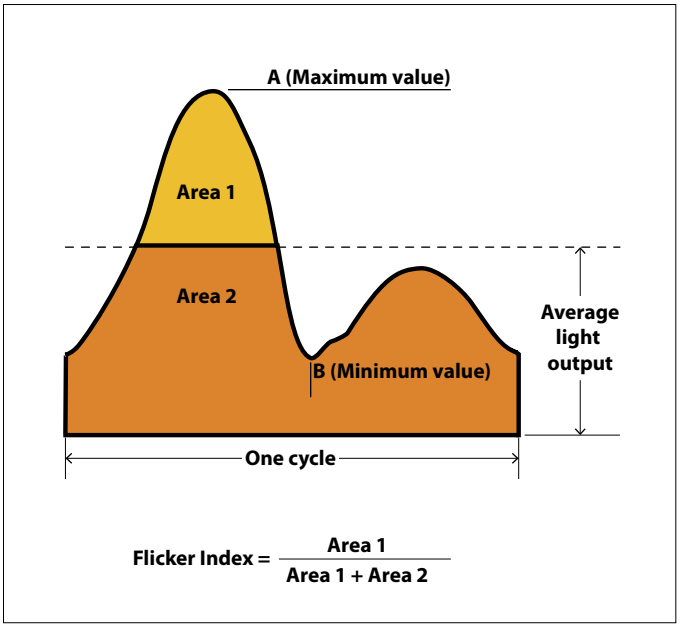


Figure 7.34 | Flicker Index
Curve of the lumen output variation from a lamp during each cycle, showing the method of calculating the flicker index.

7.4 High Intensity Discharge

High-intensity discharge (HID) lamps include the groups commonly known as high pressure mercury, metal halide, ceramic metal halide, and high pressure sodium. The light-producing element of these lamp types is an arc discharge contained within a refractory envelope (arc tube) with wall loading in excess of 3 W/cm^2 (19.4 W/in.^{2}). High pressure mercury lamps are not suitable for new specifications and are not discussed here; technical details are contained in earlier editions of the IES Lighting Handbook.

7.4.1 General Principles of Operation

All HID lamps produce light by means of an electrical arc discharge contained in an arc tube, which is usually housed within an outer bulb. The arc tube contains: electrodes that terminate the arc discharge; a starting gas that is relatively easy to ionize at low pressure at normal ambient temperatures; and metals selected to produce optical radiation. The starting gas is usually argon or xenon, or a mixture of argon, neon, and xenon, depending on the type of HID lamp. The metals, or halide compounds of metals, produce characteristic lines of optical radiation when evaporated in the arc discharge. High pressure sodium lamps produce optical radiation by exciting sodium atoms. Metal halide lamps produce optical radiation by exciting several different atoms and molecules, which may include sodium, scandium, tin, cesium, lithium, thulium, holmium, dysprosium, thallium, calcium, and others. The arc discharge has negative resistance characteristic and therefore all HID lamps must but be operated with a ballast (see 7.4.3 Ballasts).

7.4.2 Lamp Construction

The arc tube, made of quartz (fused silica) or ceramic (polycrystalline alumina), is often contained inside an outer bulb that may be made of soft or hard glass, or quartz. It protects the arc tube and internal electrical connections from the ambient environment. The outer bulb may be coated with a diffusing material to reduce source luminance. With metal halide lamps, if a diffuse coating is employed, it may be a phosphor selected to improve color rendering by converting UV to visible optical radiation. Since high pressure

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sodium arc tubes produce a negligible amount of UV, an inert white powder is employed when diffusion is desired. The diffusing material increases the luminous size of the source, which may decrease the optical efficiency of the luminaire that houses the lamp. In some metal halide lamps the outer bulb is designed to absorb UV optical radiation.

When the arc tube is housed in an outer bulb, within the outer bulb there will be: wires to conduct electricity to the arc tube; structural components to support the arc tube; and other components that may include resistors, diodes, or UV enhancers used to help start the arc discharge, and devices called getters to purify the atmosphere within the outer bulb. The atmosphere in the outer bulb might be a low-pressure gas (usually nitrogen) or a vacuum. For "O" rated lamps, which are designed for operation in open luminaires, the arc tube may be surrounded by a containment shroud.

HID lamps may have screw bases (medium or mogul) made from brass, nickel, or special alloys to minimize corrosion. Some HID lamps have bi-pin bases or pairs of single contact bases at each end of the lamp to provide electrical connections. See Figure 7.35 for common HID lamp bases

7.4.3 Ballasts

All HID lamps have negative resistance characteristics. A current-limiting device, usually in the form of a transformer and reactor ballast, must be provided to prevent excessive lamp and line currents. Lag circuit and lead circuit ballasts are available. The current control element of a lag circuit ballast consists of an inductive reactance in series with the lamp. The current control element in lead circuit ballasts consists of both inductive and capacitive reactance in series with the lamp; net reactance is capacitive in circuits for metal halide lamps and inductive in circuits for high pressure sodium. Wattage losses in ballasts are usually in the order of 5 to 15% of lamp wattage. For lamp specific considerations see 7.4.8.7 Metal Halide Ballasts and 7.4.9.5 High Pressure Sodium Ballasts.

7.4.4 Dimming

Metal halide and high pressure sodium lamps are optimized to operate at full power, but some energy savings may be obtained through dimming. The slow warm-up and hot restrike delay, which are characteristic of HID sources, also apply to dimming. HID lamps respond to changes in dimmer settings much more slowly than incandescent or fluorescent sources; delays between minimum and maximum light output varies from about three to ten minutes. In addition to speed, the range of response is not comparable to that of incandescent or fluorescent dimming. In most cases lamp efficacy and color are reasonably good down to 50% dimming. While not well suited to dramatic lighting or theatrical effects, this range can be quite satisfactory for many energy management applications. The slow response of HID lamps provides minimal occupant distraction.

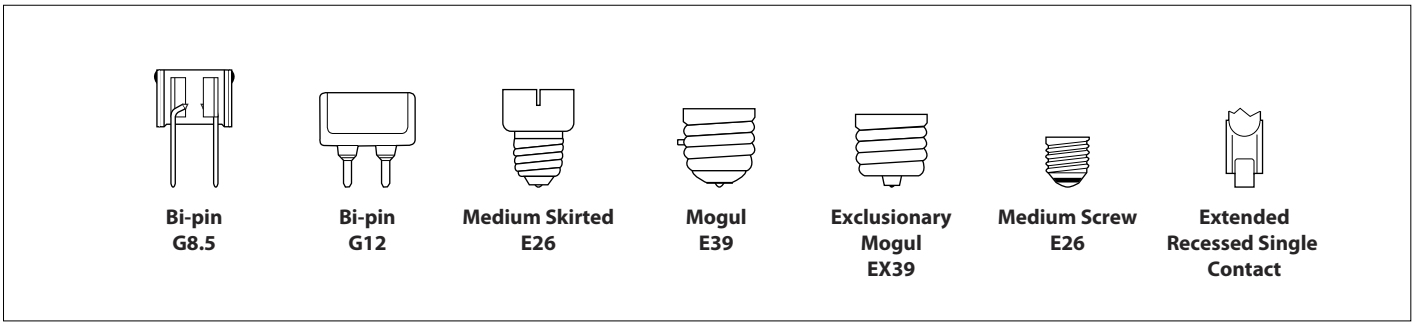


Figure 7.35 | HID Lamp Bases
Common HID lamp bases (not to scale). ANSI designations are shown.
» Images courtesy of Osram Sylvania

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HID lamps should be started at full power and the dimming delayed until the lamp is fully warmed up. Properly designed dimming systems ensure that this occurs. Figure 7.36 provides the approximate relationship between input power and lumen output for metal halide lamps with quartz arc tubes (QMH) and high pressure sodium (HPS) lamps. The lamp manufacturer's warranty may be limited when dimming.

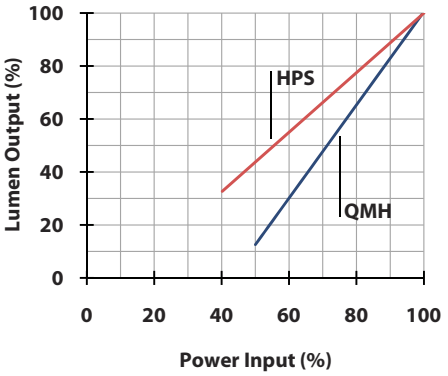


Figure 7.36 | Lumen Output vs. Power Input
Lumen output vs. power input for metal halide lamps with quartz arc tubes (QMH) and high pressure sodium (HPS) lamps. Reducing input power below the limits indicated is not recommended.

7.4.5 Lamp Life and Lumen Maintenance

Average rated lamp life is defined as that time after which 50% of a large group of lamps are still in operation. The IES procedure prescribes operating cycles for HID lamps of 11 hours on, 1 hour off [28]. HID lamp life and lumen maintenance are affected by changes in the operating cycle. It should be noted in manufacturers' literature when lamp life is based on something other than the 11 on, 1 off cycle. As a rule of thumb, as the operating period is shortened by 50%, lamp life is reduced by approximately 25%. Lamp manufacturers should be contacted for further information about shorter operating cycles and reduced lamp life. HID lamps are usually rated for initial lumens after 100 hours of operation. For certain lamp types and applications, criteria other than failure to light may be considered, such as cycling, color shift, or significant reduction in lumen output. See 7.4.8.10 Operating Characteristics for further details related to metal halide lamps, and 7.4.9.6 Operating Characteristics, for further details related to high pressure sodium.

7.4.6 Flicker and Stroboscopic Effect

HID lamps that employ magnetic ballasts and operate on 60 Hz line frequencies can exhibit visibly perceptible flicker. Flicker and stroboscopic effect may be annoying to spectators in games such as tennis or ping-pong, and operators of rotating machinery can find it distracting. To minimize the stroboscopic effect, systems with a flicker index (see 7.3.6.9 Flicker) of 0.1 or less are suggested. Table 7.7. provides the flicker index for HID lamps operated on different ballast types. In three-phase power distribution system, the effects of flicker can be partially mitigated by running alternate luminaires on different phases. The only method of completely eliminating flicker is to operate the lamps at high frequency, which can be achieved by employing high frequency electronic ballasts. However, as of this writing, some lamp types such as ceramic metal halide are not compatible with high frequency operation due to acoustic resonance instabilities and shortened life. Low frequency square wave (LFSW) electronic ballasts can be employed [29].

7.4.7 Nomenclature

The nomenclature for HID lamps tends to follow a pattern that is authorized and administered by ANSI, as summarized in Table 7.8. This is only one example; often manufacturers will adopt variations. The type of HID lamp is designated by a letter, followed by an electrical characteristic number that is used for pairing the lamp with a ballast. A code is included that describes the bulb characteristics. A luminaire characteristic letter may be included to indicate such features as whether or not the lamp can be used in an open luminaire, or if and what type of enclosed luminaire is required. Optional modifiers may follow that indicate features such as wattage or CCT. Official designations are described fully in ANSI C78.380-2007 [30].

7.4.8 Metal Halide

Metal halide has evolved into the most versatile of the HID lamps. They are employed for applications as diverse as roadway, sport fields, landscape, industrial, retail, floodlighting, and vehicular headlamps. Metal halide lamps generate their lumens from a relatively small arc tube made of either quartz or ceramic, permitting them to be efficiently coupled with optical systems. They are available in a wide variety of lumen outputs, several different CCTs, and have desirable characteristics that include, good to excellent luminous efficacy fair to excellent CRI, and fair to good life and lumen maintenance.

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Table 7.7 | Flicker Index for HID Lamps

Lamp Type	Ballast	Flicker Index
High Pressure Sodium		
250 W Deluxe	Reactor or CWA	0.131
250 W Standard	Reactor or CWA	0.200
Metal Halide with Quartz Arc Tube		
175 W Coated	CWA	0.083
175 W Clear-Vertical	CWA	0.078
175 W Clear-Horizontal	CWA	0.092
175 W 3200 K	CWA	0.090
250 W Clear-Vertical	CWA	0.102
250 W Clear-Horizontal	CWA	0.121
250 W Clear-Vertical	CWA-Premium	0.088
250 W Clear-Horizontal	CWA-Premium	0.097
250 W Coated (A)	CWA	0.070
250 W Coated (B)	CWA	0.092
250 W High Color Quality	Reactor	0.080
250 W High Color Quality	HPS-CWA	0.102
400 W Clear-Vertical	CWA	0.086
400 W Clear-Horizontal	CWA	0.095
1000 W Clear-Vertical	CWA	0.067

Table 7.8 | HID Lamp Nomenclature

	M (a)	57 (b)	PF (c)	175/3K (d)
(a)	HID lamp type. "S" is employed for HPS lamps, "M" is for metal halide with a quartz arc tube, "MC" is for metal halide with a ceramic arc tube, and "H" is for mercury vapor lamps. Other manufacturer-specific designations may be employed.			
(b)	Electronic characteristics. For example, "67" is a 175-W metal halide lamp, "51" is a 400-W HPS lamp. These numbers are used for pairing with an appropriate ballast.			
(c)	Bulb characteristics. For exampe, "PF" is a phosphor-coated ED bulb, "PE" is a clear ED bulb.			
(d)	Additional characteristics. Many lamp manufacturers add additional (and often redundant) codes that more explicitly describe the wattage (175 W) color temperature (3000 K), or other special characteristics.			

7.4.8.1 General Principles of Operation

Optical radiation is produced by the passage of an electric current through a vapor of elements and molecules that includes mercury and argon, and may include sodium, scandium, tin, cesium, lithium, thulium, holmium, dysprosium, thallium, calcium, and others, suitably blended. When the lamp is turned on the arc is initially struck through the ionization of argon. Once the arc strikes, its heat begins to vaporize the mercury, with the additional heat being sufficient to vaporize the metal halides. When the lamp attains full operating temperature, the metal halides in the arc tube are partially vaporized. When the halide vapors approach the high temperature central core of the discharge, they dissociate into the halogen and the metals, with the metals radiating their spectrum. As the halogen and metal atoms move near the cooler arc tube wall by diffusion and convection, they

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recombine, and the cycle repeats. The discharge from the metals dominate the spectrum of optical radiation that is generated (see 7.4.8.3 Spectrum and 1.4.1 Atomic Structure and Optical Radiation).

7.4.8.2 Arc Tube Construction

There are many variations in the design of the arc tube. The material may be quartz or ceramic. The shape may be nominally cylindrical and pinched closed (if quartz) or sealed closed (if ceramic). It may also be formed into a non-cylindrical shape, including being bent into an arc (if quartz) when the lamp is designed for horizontal operation, or formed into an ovoid body (employed with quartz and ceramic). Several constructions are illustrated in Figure 7.37. The purpose of shaping the arc tube is to improve temperature uniformity by keeping the arc equidistant from the wall, leading to desirable features such as improved color uniformity and stability (see 7.4.8.4 Color Uniformity and Stability). Ceramic arc tubes allow for higher arc tube temperatures, which results in better luminous efficacy, color rendering, and color stability.

7.4.8.3 Spectrum

When fully stabilized, the output spectrum is due to the characteristic spectral emission of the metals within the arc. Since there are about fifty metal iodides that can be employed, a wide range of SPDs are possible, ranging from those with mostly line spectra, to those with continuous spectra. Several SPD examples are given in Figure 7.38.

7.4.8.4 Color Uniformity and Stability

The arc tube cold spot temperature determines the vapor pressure and the composition of the halide atmosphere in the arc, and thus the color of the optical radiation. Some metal halide lamp types exhibit inherent color variations from lamp-to-lamp (uniformity) and they may change in color as they age (stability). This is a result of variations in the manufacturing process (that affect uniformity) and chemical changes that occur during operation (that affect stability). Manufacturing challenges include: electrode gap size; arc tube geometry and volume; heat reflection; and halide density. Changes that occur over life include: tungsten transport as a result of reactions with impurities such as oxygen and water; reactions between the halide dose, arc tube walls, and electrodes; and sodium ion diffusion through the arc tube wall.

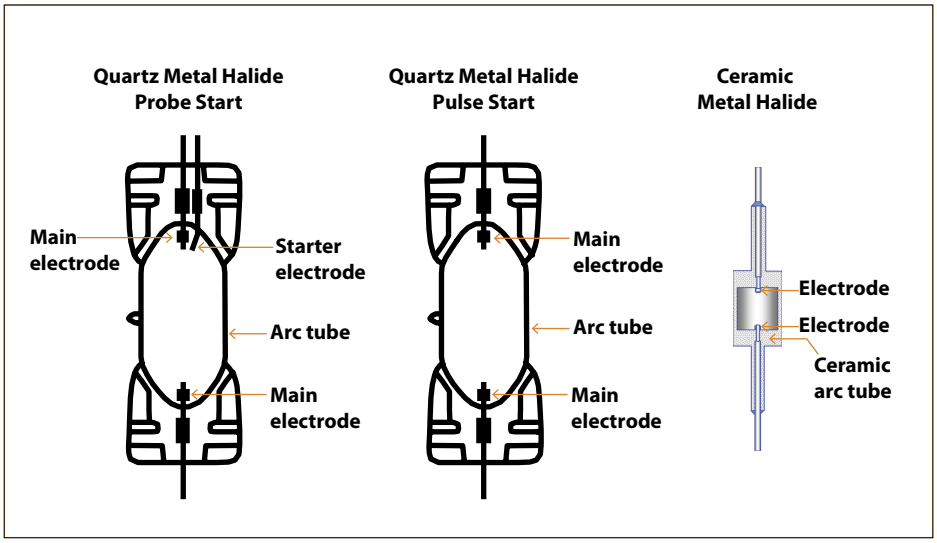


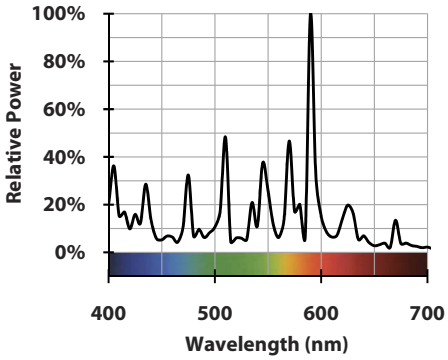
Figure 7.37 | Metal Halide Arc Tubes

Three examples of metal halide arc tubes are shown: (left) tubular quartz with pinched body, probe start, (middle) tubular quartz with pinched body pulse start; (right) cylindrical ceramic. All ceramic arc tubes employ two electrodes and are designed for pulse starting.

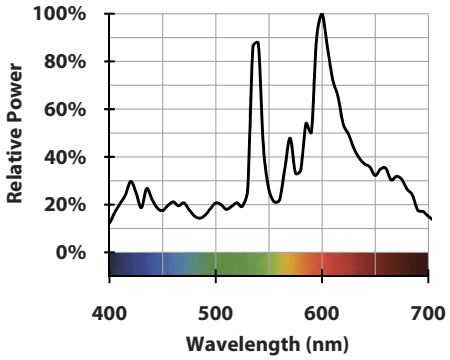
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Sodium/Scandium, Quartz Arc Tube
CCT: 4100 - 4300 K (Varies with Specific Type)
CRI: Mid 60s



3K Ceramic Metal Halide
Nominal CCT: 3000 K
CRI: Low 80s - Low 90s



4K Ceramic Metal Halide
Nominal CCT: 4000 K
CRI: Low 80s - Low 90s

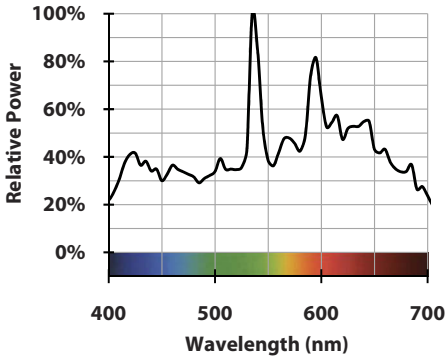


Figure 7.38 | Metal Halide SPDs
Approximate spectral power distributions for various types of metal halide lamps.

Lamps that employ the conventional cylindrical quartz arc tubes are most susceptible to color uniformity and stability problems. Improvements have been achieved with the use of ceramic arc tubes, the forming of arc tubes into ovoid bodies, and pulse starting (see 7.4.8.8 Probe and Pulse Starting Methods). Color uniformity and stability have been characterized with chromaticity coordinates and MacAdam ellipses (see 6.2.1 Chromaticity Diagrams), CCT (see 6.2.5 Color Temperature and Correlated Color Temperature), and with color difference formulae (see 6.2.3 Color Difference).

7.4.8.5 Dose Separation (Color Uniformity in the Beam)

The complex atmosphere in the arc can lead to segregation of the metals. For example, in lamps containing sodium halides, the arc may appear with a reddish/orange sheath surrounding a blue/white central core. In vertically operated lamps, dose segregation may occur due to a temperature gradient (the lower end of the arc tube will be cooler), which may change the metal atmosphere both vertically and horizontally. In applications that rely on a focused image of the arc discharge, color banding may be observed in the beam. A related problem is that the portion of the dose that condenses on the cold spot of the arc tube wall may cause a shadow in the beam. Parabolic reflectors with faceting and/or surface texturing are commonly employed to integrate the beam, thereby minimizing color banding and shadowing.

7.4.8.6 UV Optical Radiation

Metal halide discharges emit UV optical radiation. Exposure to people can produce severe erythemal effects (skin reddening) or eye damage. A hard glass outer bulb will absorb most optical radiation below 350 nm. Quartz, whether employed for the arc tube or outer bulb, may be doped with ceria-titania, which absorbs UV radiation below 375 nm. A UV-blocking thin film may also be applied to the lamp surface. Self-extinguishing lamps are available that contain a tungsten filament in place of a portion of the lead-in conductor that will oxidize quickly when the outer bulb is broken, thereby breaking the circuit and extinguishing the arc.

UV optical radiation can be purposely employed in photochemical industrial processes such as curing some inks, wood and metal coatings, and adhesives. Metal halide lamps for photochemical applications are typically of a bare arc-tube design that is transparent to UV.

7.4.8.7 Metal Halide Ballasts

The simplest form of a ballast is a lag reactor, which may also be called an inductive reactor, reactor, inductor, lag circuit ballast, or a choke. It consists of a coil of copper wire wound on an iron core placed in series with the lamp. The only function of a reactor ballast is to limit

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the current delivered to the lamp. It can only be used on its own when the line voltage is sufficient to start the lamp, otherwise an ignitor must also be part of the circuit.

Ignitors provide a high-voltage low-current pulse of between 1 and 5 kV. Among the ignitors in use today are: impulse or parallel ignitors, which use a ballast winding as the ignitor's pulse transformer; superimposed or series ignitors, which contain a pulse transformer that is independent of the ballast windings; two wire ignitors, which provide a lower pulse voltage directly across the lamp leads.

The power factor of a lag reactor circuit is about 0.50, which would require supply wiring be sized for approximately twice the normal operating current. Power factor correcting capacitors are typically connected across the supply, which also have the advantage of reducing the lamp starting current.

The reactor circuit provides little regulation for fluctuations in line voltage. For example, a 5% change in line voltage can cause a 12% change in lamp wattage. Long-term operation of lamps under high line conditions shortens lamp life. Reactor ballasts are not recommended where line fluctuations exceed 5%. However, when line voltage regulation is good, the use of a lag reactor ballast can save energy over a multi-tap lead peaked constant wattage autotransformer (CWA), discussed below.

The CWA is a lead circuit ballast that consists of a high-reactance autotransformer with a capacitor in series with the lamp. An autotransformer is a transformer connected such that part of its winding is common to both the primary and secondary circuits. The capacitor allows the lamp to operate with better wattage stability when the voltage on the branch circuit fluctuates. The CWA is appropriate when line voltage is expected to vary by more than 5%. A 10% change in line voltage, for example, would result in only a 5% change in lamp wattage. Other advantages with the CWA ballast are high power factor, low line extinguishing voltage, and line starting currents that are lower than normal line currents.

Electronic ballasts for metal halide lamps may employ low (100 to 400 Hz) or high (150 – 200 kHz) frequency current to drive the lamps. They include an ignitor and current limiting circuitry in a single package. High frequency operation does not increase metal halide luminous efficacy as it does for fluorescent lamps. However, electronic ballasts consume less power than magnetic ballasts, thereby improving system efficacy. Electronic operation is quiet, flicker free, the ballasts are smaller and lighter, and they offer better power regulation than magnetic counterparts. Improvement with lumen maintenance on electronic ballasts is claimed by most manufacturers for quartz and ceramic metal halide lamps.

At equal wattage, system efficacy tends to be best with electronic ballasts, followed by the lag reactor, then CWA.

7.4.8.8 Probe and Pulse Starting Methods

Three electrodes are present in the arc tube of a traditional quartz metal halide lamp, a starting probe electrode and two operating electrodes. Current flow between the small probe and main electrode is limited by a resistor in series with the switch. Examples are shown in Figure 7.37b-d. A discharge across the small gap between the probe electrode and one of the operating electrodes occurs first, initiating the ionization of the starting gasses and facilitating the striking of the arc between the two operating electrodes. Once current is flowing between the main electrodes, a bi-metal switch removes the starting probe electrode from the circuit.

Pulse start metal halide lamps do not have a starting probe electrode. An example is shown in Figure 7.37a. They have a high-voltage ignitor as a component of the ballast to start the lamp using a series of high-voltage pulses, typically in the range of 3 to 5 kV. Without the probe electrode the seal areas at the ends of the arc tube can be reduced, which allows for better shaping of the arc tube and better management of the cold-spot temperature. In comparison to probe starting, pulse starting: reduces warm-up and

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restrike times; provides longer lamp life; improves lumen maintenance by reducing electrode sputtering; and provides better cold starting capability. Some ceramic metal halide lamps require pulse starting; others are available for retrofit on probe start ballasts.

7.4.8.9 Types

Metal halide lamps generate their lumens from relatively small arc tubes that have been fitted into: single-ended clear and phosphor coated outer glass bulbs of various shapes and sizes; single-ended outer bulbs that have integral reflectors to create a beamed luminous intensity distribution; and double-ended linearly shaped outer bulbs. Metal halide lamps designed to emit UV optical radiation do not generally have an outer bulb. Some common shapes are illustrated in Figure 7.39. The arc tube of a metal halide lamp approximates a point source permitting the design of optically efficient reflectors, which may be the outer envelope (as with PAR and MR shapes) or a luminaire (as with the BT, E, and T shapes). The typical wattage range is from 20 W in the MR16 bulb shape to 2000 W in the double-ended T9 that is designed for sports lighting luminaires. Metal halide lamps as high as 9000 W have been produced for specialty applications.

Manufacturers have been active in developing metal halide technologies with ceramic arc tubes, since such products are superior to those that employ quartz (see 7.4.8.2 Arc Tube Construction). These sources employ pulse-starting, tend to have good color consistency and stability, good lumen maintenance, good to excellent color rendering, and are available in several color temperatures between 2700 and 5600 K, the most common at approximately 3000 and 4000 K. As of this writing, ceramic metal halide lamps are available from 20 to 400 W, and in envelope shapes that include MR16, PAR20, PAR30, PAR38, ED17, ED18, ED28, ED37, T4.5, T6, T7, and T9. For new specifications, if ceramic and quartz lamps are both available in the desired shape and wattage, the lamp with the ceramic arc tube should typically be employed. Not all ceramic metal halide lamps are suitable for use on existing ballasts that were intended to operate lamps with quartz arc tubes. The main incompatibility is with high frequency electronic ballasts. Suitability for retrofit should be verified prior to specification.

7.4.8.10 Operating Characteristics

Luminous Efficacy

New metal halide lamps have a luminous efficacy of 80 to 120 lumens per watt. As the lamp ages, voltage rises and lumen output declines, both of which combine to reduce

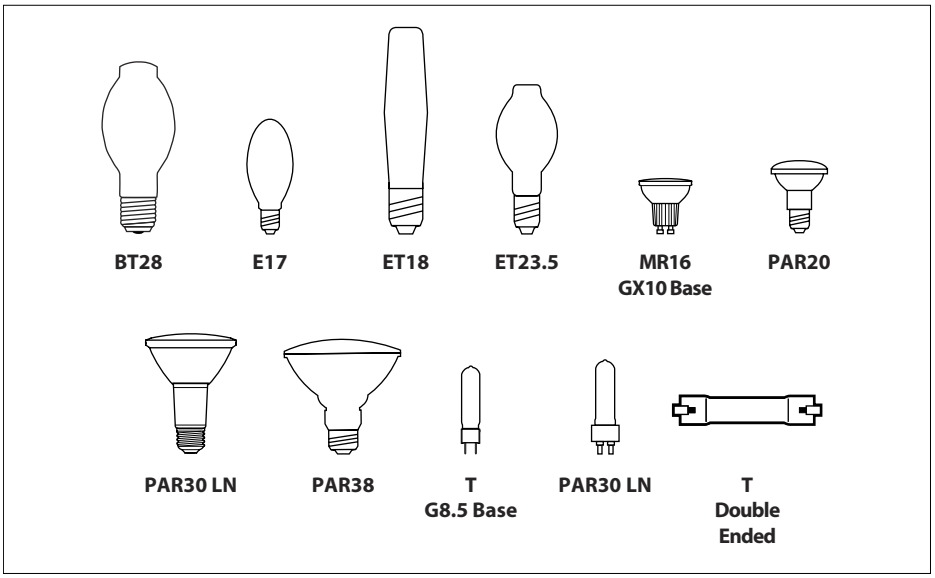


Figure 7.39 | Common Shapes for Metal Halide Lamps
A sampling of the range of shapes available. Not to scale.
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luminous efficacy. Figure 7.40 provides a plot of luminous efficacy over time for typical quartz and ceramic lamps with the most common starting methods.

Lamp Life and Lumen Maintenance

Metal halide lamp life and lumen maintenance are related to lamp design factors and external factors.

Lamp design factors include: control of wall blackening due to electrode sputtering and evaporation; control of sodium loss; and depreciation of the phosphors for coated lamps. Wall blacking results from tungsten depositing on the wall of the arc tube causing a reduction in light transparency. Electrodes are designed to minimize tungsten loss by proper choice of their size, and by controlling their maximum temperature through the use of impregnated emitters such as thorium, or by the use of gas phase emitters such as cerium, cesium, dysprosium, and other rare earth materials. These rare earths also make up part of the iodide salt mix, especially in ceramic metal halide lamps, and are significant contributors to the high CRI's of those types. Tungsten is also deposited on the walls through chemical transport processes as a consequence of the lamp metal halide chemistry. Control of sodium loss in quartz metal halide lamps is paramount to lumen maintenance and lamp life as sodium is one of the main radiative components in sodium-scandium quartz metal halide lamps. Ceramic metal halide lamps do not suffer from sodium loss to the extent of quartz metal halide lamps and, as a result, have much better lumen maintenance and color stability performance over that of quartz metal halide lamps.

External factors include: type of ballast and ignitor; the value and stability of the supply voltage; the orientation of the arc tube; and the on/off switching cycle. The type of ballast may influence voltage stability across the arc tube, and the type of ignitor will influence sputtering of electrode material. Voltage variations of more than about 10% will result in color shifts, and high voltages will shorten lamp life. Orientation affects the cold spot temperature, which, in addition to affecting the color of optical radiation, can also have a deleterious effect on lamp life by changing the vapor pressure of the discharge. More frequent switching will reduce the hours that the lamp operates, but may not reduce the length of time between relamping.

There is a rather wide range of lumen maintenance for different types of metal halide lamps. Figure 7.41 illustrates light loss for several types; the variation is indicative of the need to look at lamp specific data when making a specification decision and determining a lamp lumen depreciation factor. See also 7.4.5 Lamp Life and Lumen Maintenance.

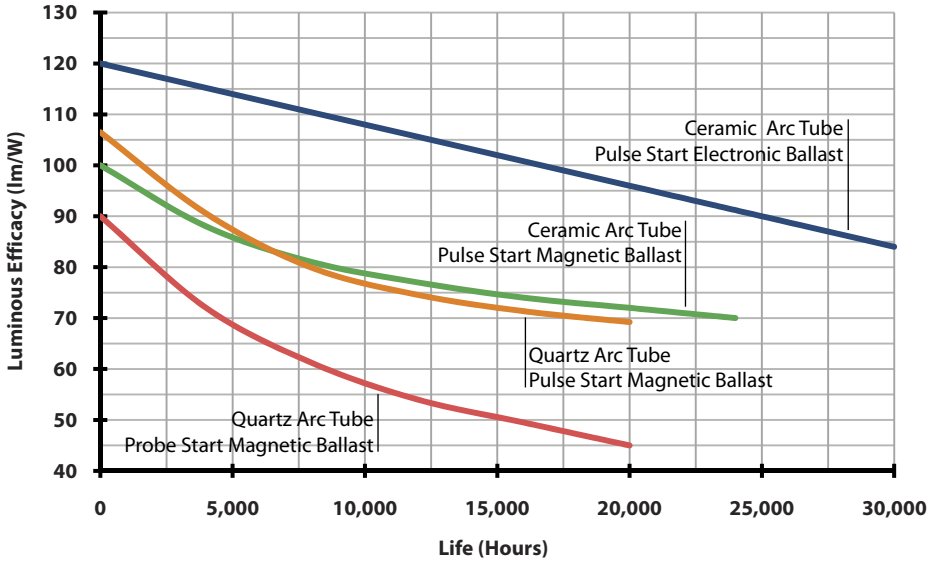


Figure 7.40 | Metal Halide Lamp Efficacy vs. Time
The decline of metal halide lamp efficacy over time for common lamp/ballast configurations.

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Starting and Restrike

A metal halide lamp does not reach full light output immediately but instead must warm up over a period of several minutes. During this phase, the color of the discharge changes as the metal halides warm up, evaporate, and incorporate into the arc. Upon full warm up, the lamp color and electrical characteristics stabilize. The time to reach stabilization is longer for higher lamp wattages. If the arc is extinguished, the lamp will not relight until it is cooled sufficiently to lower the vapor pressure to a point where the arc will restrike with the voltage available. The hot restrike time in a conventional pinched body arc tube with a probe-start electrode can be 15 minutes or longer. Lamps that use pulse-starting restrike much faster than the conventional pinched body arc tube constructions. For the most common metal halide lamps, starting takes between 3 and 5 minutes and restrike take between 4 and 20 minutes. Instant restrike metal halide lamps are available; they may have an extra contact at the top of the outer bulb for the application of a very high (60 kV) re-ignition voltage.

Lamp Current Wave Shape

Lamp current crest factor (CCF) is defined by ANSI as the ratio of the peak value of lamp current to the root mean square value of the current. ANSI and/or the lamp manufacturer specify a suitable current wave shape to the lamp; the ballast must be designed accordingly. A low CCF in the range of 1.4 to 1.6 contributes to the achievement of rated lumen maintenance and lamp life

Thermal Characteristics

The lumen output of a typical double-envelope metal halide lamp is little affected by ambient temperature. Operation is generally satisfactory for ambient temperatures down to -29° C (-20° F) or lower. Single envelope lamps, which are intended primarily for use as UV sources, are affected by low temperatures, particularly if the air is moving. They are not considered suitable if the ambient temperature is below 0° C (32° F). Ambient temperature affects the striking voltage of all discharge lamps; ballasts for low-temperature applications are designed to provide the necessary voltage to start and operate lamps at low temperatures. Recommendations for starting voltages have been developed by ANSI [31].

Excessive envelope and base temperatures may cause failures or unsatisfactory performance due to: softening of the glass; damage to the arc tube by moisture driven out of the outer envelope; softening of the basing cement or solder; or corrosion of the base, socket, or lead-in wires. Luminaires should be designed so that optical radiation is not concentrated on the outer envelope. Optical radiation should not be concentrated on the arc tube either, as this can change the vapor pressure and have a deleterious effect on the color of illumination, electrical characteristics, and lamp life.

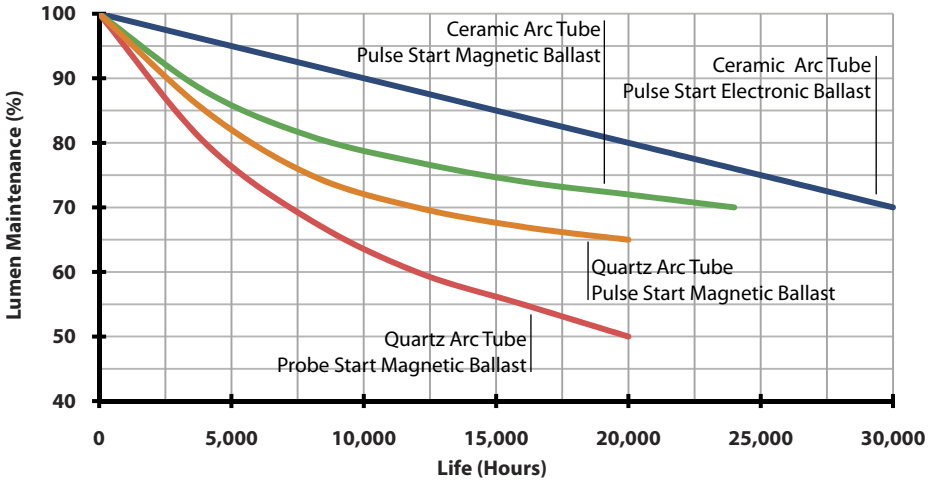


Figure 7.41 | Lumen Maintenance for several Metal Halide Lamps
Illustrated is the variation in lumen maintenance for different metal halide lamps.

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Orientation
Metal halide lamps may be rated for universal orientation, horizontal-only, vertical-only, or for a limited range of rotation. Orientation will affect the cold-spot temperature of the arc tube, thus affecting lumen output and color. This is less problematic for ceramic metal halide lamps. Figure 7.42 [32] provides tilt information for various 1500 W metal halide lamps that are commonly employed for sport field lighting. It is illustrative of the range of variability in lumen output that is possible when metal halide lamps are tilted. Manufacturer's literature should be consulted to determine whether or not a lamp tilt factor will need to be employed as part of the design process.

Flicker
Flicker in metal halide lamps is partially dependent on operating position and is more likely to be problematic in vertically operated lamps. See 7.4.6 Flicker and Stroboscopic Effect.

Non-Quiescent Failure
Metal halide lamps operate at pressures significantly greater than atmospheric pressure (1 atm). There is the danger that lamps weakened by long-term chemical effects, a manufacturing defect, or external damage, may cause a non-quiescent failure. Since an operating pressure of 10 – 15 atm is common, such failures can be violent and demand that adequate precautions are taken. Some metal halide lamps are designed with an internal shroud that surrounds the arc tube. Other lamps are only for use in luminaires designed to contain lamp fragments in the event of a failure.

Disposal and Recycling
The arc tube of metal halide lamps contains mercury; some metal halide lamps use lead in the solder. Metal halide lamps are regulated in the U.S. under the Universal Waste Rule. IES recommends recycling of spent metal halide lamps. See also 13.11.1 Component Toxicity, the Universal Waste Rule, and Recycling.

7.4.9 High Pressure Sodium

High pressure sodium lamps are employed for applications such as roadway, industrial, outdoor-area, and floodlighting. They generate their lumens from a relatively small arc tube, permitting them to be efficiently coupled with optical systems. They are available in a wide variety of lumen outputs, several different CCTs (all of them warm), and have desirable characteristics that include good to excellent luminous efficacy, and good to excellent life and lumen maintenance.

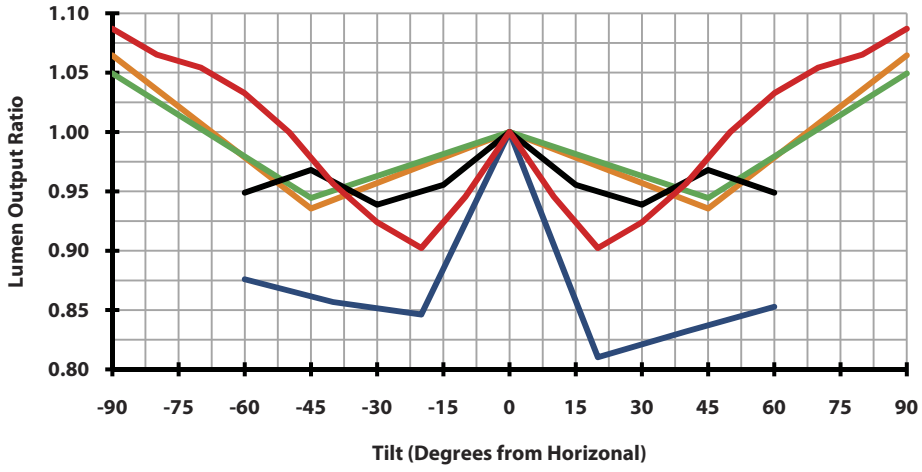


Figure 7.42 | Lumen Output vs. Tilt for 1500 W Metal Halide Lamps
The range of variation between five different types of 1500 W metal halide lamps is illustrated. All data are based on initial lamp lumens at 100 hours of operation. [30]

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7.4.9.1 General Principles of Operation

Optical radiation is produced by electric current passing through a sodium-mercury amalgam, which is partially vaporized when the lamp attains its full operating temperature. The lamp is ignited by a high voltage pulse, typically in the range of 1.5 to 4 kV, depending on the lamp type and wattage. The optical radiation is initially white in color, from the xenon discharge, which is used as a starting gas. As the sodium evaporates and enters the arc, the discharge yellows and lumen output increases. The mercury in the stabilized arc acts as a buffer gas, reducing thermal losses from the discharge and raising the operating voltage to a suitable level. The contribution of the mercury to the optical radiation is very low because the excitation potential of mercury is much higher than that of sodium.

7.4.9.2 Construction

High pressure sodium lamps are constructed with two envelopes, the outer envelope being hard glass (typically borosilicate) and the inner arc tube being sintered polycrystalline alumina (PCA) tubing. Desirable characteristics of PCA include: a high melting point; resistance to sodium attack at high temperatures; and light transmission of more than 90%. PCA is a ceramic. It cannot be fused to metal by melting since ceramic cannot be worked like glass or quartz. The seal at either end of the arc tube is made up of a ceramic plug, solder, glass, and/or metal. The arc tube is kept in place by support wires, and the internal electrical connections are flexible. This is to allow for expansion when the arc tube is hot.

The arc tube contains xenon as a starting gas and a small quantity of sodium-mercury amalgam. Some new lamp designs are mercury free. The outer glass envelope is evacuated and serves to prevent chemical attack of the arc tube metal parts. The outer envelope also helps to maintain arc tube temperature by isolating it from ambient temperature effects and drafts.

The electrodes are similar to those used for pulse-start metal halide lamps, consisting of a rod of tungsten with tungsten wound around the rod and coated with an emitter material. The metal that feeds through the ends of the arc tube is usually niobium because it is nonreactive with sodium and has a similar coefficient of expansion to PCA.

In some constructions a starter and/or starting aid will be built into the outer bulb. The starter may be: a bimetal switch connected in parallel with the arc tube, which by opening creates a high voltage peak across the electrodes; or an electronic device in the lamp base that generates starting pulses. Once the arc stabilizes the current through the starter will be shunted, usually with a bimetal switch that is heated by the discharge. The starting aid may be an ignition wire running alongside the arc tube, or an ignition coil wrapped around the arc tube. Some lamps employ both a starter and a starting aid.

Lamps are available with diffuse coatings on the inside of the outer bulb to increase the luminous size of the source or reduce source luminance. Since high pressure sodium lamps produce almost no UV, there is no point in using a phosphor and so a nonreactive layer of diffuse white powder is employed, such as calcium pyrophosphate.

Electrical connections are primarily made with medium (E26) or mogul (E39) screw bases. Lamps that are started with an external ignitor typically employ a ceramic insulator in the base to reduce the risk of shorting. Lamps with an internal starter typically have an insulator made of glass. A small number of high pressure sodium lamps have bi-pin bases to ensure exact positioning within a luminaire reflector, and there are a few double-ended high pressure sodium lamps.

7.4.9.3 Spectrum

The discharge of sodium is dependent upon pressure. At the low vapor pressure (~ 7×10^{-6} atm) of a low-pressure sodium discharge, the optical radiation is almost monochromatic, consistent of a double line at 589.0 and 589.6 nm, known as the D lines. Increas-

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ing vapor pressure broadens the spectrum such that high pressure sodium lamps radiate across the visible spectrum. Standard high pressure sodium lamps, with sodium pressures in the 0.05 to 0.1 atm range, typically exhibit CCTs of 1900 to 2200 K with a CRI of about 22. At higher sodium pressures, above approximately 0.26 atm, sodium radiation of the D lines is self-absorbed by the gas and is radiated as a continuous spectrum on both sides of the D lines. This results in a gap of optical radiation in the region about 589 nm. Increasing the sodium pressure increases the CRI at a somewhat higher CCT, but at the expense of life and luminous efficacy. White high pressure sodium lamps have been developed with CCT of about 2700 K and a CRI above 80, but these lamps have been largely replaced by ceramic metal halide for new specifications. SPDs are given for several types of high pressure sodium lamps in Figure 7.43.

7.4.9.4 UV Optical Radiation

High pressure sodium lamps produce very little UV optical radiation. In a typical 400 W lamp, for example, approximately 2 W of UV will radiate from the arc tube, and approximately 1 W will radiate from the outer bulb wall.

7.4.9.5 High Pressure Sodium Ballasts

Unlike metal halide lamps, which exhibit relatively constant lamp voltage with changes in lamp wattage, the high pressure sodium lamp voltage varies with lamp wattage. Operating parameters for maximum and minimum permissible lamps wattage and voltage have been established as ANSI standards [33]. Figure 7.44 shows the lamp voltage and wattage limits for a 400 W high pressure sodium lamp, which forms a trapezoid that defines the electrical boundaries of operation.

High pressure sodium lamps may be operated on a lag ballast, which is a simple reactor in series with the lamp, designed to keep the operating characteristics within the trapezoid. A starting circuit is incorporated to provide the starting pulse. Step-up or step-down transformers are provided where necessary to match the line voltage. In most cases, a power-factor-correcting capacitor is placed across the line or across a capacitor winding on the ballast primary. This type of ballast usually provides good wattage regulation for variations in lamp voltage, but poor regulation for variations in line voltage.

Magnetic regulator or constant wattage ballasts may also be employed. These consist of a voltage-regulating section that feeds a current-limiting reactor and the pulse starting circuit. It provides good wattage regulation for changes in line voltage, as a result of the voltage-regulating section, and good regulation for changes in lamp voltage, which is the main characteristic of the reactor ballast.

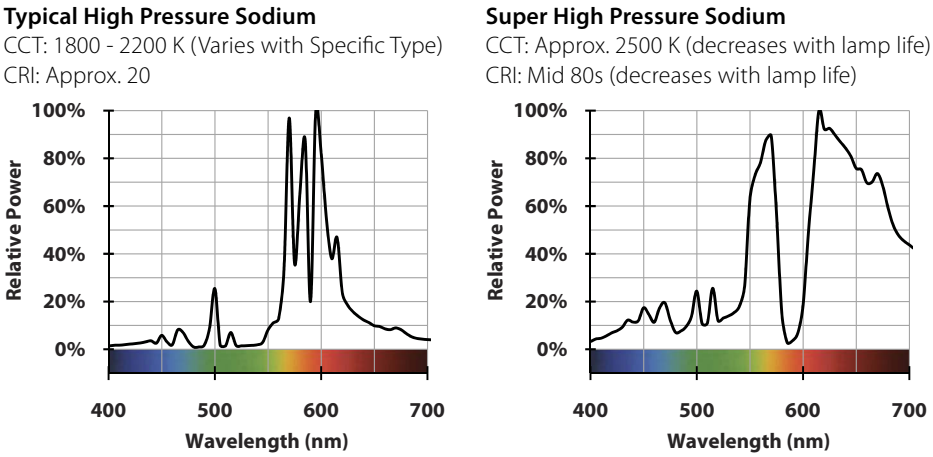
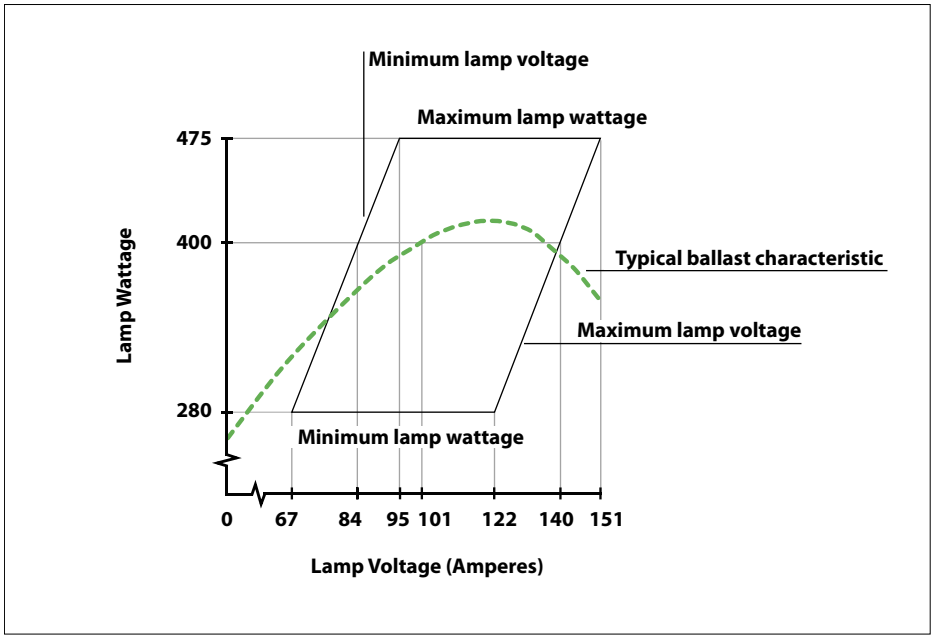


Figure 7.43 | High Pressure Sodium SPDs
Approximate spectral power distributions for high pressure sodium (HPS) lamps. Left: typical HPS. Right: color improved or "super" HPS. Note the broadening of the spectrum around the D lines near 589 nm on the color-improved lamp, which is a result of increasing the vapor pressure.

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Figure 7.44 | High Pressure Sodium Trapezoid
Wattage and voltage limits for 400 W high pressure sodium lamps.



A lead circuit ballast may also be employed, which operates with a combination of inductance and capacitance in series with the lamp. It decreases the current as the lamp voltage increases to keep the lamp operating wattage within the trapezoid limits. This ballast type provides wattage regulation for changes in both line voltage and lamp wattage. It maintains the lamp wattage within the trapezoid if the line voltage change is no greater than 10%.

7.4.9.6 Types

High pressure sodium lamps generate their lumens from relatively compact cylindrical arc tubes that have been fitted into several lamp shapes, the most common of which are illustrated in Figure 7.45. They are available in a range of wattages from 35 to 1000 W.

Recent innovations include non-cycling lamps, lamps with reduced mercury, and lamps that are entirely free of mercury and that employ lead-free welded bases. At present, these features are only available for the most popular high pressure sodium lamp wattages. Unlike conventional high pressure sodium lamps, these newer constructions pass the TCLP test, and therefore are not controlled under the Universal Waste Rule. See also 13.11.1 Component Toxicity , the Universal Waste Rule, and Recycling. They operate on standard high pressure sodium ballasts and are suitable for retrofit applications. Operating characteristics may not be identical to conventional high pressure sodium lamps. Manufacturers' data sheets should be checked for technical details and suitability for a particular application.

7.4.9.7 Operating Characteristics

Luminous Efficacy

High pressure sodium lamps have efficacies of 45 to 150 lumens per watt, depending on the lamp wattage and desired color rendering properties. Luminous efficacy is inversely proportional to both sodium vapor pressure and CRI. Both factors can be attributed to the widening self-absorption of the D lines (see 7.4.9.3 Spectrum), which reapportions radiation from the region near the peak of the luminous efficiency function, to the long- and short-wavelength regions where the luminous efficiency function has lower sensitivity. All else being equal, higher wattage high pressure sodium lamps have higher luminous efficacy than those at lower wattage because electrode losses are approximately constant.

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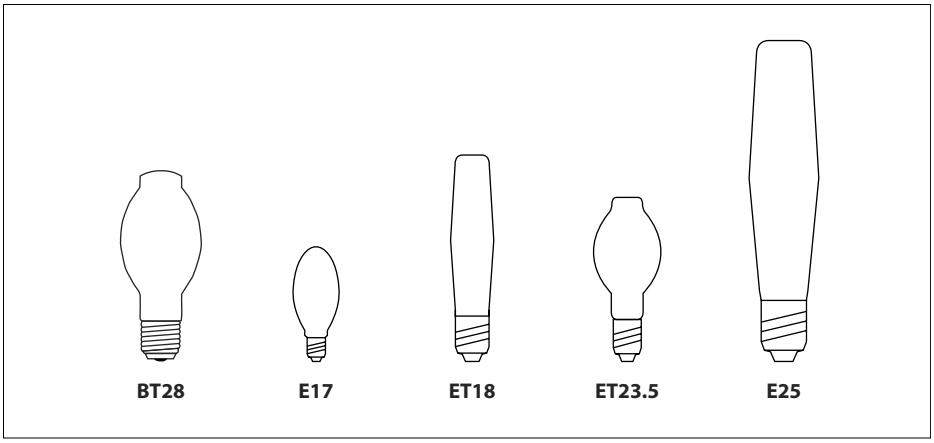


Figure 7.45 | Common Shapes for High Pressure Sodium Lamps
A sample of the range of shapes available.
» Images courtesy of Osram Sylvania

Lamp Life and Lumen Maintenance

High pressure sodium lamp life and lumen maintenance are related to lamp design factors and external factors.

The lamp design factors include: leakage of the arc tube end seals; loss of sodium from the discharge; and sputtering of the electrode emitter material. Arc tube leakage will result in immediate lamp failure. The more common failure mode, however, is from gradual sodium loss that leads to a concomitant increase in lamp voltage. Sodium loss occurs as the sodium combines with scattered emitter material and by diffusion through the ends of the arc tube. The blackening of the arc tube from electrode sputtering also contributes to the voltage rise, as the sputtered material absorbs radiation, heats the discharge, and causes more of the amalgam to vaporize. Eventually, the lamp voltage will become so high that under normal operating temperature the arc will no longer reignite after the off period of the current waveform. The lamp will ignite when cool, begin to warm up, extinguish as the voltage rises, cool off, and then reignite. The lamp has reached end of life when this cycling occurs. Non-cycling high pressure sodium lamps are also available. When they fail, rather than producing the characteristic yellowish light, they produce a dim blue light. This is because the sodium is spent and the discharge is dominated by a weak mercury discharge.

External factors include: type of ballast and ignitor; the magnitude and stability of the supply voltage; the arc tube cold spot temperature; and the on/off switching cycle. The type of ballast may influence the stability of the voltage across the arc tube, and the type of ignitor will influence the sputtering of electrode emitter material. High supply voltages may increase the arc tube voltage, which will shorten lamp life. Luminaire optical designs that reflect the optical radiation generated by the lamp back onto the arc tube lead to an increase in lamp voltage and early lamp failure. More frequent switching will reduce the hours that the lamp operates, but may not reduce the length of time between relamping.

The loss of lumens over life is gradual, and is primarily due to a reduction in the transmittance of the arc tube. The ends have a tendency to blacken from electrode sputtering, and the central part tends to grey as a result of chemical reactions between the sodium and the alumina in the ceramic. Lumen maintenance is considered to be good to excellent. Figure 7.46 illustrates a typical light loss curve. See also 7.4.5 Lamp Life and Lumen Maintenance.

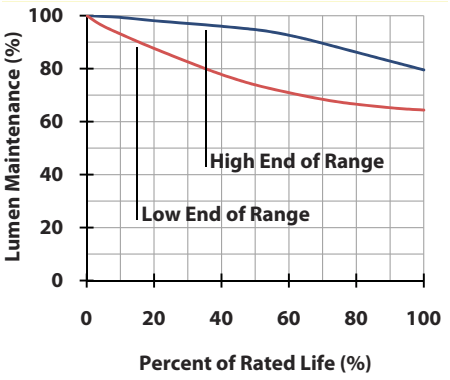


Figure 7.46 | Typical Lumen Maintenance for High Pressure Sodium Lamps
The typical range of lumen maintenance for high pressure socium lamps is shown.

Starting and Restrike

A high pressure sodium lamp does not reach full light output immediately. Warm up time is fast in comparison to metal halide, with 90% of full lumen output being reached in just a few minutes. When a lamp has been extinguished, restrike cannot occur until the sodium vapor pressure in the arc tube has cooled down enough to be ionized. For lamp constructions without an integral starter, and where the starting pulse is supplied by the

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ballast, restrike generally takes about one minute. For lamps that have an integral ignitor, restrike time can be as much as 15 minutes. This is because, soon after ignition, heat from the arc tube opens a bimetal switch that shunts the ignitor from the lamp circuit. When the lamp is turned off, the bimetal switch must cool down and close before the ignitor returns to the circuit.

Instant restrike can also be achieve with high pressure sodium lamps that contain two identical arc tubes, connected in parallel and contained within the outer bulb. Only one arc tube is started with the ignitor pulse. In the event of a momentary power outage, the other arc tube will strike when power is restored.

Thermal Characteristics
The lumen output of a high pressure sodium lamp is little affected by ambient temperature due to the double-envelope construction. Operation is generally satisfactory for ambient temperatures down to -29° C (-20° F) or lower. Ambient temperature affects the striking voltage of all discharge lamps; ballasts for low-temperature applications are designed to provide the necessary voltage to start and operate lamps at low temperatures. Recommendations for starting voltages have been developed by ANSI [31].

Excessive envelope and base temperatures may cause failures or unsatisfactory performance due to: softening of the glass; damage to the arc tube by moisture driven out of the outer envelope; softening of the basing cement or solder; or corrosion of the base, socket, or lead-in wires. Luminaires should be designed so that optical radiation is not concentrated on the outer envelope. Optical radiation should not be concentrated on the arc tube either, as this can change the vapor pressure and have a deleterious effect on electrical characteristics and lamp life.

Flicker
High pressure sodium lamps are less susceptible to flicker than metal halide lamps because the sodium discharge exhibits afterglow that is sufficient to bridge the off-cycles associated with 60 Hz operation.

Orientation
Unlike metal halide lamps, high pressure sodium lamps can be operated in any position without a significant effect on lumen output, life, or other operating characteristics.

7.5 Solid State Lighting

Solid-state lighting (SSL) is a term for a family of light sources that includes: semiconductor light-emitting diodes (LEDs); *organic* light emitting diodes (OLEDs); and polymer light-emitting diodes (PLEDs). The descriptor "solid state" is shorthand for solid state *electroluminescence*. Most important for architectural lighting at the time of writing and into the near future, are LEDs, which generate light based on *injection luminescence*, which is the most efficient kind of electroluminescence. Thus, LEDs are the most efficient SSL light sources and are the focus of this section.

Organic A class of chemical compounds that includes carbon.

Electroluminescence The emission of light caused by the interaction of an electric field with certain solids.

Injection Luminescence A particular type of electroluminescence that occurs when surplus carriers of energy are injected into a semiconductor, and then recombine to emit optical radiation.

7.5.1 General Principles of Operation

A diode is an electronic component that substantially conducts electric current in only one direction. In lighting, diode is shorthand for semiconductor diode. A semiconductor is a material that has electrical conductivity greater than that of an insulator, but less than that of a conductor. The resistance of a semiconductor may change in the presence of an electric field. In the semiconductors employed for LEDs, current is carried by the flow of "electron holes" (usually referred to simply as "holes") in the electron structure. In

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solid-state physics, a hole is a theoretical concept that describes the lack of an electron at a position where one could exist, such as the absence of an electron from an otherwise full valence band. The concept of a hole has been introduced in solid-state physics as a matter of convenience: when an electric field is applied, instead of analyzing the movement of an empty state in the valence band as the movement of billions of electrons, the empty state is treated as a single imaginary particle moving in the opposite direction, a hole. See also 1.4.5.4 Electroluminescence: Light Emitting Diodes. All diodes emit radiation due to the recombination of holes and electrons. The type of material in the construction of the diode determines the wavelength of emission. The wavelength of emission for certain diodes can be in the visible, or nearly visible, range. These are LEDs, which are optimized to take advantage of this photon emission property.

The simplest form of an LED is a semiconductor crystal that is connected to two electrical terminals forming a positive-negative (p-n) junction. A p-n junction is a transition point for recombination between electrons and holes, which is the basis of injection luminescence. By selectively adding impurities to a crystalline semiconductor, semiconductors can be formed with either an excess of free electrons (n-type) or an excess of holes (p-type). Manufacturing techniques have been developed to create crystals in which the conductivity changes from p-type to n-type within a narrow transition region, forming a p-n junction. If a forward bias voltage is applied across the p-n junction, electrons flow into the p-side and holes into the n-side. This can be conceptualized as electrons being injected into holes, where the recombination process produces optical radiation (radiative recombination) and heat (nonradiative recombination).

The simplest type of recombination takes place in a direct-gap semiconductor, also known as a p-n homojunction, where a free electron recombines with a free hole and the emitted photon has energy nearly equal to that of the energy gap. An energy gap, which is also known as a band gap, is an energy range in a semiconductor between a valence band and conduction band where no electron states exist. Electrons can exist in the conduction or valence bands, but not in the energy gap between, a region known as the forbidden gap. In indirect-gap semiconductors, a controlled introduction of impurities allows for electron states within the forbidden gap. Recombination in indirect-gap semiconductor materials takes place via forbidden gap states. Structures composed of semiconductors that have different energy gaps due to different chemical composition are called heterostructures, and they form p-n heterojunctions. While the photon generation process is less efficient in a heterojunction than in a homojunction (because the energy of the emitted photons is less than that of the full energy gap), heterojunctions can be designed so that less optical radiation is absorbed within the semiconductor, markedly improving the injection and internal quantum efficiencies. Practical high brightness LEDs employ double heterostructures, also called quantum wells, which employ advanced energy-gap engineering.

7.5.2 Construction

LED chips are manufactured using standard production processes for multilayer semiconductor devices. Clean rooms are necessary as a high level of crystalline perfection is required, as is a high level of chemical purity. The substrate for the light-emitting element of a LED chip is a crystal wafer that has been sliced from a rod-shaped ingot of single-crystal material, which itself is made by slowly withdrawing a seed crystal (of, for example, gallium phosphide or gallium arsenide) from pure molten material. Since alloys cannot be grown in this way, the active LED area is deposited on the pure wafer with *epitaxial* deposition techniques, which are employed to first grow an n-type material, and on top of that, a p-type material. Electrical contacts to the n-type and p-type sides are formed by photolithography and metal evaporation, after which the wafer is scribed and divided into dice, which are the small LED chips that are the actual emitters of optical radiation. To form an *LED package*, the dice are mounted on a base and lead wires are attached. Most typically,

Epitaxial An oriented overgrowth of crystalline material upon the surface of another crystal of different chemical composition but similar structure.

LED Package An assembly of one or more LED dies that contains: wire bond connections; possibly an optical element; and thermal, mechanical, and electrical interfaces. The device does not include a power sources, does not include an ANSI standardized base, and is not connected directly to the branch circuit.

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dice are encapsulated in a lens, which is most typically made with an epoxy resin. The base in high-flux LED packages (see 7.5.5 Types) is the first component of a thermal heatsink, designed to be coupled to a larger heatsink when the LED package is incorporated into a LED luminaire. Schematics of two LED packages are illustrated in Figure 7.47.

Inorganic Compounds that are not hydrocarbons or their derivatives.

The n-type and p-type layers are made from a variety of *inorganic* semiconductor materials. The two most common materials are aluminum indium gallium phosphide (AlInGaP) for the wavelength region above about 580 nm, and indium gallium nitride (InGaN) for the wavelength region below about 550 nm. During the epitaxial deposition phase, the ratio of the chemical elements, and the selective introduction of impurities, governs the spectral emission of the final product. Other elements employed to create n- and p-type semiconductor materials include: gallium arsenide phosphide (GaAsP); gallium phosphide (GaP); aluminum gallium arsenide (AlGaAs); aluminum gallium phosphide (AlGap); silicon (Si); and silicon carbide (SiC).

7.5.3 Spectrum

The optical radiation emitted from a p-n junction is within a narrow spectral region around the band gap of the semiconductor material. SPDs are approximately Gaussian, with typical full-width at half-maximum (FWHM) in the range of 20-25 nm [34]. LEDs designed to emit in the middle-wavelength (green) region of the spectrum tend to have broader emission spectra than those in the short- and long-wavelength regions. LEDs may have FWHM of less than 5 nm if they employ a resonant cavity construction. White light is created by additively mixing the optical radiation from two or more narrow-emitting LEDs, or by coupling a short-wavelength emitting LED with one or more phosphors.

7.5.3.1 Colored Light from LEDs

With their narrow SPDs, LEDs are highly efficient emitters of deeply saturated colored light. Figure 7.48 illustrates the dominant wavelength of some colored LEDs plotted on the 1931 CIE chromaticity diagram. LEDs emit deeply saturated colors without the use of subtractive filters, as are commonly employed to create richly colored light from other light sources. For applications where colored light is desired, LEDs are likely to be more efficient than technologies that employ subtractive filters.

7.5.3.2 White Light from LEDs

Two common ways of generating white light with LEDs are: 1) convert short wavelength optical radiation with a down-conversion phosphor to create a broad emitting SPD; and 2) combine multiple narrow-band LEDs using additive color mixing.

Down-Conversion Phosphor

Phosphor-based LEDs operate on the same general principles as a fluorescent lamp: short-wavelength energy is converted to longer wavelengths by one or more phosphors. In such LEDs, the chip emits short-wavelength optical radiation (typically in the range of 380

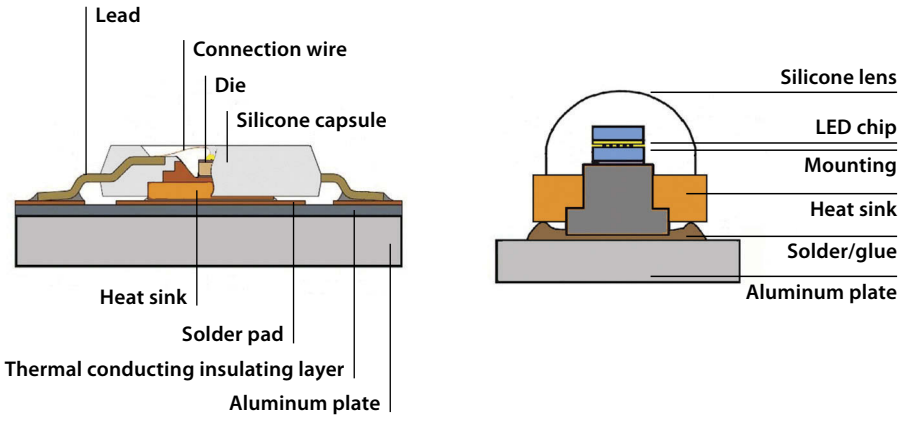


Figure 7.47 | LED Package Schematics
LEDs are available in a variety of packages based on optical, color, light output, and dimensional requirements of various applications. These cross sections illustrate some of the basic construction components, but arranged in different packages. Silicone is used for making the lenses. Silicon is used in the manufacture of the actual LED. Not to scale.

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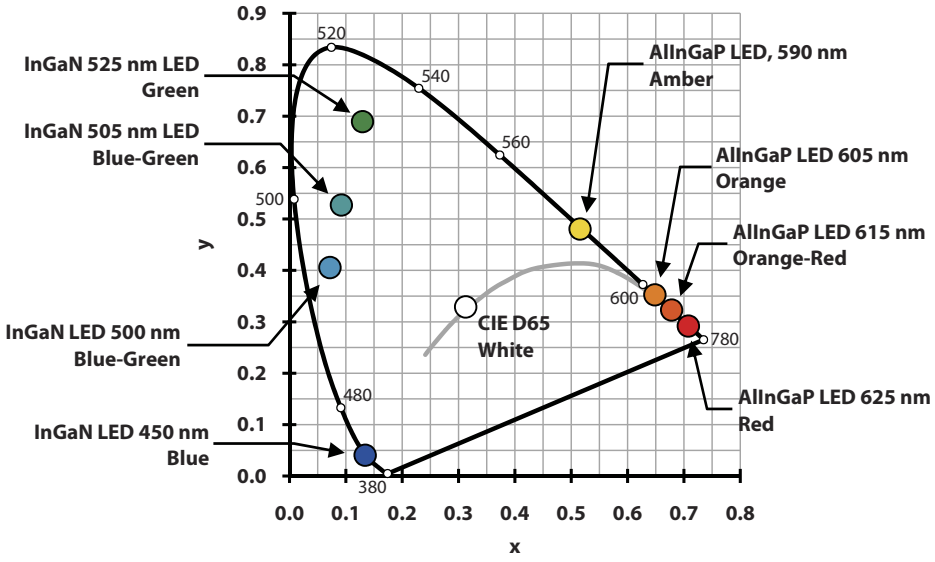


Figure 7.48 | Chromaticity and Dominant Wavelength for LEDs
Chromaticity and dominant wavelength are plotted for some LEDs. The closer the LED plots to the spectrum locus, the narrower the SPD.

– 470 nm) via injection luminescence, and one or more phosphors convert some of that into longer wavelength optical radiation via down-conversion and Stoke's shift. The loss of energy during the down-conversion and nonradiative recombination make this process inherently less efficient than direct emission in the visible range. LEDs that employ one phosphor are bimodal, and those that employ more than one phosphor are multimodal. Bimodal phosphor-based LEDs employ a single chip and a single phosphor coating. Most typically, short-wavelength energy in the blue spectral region is converted into a broad spectrum that peaks near the peak of the photopic luminous efficiency function. Colloquially, the phosphor would be considered an emitter of "yellow" optical radiation. The phosphor thickness and density are specified such that a predetermined amount of "blue" light is leaked, creating a bimodal blended spectrum [35]. Luminous efficacy, CCT, and CRI, which are conventional quantities employed for spectral optimization, can be adjusted by changing the blue/yellow concentrations. Examples are given as Figure 7.49a and b.

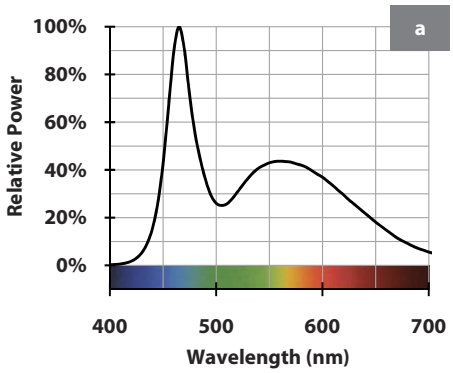
Single phosphor spectrums tend to be deficient of long-wavelength (red) optical radiation. To improve the color characteristics one or more additional phosphors may be added to emit long-wavelength optical radiation. The white-point can be varied by adjusting the thicknesses of the phosphors. Color rendition is improved at the expense of luminous efficacy, since the emission of optical radiation is moved away from the peak of the luminous efficiency function. An example is shown in Figure 7.49c.

LEDs that make use of long-, medium-, and short-wavelength emitting phosphors are also possible. In such constructions, a UV-emitting chip may be used, and the phosphors are selected to completely absorb the UV optical radiation. The short-wavelength phosphor is selected to generate optical radiation at a predetermined wavelength that yields a SPD with a higher CRI than directly leaked blue emission.

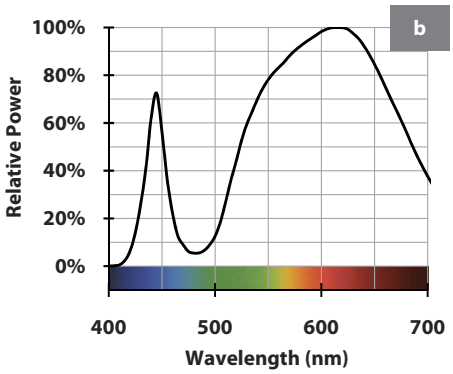
UV and near-UV energy has greater potential to degrade packaging materials, leading to the possibility of chemical bond cracks, especially at higher operating temperatures. Such cracks can allow UV to escape. This safety concern necessitates additional UV considerations to guarantee safety, which are not a concern for LEDs that do not generate high levels of UV, a category that includes nearly all mixed LED sources and most LEDs that employ one or more down-conversion phosphors.

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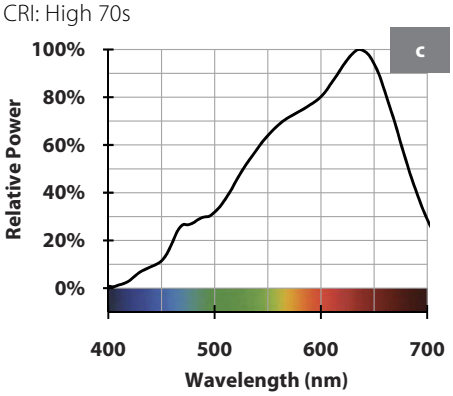
Single-Phosphor LED
CCT: Approx. 6800 K
CRI: Low 80s



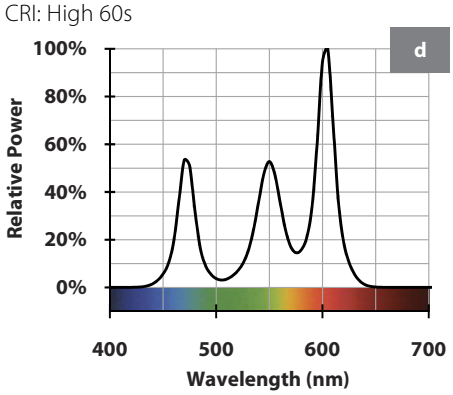
Multiple-Phosphor LED
CCT: Approx. 2900 K
CRI: Low 90s



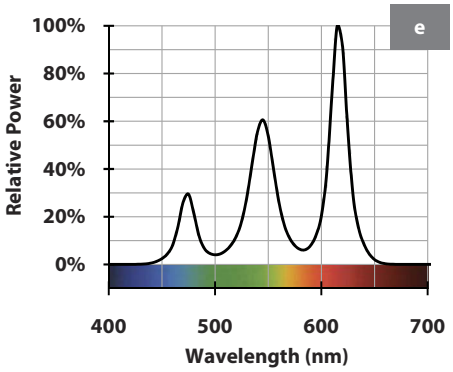
Remote-Phosphor LED
CCT: Approx. 2900 K
CRI: High 70s



Three-Chip LED (Commonly called RGB)
CCT: Approx. 3300 K
CRI: High 60s



Three-Chip LED (Commonly called RGB)
CCT: Approx. 3300 K
CRI: Mid 80s



Four-Chip LED (commonly called RGBA)
CCT: Approx. 3300 K
CRI: Mid 90s

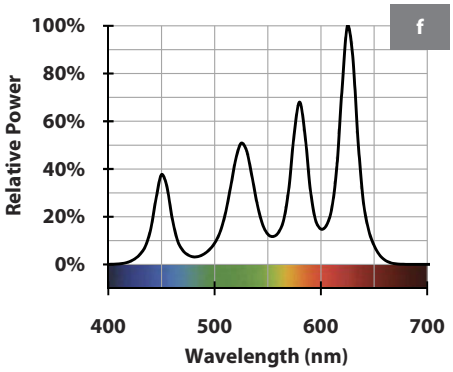


Figure 7.49 | LED Lamp SPDs
Approximate spectral power distributions for various types of LED lamps.

Mixed LED Sources

The photometric and colorimetric concepts behind mixed LED sources are identical to phosphor-based LEDs, but the physical realization influences color, luminous efficacy, and general utility. Both methods employ additive color mixing. With mixed LED sources, two or more LED chips are employed to radiate within specific wavelength regions, corresponding to specific colors. In comparison to phosphor-based LEDs, optical coupling is more difficult. Although phosphor-based LEDs are often clustered similarly to mixed LED sources, phosphor-based LEDs do not require the same level of mixing of the color components. Other obstacles include stability of color and lumen output in the different color channels (see 7.5.6.9 Color Uniformity and Stability). The three primary benefits of mixed LED sources are: increased theoretical efficiency; longer life; and an ability to change color. Since mixed LEDs do not employ phosphors there are no down-conversion losses. Practical life is longer because damaging UV energy is not emitted and phosphor degradation is not present. Also, the direct emission of an LED chip has a much narrower spectral distribution than typical phosphor emissions, which allows energy to be concentrated in the visible region, thus decreasing UV and IR losses. A dynamic color point is also possible because the lumen output of each LED chip can be separately adjusted.

Just as LEDs that employ phosphors use either a bimodal or multi-modal spectrum, mixed LED sources utilize either two, three, or more LED chips to generate white light. The simplest way to generate white light from LED direct emission is to use two separate

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LED chips. These sources have the highest luminous efficacy of all white-light LEDs, but they are unacceptable for general illumination if color rendition is even moderately important. Because of the color limitations of the two LED source, three- and four-chip sources are more common, and products are commercially available with five or more chips. The most frequently employed primary colors for a three-chip source are red, green, and blue. The selection of different wavelengths for the primaries leads to a wide range of colorimetric performance. Figure 7.49d and e illustrate two examples.

For environments that require very high color rendering, four-chip LEDs may be employed; an example is illustrated in Figure 7.49f. These constructions are colloquially referred to as RGBA, for red, green, blue, amber. As with the three-chip LED, the choice of the LED primaries is critical to colorimetric performance. An even wider range of colors can be obtained due to the increase in color gamut. The inclusion of the fourth chip often reduces luminous efficacy, as the peak wavelengths of spectral emission moves away from the peak of the luminous efficiency function.

Sources with a Mix of Multiple LED Chips and Phosphors
It is also possible to combine two or more LED chips with one or more phosphors, suitable blended, to create white light. In one possible construction, short-wavelength (blue) and long-wavelength (red) emitting LED chips are employed, in concert with a middle-wavelength (green/yellow) emitting phosphor. The phosphor converts a predetermined fraction of the short-wavelength optical radiation to middle-wavelength optical radiation. These sources tend to be more efficacious than three-chip LED sources, and are designed to generate white light with a CRI in the high 80s to low 90s.

Characterizing "White" for SSL Products
LEDs that generate "white" light and are marketed to have a specific CCT should comply with ANSI C78.377, which establishes tolerances for the specification of chromaticity for SSL lighting products [36]. The standard is based upon fluorescent lamp chromaticity tolerances [37] [38], but modified to meet the manufacturing practicalities of SSL products. Whereas the fluorescent tolerances are based on 4-step MacAdam ellipses (see 6.2.1 Chromaticity Diagrams) for linear fluorescent lamps [37], and 7-step MacAdam ellipses for CFLs [38], SSL tolerances employ trapezoids comparable in area to 7-step ellipses. ANSI C78.377 defines CCT tolerances in 100 K steps from 2700 to 6500 K. In applications where a design goal is to match the CCT of LEDs with another lamp type, it is advisable to evaluate samples rather than relying upon product datasheets.

7.5.3.3 UV and IR Optical Radiation

Properly functioning LEDs for architectural applications will emit negligible amounts of UV (< 400 nm) and IR (> 800 nm). This can be observed on Figure 7.49, which illustrates the drop-off in spectral power at both ends of the visible spectrum. Some types of phosphor-based LEDs may emit UV in the event of a mechanical failure in the device package, such as lens cracking, that does not coincide with a failure of the chip (see 7.5.3.2 White Light from LEDs).

LEDs may be purposely designed for UV or IR emission. UV optical radiation can be created from p-n junctions in aluminum gallium indium nitride (AlGaInN), aluminum gallium nitride (AlGaN), aluminum nitride (AlN), boron nitride, and diamond. UV and near-UV applications include inspection of anti-counterfeiting UV-sensitive watermarks, disinfection, and sterilization. Gallium arsenide (GaAs) and aluminum gallium arsenide (AlGaAs) may be employed to create a p-n junction that emits IR optical radiation. As of yet, there are few practical applications for IR-emitting LEDs since other light sources radiate IR more efficiently.

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7.5.4 Nomenclature

Most current SSL products resemble both light sources and luminaires, making it difficult to separate LED packages from LED luminaires.

LED Packages

There is no standard nomenclature for ordering or characterizing LED packages; multi-page data guides are required to communicate the relevant characteristics, which includes: physical size; maximum ratings for DC forward current; maximum permissible peak forward current; maximum LED junction temperature; reverse voltage limit; operating and storage temperature ranges; and minimum, typical, and maximum forward voltages. LEDs are typically sorted into *bins* with respect to radiant flux and dominant wavelength, both of which must be specified with respect to a DC forward current. The cut sheet may also provide plots of wavelength shift versus forward current, relative output versus forward current, SPDs, and a polar plot of luminous intensity. The operational data are temperature dependent; data guides are typically based on a 25° C ambient temperature.

Bin A restricted range of LED performance characteristics used to delimit a subset of LEDs near a nominal LED performance as identified by chromaticity, and photometric performance. Note: As the result of small but meaningful variations in the manufacturing process of LED wafers and subsequent dies, the electrical and photometric characteristics of LEDs may vary from LED to LED, even when the dies are from the same wafer. LEDs are sorted or binned in accordance with these characteristics, but there is no existing standard for binning. See also 7.5.6.9 | Color Uniformity and Stability

LED Luminaire A complete LED lighting unit consisting of a light source and driver together with parts to distribute light, to position and protect the light source, and to connect the light source to a branch circuit.

LED Luminaires

The U.S. Department of Energy developed the Lighting Facts^{CM} label for *LED luminaires*. The label is intended to provide specifiers and end-users with objective information and facilitate comparisons. An example is given as Figure 7.50. The label includes: lumen output; input power; system efficacy (reported as "efficacy"); CRI; CCT; model number, type, and brand; and a unique registration number. To participate in the program manufacturers must pledge to comply with conditions, including random product testing and compliance with LM-79: Approved Method for Electrical and Photometric Measurement of Solid State Lighting Products. Notably absent from the Lighting Facts^{CM} labeling are data about lumen maintenance and life. Recommendations for testing and reporting LED luminaire lifetime have been separately published by DOE in cooperation with the Next Generation Lighting Industry Alliance (NGLIA) [39]. The efficacy listed on the label is an initial value which can be expected to be cut in half (when L_{50} is reached) as the product ages. In many LED luminaires, the LED package is non-replaceable and the entire luminaire must be discarded at failure; this is unlike traditional luminaires that have replaceable lamps.

LED package data are particularly relevant to luminaire manufacturers that are incorporating packages into LED luminaires. However, LED package data may also be relevant to lighting specifiers because characteristics of the LED package may be influenced by the design application. Ambient temperature, in particular, cannot be controlled by the manufacturer of either the LED package or LED luminaire. Successful use of LEDs therefore requires good coupling between the LED package, LED luminaire, and design application.



Figure 7.50 | Lighting Facts^{CM} Labeling Scheme
An example of the U.S. DOE Lighting Facts^{CM} label for LED luminaires. The label must list the following:

1. Light output/lumens
2. Watts
3. Lumens per watt/efficacy
4. IESNA LM-79-2008 testing
5. DOE luminaire registration number and manufacturer's model number
6. Color rendering index (CRI)
7. Correlated color temperature (CCT)

» Image U.S. Department of Energy

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7.5.5 Types

LEDs entered applied lighting in the 1960s as narrow emitting, long lasting, low intensity replacements for incandescent indicator lights. They have blossomed into sources that, at the time of publication, have moderate lumen output, moderate luminous efficacy, and potential for extensive use in general illumination.

Miniature *LED lamps* are available in many shapes and sizes ranging from 2 to 8 mm. Several are illustrated in Figure 7.51. They do not have a heat sink or mechanism for coupling to a heat sink, which sets an upper limit for both power consumption and lumen output. Common drive currents are 1 to 20 mA. In addition to individual use as indicator lights, they have been grouped into arrays for use in traffic signals, variable message signs, commercial advertising signs, and EXIT signs.

LED Lamp, Non-Integrated A lamp with LEDs, without an integrated LED driver or power source and with an ANSI standardized base designed for connection to a LED luminaire.

LED Lamp, Integrated A lamp with LEDs, an integrated LED driver or power source and with an ANSI standardized base designed for connection to a LED luminaire. Sometimes abbreviated as LEDi.

In architectural applications, it is more typical to employ so-called "high-flux" LED lamps. Unlike miniature LED lamps, high-flux LED lamps have their die coupled to a heat sink, which is intended to be coupled to another heat sink when integrated into an LED luminaire. "High-flux" is a relative term, as the lumen output is greater than that of miniature LED lamps, but still low in comparison to other light sources. At the time of this writing, a single-chip high-flux LED lamp may generate 60 to 100 lumens at a drive current of 350 mA. Such LEDs can typically be driven up to 500 mA, or in some cases as high as 700 mA, which increases lumen output, but with a higher junction temperature, and thus shorter life. There are no conventions with respect to high-flux LED lamp characteristics in any category, including: physical (size, shape); optical (SPD, lumen-output, intensity distribution); electrical (forward current, voltage, wattage); or mechanical (base type, heatsinking). High-flux LED lamps are rapidly evolving products on an open market that has not yet matured to the point of commodification. Several examples are given in Figure 7.52.



Figure 7.51 | Miniature Non-Integrated LED Lamps
Miniature non-integrated LED lamps commonly employed as indicator lights, in sizes of 3, 5, and 8 mm are shown, next to a matchstick for scale.

LED lamps are not typically specified directly by lighting specifiers on luminaire schedules or in specifications. Rather, they are incorporated into LED luminaires as an integral component, and may or may not be replaceable. It is incumbent upon the LED luminaire manufacturer to effectively couple the LED lamp into the LED luminaire, and for the lighting specifier to apply the product in the intended manner. Thermal management is among the most important considerations in achieving rated performance.

7.5.6 Operating Characteristics

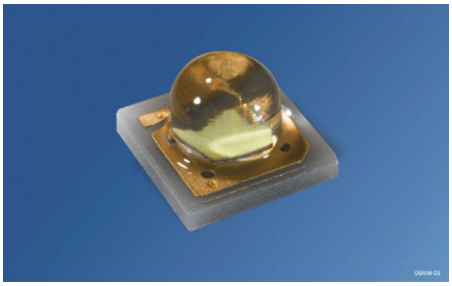
Salient LED operating characteristics include: lumen output; lamp life and lumen maintenance; lamp lumen depreciation; failure mechanism; wall-plug, lamp, and system efficacy; dimming characteristics; and color rendition. Many of these characteristics are quite different than those of traditional light sources, even when similar language is employed.

LED Die A small block of semiconducting material on which a given functional circuit is fabricated.

7.5.6.1 Lumen Output

The amount of luminous flux varies according to the LED's color and depends upon the current density that the *LED die* can manage. All else being equal, luminous flux is greater when there is a greater percentage of optical radiation near the peak of the luminous efficiency function, and when the LED device can handle more current. The amount of optical radiation near the peak of the luminous efficiency function is limited by many factors, including the physics and chemistry of semiconductor-based light production, and spectral design considerations related to CCT and color rendition. LED package properties limit the electrical current that can be safely driven to the die.

Figure 7.52 | High-Flux LED
An example of a high-flux LED.
» Image ©OSLON SSL, photo courtesy of OSRAM Opto Semiconductors



Lumen output per LED package is a rapidly changing landscape, especially in the category of so-called "high-flux" LEDs. As of this writing, LED packages are available that deliver in excess of 1500 lumens at efficacies greater than 75 lumens per watt, when driven at 250 mA. Such packages are comprised of an array of chips (in this example, 49 chips) mounted on a single board, and encapsulated in one refractive optic. High flux devices are made by combining several dies into a single luminaire.

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7.5.6.2 Lamp Life and Lumen Maintenance

LEDs have the potential to exhibit very long operational lives. Depending on their construction and use conditions, they may achieve service lives of 50,000 hours or longer. Use conditions that affect performance include: operating cycle; electrical conditions imposed by auxiliary equipment; thermal conditions associated with the luminaire; ambient temperature; airflow; and orientation. Unlike traditional light sources, lamp life is more commonly governed by parametric rather than catastrophic failure (see 7.5.6.3 Failure Mechanism). Like all light sources, the lumen output from LEDs decreases over time. Therefore, even though the LED source may continue to light, lumen depreciation can result in lower light output than intended in the specification, or required by codes, standard practices, or regulations. For these reasons, lamp life and lumen maintenance are connected more intimately with LEDs than they are with traditional light sources.

Like all other electric light sources, LEDs produce less lumens as they age. As of this writing, it is difficult to generalize the lumen maintenance performance of LEDs because they are a rapidly development technology. Further, LEDs are expected to have long-lives, and as a result long-term testing for new and recently introduced products is based largely on probabilistic projections, rather than on actual measurement. One example of a lumen maintenance curve is given in Figure 7.53. For computing lamp lumen depreciation for LEDs, see 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS.

7.5.6.3 Failure Mechanism

Failure occurs when the LED can no longer perform its intended function. Failure can be catastrophic or parametric.

Catastrophic failure means that the LED will no longer light; it is not accompanied by glass breaking or other non-passive failure mechanisms. Catastrophic-failure mechanisms are generally due to electrical or thermal overstress, and may include: broken bond wires; delamination of the package layers; or a break in the metallization of the die. The typical end-result is either an open circuit or a short circuit within the package. Failures in the package cannot be repaired.

Parametric failure means a key parameter has drifted by more than an acceptable amount from its initial value, even though the LED package will still produce optical radiation. Parametric-failure mechanisms include degradation or shifts in: luminous flux; luminous intensity; luminous efficacy; dominant wavelength; forward voltage; and reverse leakage current. L_{70} and L_{50} are examples of criteria that could be used to define parametric failure.

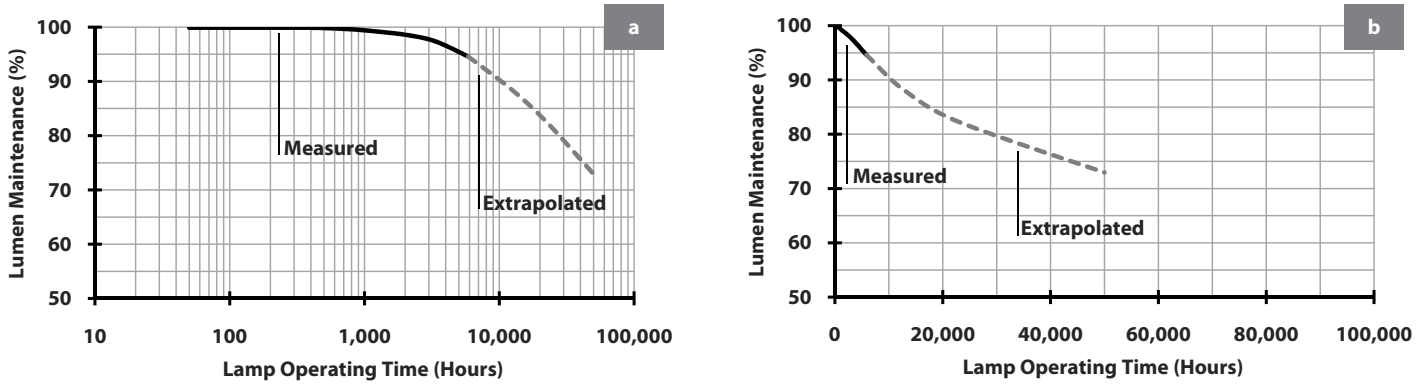


Figure 7.53 | Lumen Maintenance for an AlInGaP LED driven at 350 mA
The data for (a) and (b) are identical, but plotted with a logarithmic scale (a) and linear scale (b) on the horizontal axis. These data should not be generalized as the shape of the curve may not be typical of all LEDs. Contact the manufacturer for comparable data for product under consideration. As of publication, 350 mA is a typical drive current for high-flux LEDs.

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In considering a large batch of LED packages, some early failures should be expected ("infant mortality"), followed by a useful-life period in which occasional random failures may occur ("middle age"), followed by a more rapid wear-out period among the batch ("old age"). Age is not just a function of operating time, but is also a function of stress during operation. LED package stress is most closely related to heat (thermal stress), though electrical stress may also lead to failure. Thermal and electrical stresses are both directly related to the drive current. Figure 7.54 provides expected lifetimes for one type of LED as a function of junction temperature and forward current; note that such curves may vary considerably between products and this figure should not be generalized. Refer to manufacturer's literature.

7.5.6.4 LED Drivers

LED lamps require a driver, which is an auxiliary electronic component connected between the power supply and the LED package, array, or module. The LED driver provides the interface between the input line power and the output to the LED load, and may: convert line voltage AC power to DC power of appropriate voltage and current; provide filtering of variations in line voltage; provide power factor correction; and/or provide dimming control. Even *AC-LED* systems only conduct current through each LED for half of the AC line cycle. The driver may be incorporated into the luminaire as an integral component, or it may be a separately specified component in a system.

LED drivers can employ various power conversion topologies to achieve the desired regulated DC output, including a linear regulator or switch mode converter. A typical LED driver block diagram is given as Figure 7.55. An LED driver may employ constant current or constant voltage, and thus, a driver may be categorized as either a constant current driver or a constant voltage driver.

A constant current driver regulates the current that passes through the LEDs, regardless of the LED voltage. An *LED array* designed for a constant current driver may have LEDs in series, or in a series/parallel combination. If the array includes LEDs in parallel, it should be designed to ensure that the LEDs share current equally.

A constant voltage driver regulates the voltage across the LEDs, regardless of the LED current. Since LEDs require a specific current, many constant voltage LED loads also include an impedance between the voltage driver and the LEDs to ensure proper current

AC-LED An AC-LED is a device that operates without a DC converter. Since diodes permit the flow of electricity in only one direction, they are inherently DC devices. The basic approach with AC-LEDs is to allow one set of die to be illuminated during the positive half of the AC cycle, and another set during the negative half cycle. By alternately energizing and de-energizing an equal number of die, AC-LEDs appear to produce constant light.

LED Array An assembly of LED packages on a printed circuit board or substrate, possible with optical elements and additional thermal, mechanical, and electrical interfaces. The device does not contain a power source, does not include an ANSI standardized base, and is not connected directly to the branch circuit.

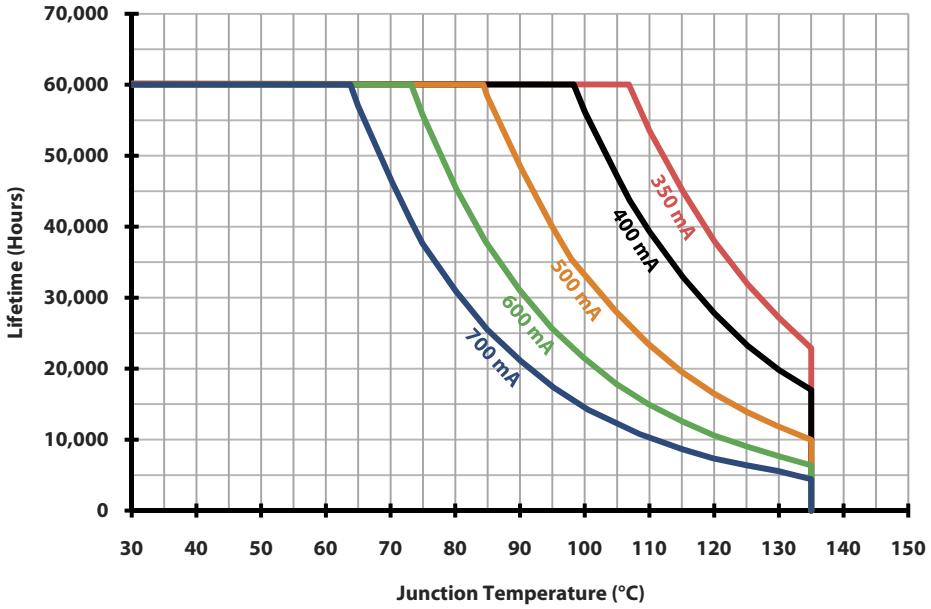


Figure 7.54 | LED Lifetime versus Junction Temperature
Expected (B_{50}, L_{70}) lifetimes for AlInGaP (e.g. amber, red-orange, and red) Luxeon Rebel LED packages as a function of junction temperature, and for different drive currents. (B_{50}, L_{70}) is the time to when either 50% of the population is expected to have either failed catastrophically (B_{50}), or degraded by more than 30% from initial lumen output (L_{70}). Note that these curves vary considerably with LED package and these data should not be generalized.

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flow. LED arrays designed for constant voltage typically include several series strings of LEDs, connected in parallel.

Power Quality A set of limits on electrical properties that allows an electrical system to operate in the intended manner without deleterious effects to performance or life.

A driver must meet electrical specifications related to *power quality*, including: power factor (PF); total harmonic distortion (THD); inrush current; and radiated and conducted electromagnetic interference (EMI).

PF: Electronic equipment, like an LED driver, contain reactive circuit elements which cause the current drawn from the line to be out of phase with the line voltage, reducing PF and causing power line losses. To minimize these losses, products should have corrective circuit elements to bring the PF as close to unity as possible, preferably above 90%. By way of comparison, the filament of an incandescent lamp is a purely resistive element which draws current that is in phase with the AC line voltage, and thus has a PF of unity.

THD: Typical LED drivers contain at least one switching power supply. The high-frequency current drawn by these supplies causes harmonic distortion of the current drawn from the line, and may also result in neutral wire heating and load imbalance in three-phase systems. ANSI requires that THD be below 33% for fluorescent lamp ballasts [24]. Until a specific standard is developed for SSL drivers, the THD requirements ANSI C82.11 should be met. Products must contain adequate filtering to meet this specification in application.

Inrush Current: LED loads which contain large input capacitance may draw a large "inrush" current when power is first applied, or during each line half-cycle, if operated from a leading edge phase-control dimmer., which is the type commonly employed for filament lamps. This inrush current can stress circuit breakers, switches, and dimmers if it is significantly higher than the peak line current. Figure 7.56 schematically illustrates an inrush current spike.

EMI: EMI is caused by the emission in the radio spectrum by some electronic equipment, such as LED drivers and fluorescent lamp ballasts. EMI not only interferes with radio systems, but may interfere with other electronic equipment. LED drivers should, at minimum, be designed to meet the emission standards of IEC EN 61000-6-3 [40]; more stringent control may be required for EMI sensitive applications, such as in the vicinity of medical equipment.

Many LED loads today have circuit elements which can be touched by the user. This requires isolation of the output of the driver from the electrical feed, which is most commonly "Class 2" *isolation* as defined by the National Electric Code [41]. Similar standards exist in Canada [42].

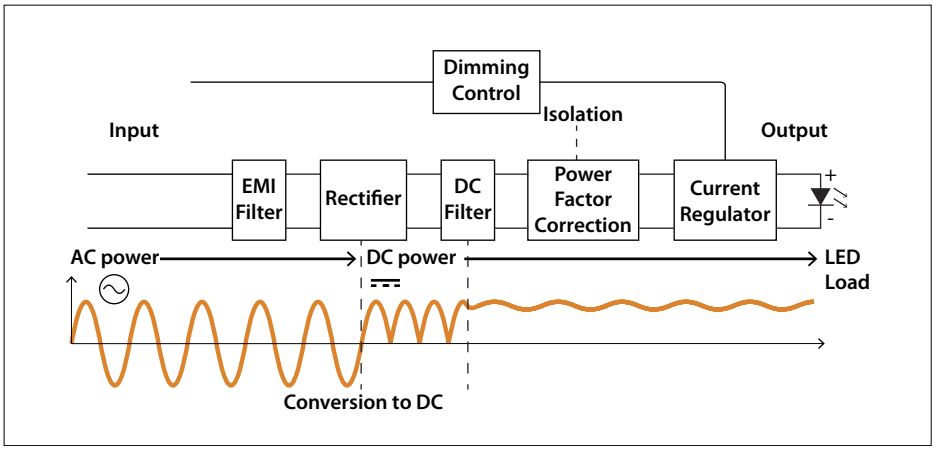


Figure 7.55 | Typical LED Driver Block Diagram
The principal components of an LED driver are illustrated. Input AC line power is on the left, through DC power delivered to the load, on the right.

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An isolated power supply is not as efficient as one which is referenced to the line (non-isolated), since all of the energy must be transferred through one component (typically a transformer). As of publication, typical conversion efficiency for isolated power supplies is about 85%.

Some LED drivers are designed for multiple applications with different loads, which requires output regulation circuitry. While this can be done in many ways, all methods depend on passing current through an impedance which has some resistive element. The resistance causes loss in the circuit in proportion to the current. Hence, higher power output drivers, operating at a higher current, will be less efficient than lower power output drivers.

Line voltages used for LED lighting applications typically range from 100 – 277 V. Some drivers are designed for multiple input voltages, adding to the internal driver circuitry. All else being equal, a driver designed for multiple input voltages will be less efficient than one designed for a single input voltage. However, all is not usually equal; a driver for multiple input voltages from one manufacturer may be more efficient than a driver for a single input voltage from a different manufacturer.

While LED drivers are designed to be as efficient as possible, the ability to regulate the output and/or operate under a range of input voltages affects driver efficiency. These driver requirements may require a compromise between efficiency, cost, application flexibility, and product quality. Datasheets from different manufacturers should be evaluated when making specification decisions.

Some LED drivers provide an indication of when LED output as degraded below a certain point, such as L_{70}, indicating that end-of-life has been reached. LED drivers are electronic components that are susceptible to heat. Since L_{70} is most typically predicted to be reached at 50,000 hours, consider replacing the driver at the same time as the LED lamps.

Drivers must typically conform to UL safety standards [43] [44] [45].

7.5.6.5 Dimming

In theory, it is possible to dim LED lamps from 100% lumen output to less than 1%. Much like a ballast (the auxiliary component that permits dimming in discharge lamps by controlling the electrical conditions), the LED driver is the auxiliary component that permits dimming of LEDs by controlling the electrical conditions.

There are two principle methods for dimming LEDs: linear reduction of forward current (constant current reduction, CCR); and pulse-width modulation (PWM). Constant current drivers can be designed to employ either method, whereas PWM is the only method that can be employed by constant voltage drivers. Figure 7.57 schematically illustrates PWM and CCR waveforms. Most drivers for new specifications employ PWM, which rapidly switches the LED lamp on and off from hundreds to hundreds of thousands modulations per second. At such frequencies LED flicker is undetectable by the human visual system.

Note that most dimmers today were designed around the electrical characteristics of purely resistive incandescent loads. When multiple LED loads are connected to the same dimmer, the electrical stresses placed on the dimmer may not be adequately represented by the published load wattage. Higher initial inrush current or repetitive peak currents (when used with a leading edge dimmer) may stress the dimmer beyond its design margins, even if the nominal wattage rating has not been exceeded. Refer to Figure 7.56 for an illustration of an inrush current spike.

Important caveats include the facts that there are no standards for LED lamp/driver compatibility and there are no standards to characterize dimming performance. With some LED lamp/driver combinations, flicker will occur during dimming, rather than the smooth change in lumen output associated with incandescent and fluorescent dimming

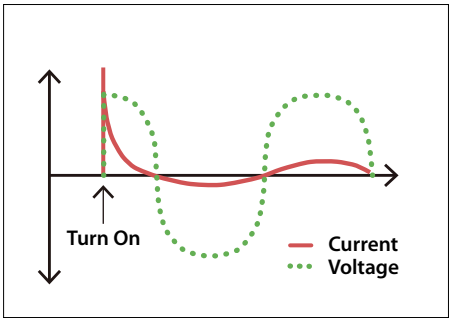


Figure 7.56 | LED Inrush Current
Schematic illustration of an inrush current spike, which may be many times greater than the operating current for LEDs.

Isolation The condition of being electrically separated.

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systems. In some systems, LED lamps may abruptly extinguish at 10 – 20% lumen output rather than providing continuous dimming to less than 1%.

Shifts in CCT and color rendition may occur, though they tend to be negligible in phosphor-based LED lamps. Before making a specification, samples of the products under consideration should be evaluated to ensure compatibility with the expectations of the owner and design team.

Dimming LEDs does not result in a reduction in luminous efficacy. Lamp life is not shortened, and may in fact be lengthened since dimming reduces the p-n junction temperature, which is one of the leading determinants of LED life.

7.5.6.6 Wall-Plug Efficiency, Luminous Efficacy, and System Efficacy

LEDs are characterized in part by their radiant efficiency, which is also called wall-plug efficiency, which is expressed as:

$$\eta_e = \eta_f \times \eta_{inj} \times \eta_{rad} \times \eta_{opt} \times \eta_{pho} \quad (7.11)$$

Where:

η_e = Radiant efficiency, or wall-plug efficiency, which is expressed as an integer between 0 and 1.0, or multiplied by 100 and expressed as a percentage.
η_f = Feeding efficiency, which is the ratio of the mean energy of the photons emitted, to the total energy that the electron-hole pairs acquire from the power source.
η_{inj} = Injection efficiency, which is the ratio of electrons that are injected into the region where recombination takes place, to the total number of electrons that flow through the LED.
η_{rad} = Internal quantum efficiency, which is the ratio of the number of electron-hole pairs that recombine radiatively (the emission of optical radiation), to the total number of pairs that recombine. Electrons and holes that recombine nonradiatively produce conductive heat loss.
η_{opt} = Optical efficiency, also known as light-extraction efficiency, which is the ratio of photons generated, to the photons that escape the device.
η_{pho} = Phosphor conversion efficiency, which is ratio of the photons emitted as optical radiation, to the photons absorbed. For LEDs that do not employ a phosphor this is equal to 1.0.

Luminous efficacy is dependent upon the wall-plug efficiency considerations described above, but also on the relationship between the wavelengths of optical radiation that can be generated with current materials science, and the luminous efficiency function. Figure 7.58 [46] plots radiant efficiency for InGaN and AlInGap LEDs as a function of wavelength, overlaid with the luminous efficiency function. While it is theoretically possible to construct an LED with virtually any peak wavelength in the visual spectrum, it is currently impractical to do so in the region from approximately 550 to 580 nm. Bridg-

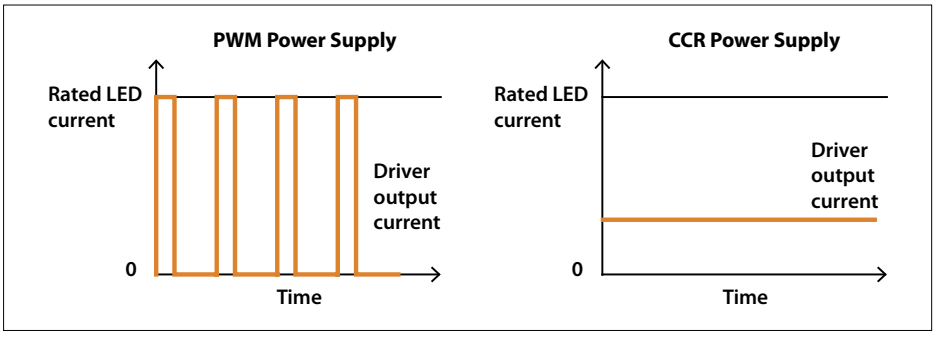


Figure 7.57 | LED Dimming Methods
Current waveforms are schematically illustrated for the two most common methods of dimming LEDs. Left: Pulse Width Modulation (PWM). Right: Constant Current Reduction (CCR). Both represent approximately 30% output.

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ing this gap is an active area of research [47]. The power consumed by the driver must be considered when determining system efficacy.

7.5.6.7 Thermal Characteristics

Several characteristics of LEDs are sensitive to heat, including: lumen output; luminous efficacy; the color of the optical radiation; and life. These characteristics are related to the p-n junction temperature, more simply referred to as junction temperature. The colder the junction temperature, the better a LED will perform. Temperatures exceeding the maximum junction temperature (T_{JMAX}), which should be listed on the data sheet for the LED package (see 7.5.4 Nomenclature), should always be avoided since exceeding this temperature may result in catastrophic failure of the packaging. Plots showing temperature-dependent characteristics as a function of temperature should be provided by the LED lamp manufacturer. For example, a plot of the change in dominant wavelength as a function of temperature for an InGaN LED lamp is given as Figure 7.59.

7.5.6.8 Color Rendering

Experiments have shown that visual-rankings contradict CRI-rankings when white LED light sources are among the light sources used to illuminate an array of colored objects [48] [49] [50]. As a result, CIE concluded that CRI is not applicable to predict the CRI rank-order of a set of light sources when white LED lamps are involved in the set [51], and CIE recommended the development of a new color rendering index, or a set of color rendering indices. This work is currently being undertaken by TC1-69 Colour Rendering of White Light Sources. For some alternatives to CRI that already appear in the literature, see 6.3.3 Other Methods for Assessing Color Rendition.

7.5.6.9 Color Uniformity and Stability

Some LED lamps exhibit inherent color variations from lamp-to-lamp (uniformity), and they may change in color as a result of a change in some operating conditions (stability).

Uniformity problems are a result of the inherent complexities of manufacturing semiconductors (see 7.5.2 Construction). When a semiconductor wafer is scribed and cut into die, different parts of the die will have different properties. Also, different wafers will have different properties, varying from batch-to-batch. The most workable solution has been to employ binning. A bin is a restricted range of LED performance characteristics used to

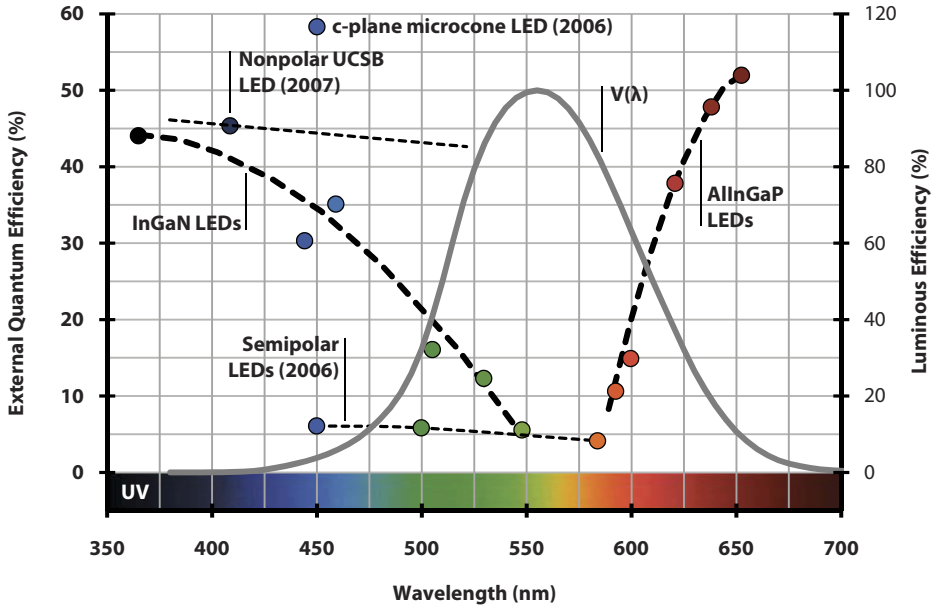


Figure 7.58 | External Quantum Efficiency for InGan and AlInGaP LEDs
Current knowledge of materials science results in unequal external quantum efficiency at different wavelengths. This figure provides an overlay with the luminous efficiency function. [44]

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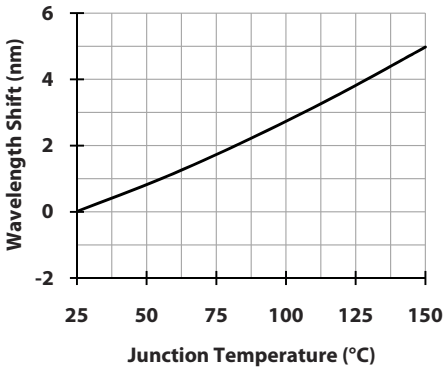


Figure 7.59 | Dominant Wavelength versus Junction Temperature for an InGan LED
This curve should not be generalized as the dominant wavelength shift is quite variable for different types of LEDs. If color shift is important, then contact the manufaccturer to attain a comparable plot for the product under considerationn.

delimit a subset of LEDs near a nominal LED performance as identified by chromaticity and photometric performance. There is no existing standard for binning colored LEDs, and so manufacturers adopt their own criteria; such data should be available on product datasheets. LEDs that generate white light at a constant CCT should be binned according to ANSI C78.377 (see 7.5.3.2 White Light from LEDs). Note that some manufacturers employ tighter (smaller) bins than other manufacturers, and there may be visibly discernable differences between LED lamps even within the same bin. If color uniformity is critical, numerous device samples should be attained, preferable at the extents of the bin limits. Binning is performed for LEDs with and without phosphors. At the time of writing, LEDs that employ a phosphor tend to have better color uniformity than colored LEDs. Figure 7.60 provides a graphical representation of bins for nominally white SSL products ranging from 2700 – 6500 K [36].

Some LEDs shift in color with changes in the junction temperature, which may be a result of dimming. It is not possible to generalize the magnitude of the color shift. AlInGap LEDs (above about 580 nm) tend to have larger color shifts with a change in temperature than to InGaN LEDs (below about 550 nm). LED lamps may also shift in color as they age, and different spectral components may have unequal lumen depreciation. Some multimodal LED systems that create white light with the additive mixing of red-, green-, and blue-emitting LEDs employ active feedback to hold chromaticity constant during dimming and over life. This is achieved by differentially adjusting the red-, green-, and blue-emitting components. As of publication, LED lamps that employ a phosphor tend to be less susceptible to color shift with respect to both diming and life.

7.6 Disfavored Light Sources

Certain lamp types have been employed for many decades, but are no longer appropriate for new specifications. These include: standard filament incandescent; mercury vapor HID; and low-pressure sodium. Standard filament incandescent lamps have been superseded by halogen and halogen infrared technologies, which have improved life and luminous efficacy. High pressure mercury vapor lamps have been superseded by metal halide lamps, which have better color-rendering and luminous efficacy. Low-pressure sodium lamps were employed in the past due to their high luminous efficacy, which is achieved at the expense of color rendition. They are disfavored because the tradeoff between luminous efficacy and color rendition is too severe. Low pressure sodium lamps produce monochromatic-yellow light, resulting in abysmal color rendition and making them unsuitable for general lighting applications where color rendition is of even minor importance.

7.7 Other Light Sources

Short-arc or compact-arc lamps include mercury and mercury-xenon lamps, xenon short-arc lamps, and ceramic-reflector xenon lamps. They are primarily used in searchlights, projectors, display systems, optical instruments, and for simulation of solar radiation. Compact-source metal halide lamps, also called medium-arc metal halide lamps, are available in various constructions in wattages from 70 to 18,000 W. They are used for motion picture and television lighting, outdoor location lighting, theatrical lighting, sports lighting, fiber-optic illuminators, liquid crystal displays (LCD), and video projectors. Other lamps include glow lamps, zirconium-concentrated arc lamps, pulsed-xenon arc lamps, flashtubes, linear-arc lamps, and electroluminescent lamps. Additional details about the above lamp types are provided in earlier editions of the IES Lighting Handbook.

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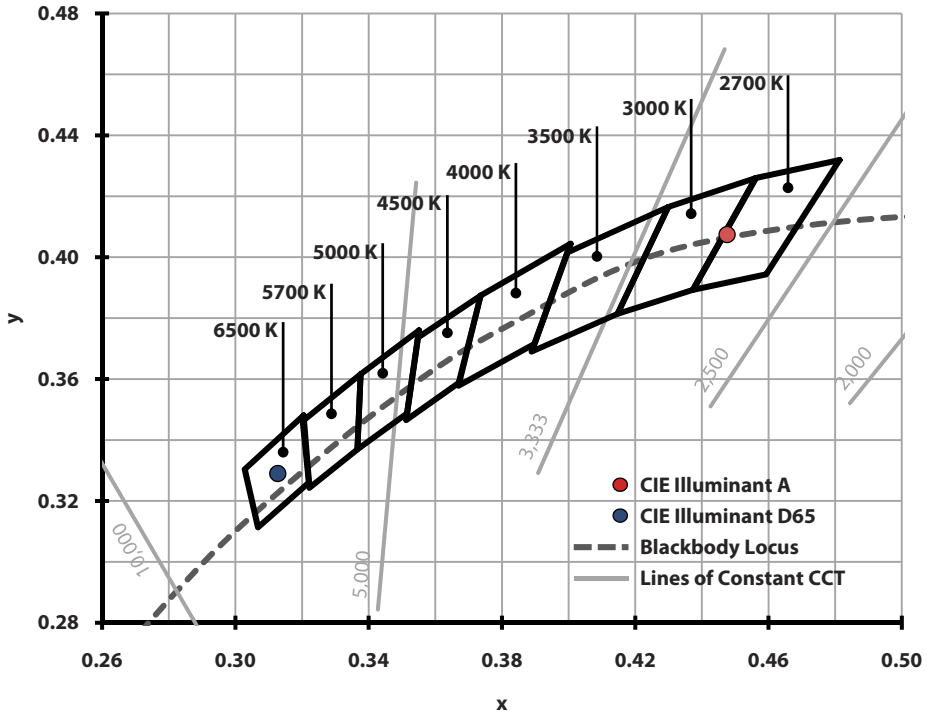


Figure 7.60 | LED Binning
Graphical representation of the chromaticity specification of nominally white SSL products on the 1931 CIE (x, y) chromaticity diagram, in accordance with ANSI C78.377 [34].

7.8 References

[1] IESNA. 1999. IES Recommended practice for daylighting, IES RP-23-1989. New York: IESNA.

[2] Murdoch JB. 2003. Illuminating engineering: from Edison's lamp to the LED. 2nd ed. New York: Visions Communications. 750 p.

[3] Hopkinson RG, Petherbridge P, Longmore J. 1966. Daylighting. London: Heinemann. 606 p.

[4] IES. 1984. IES Recommended practice for the calculation of daylight availability, IES RP-21-1984. IESNA: New York.

[5] Commission Internationale de I'Eclairage. 2004. Colorimetry. Publication 15:2004 . CIE: Vienna. 79 p.

[6] Vartianinen E. 2000. A comparison of luminous efficacy models with illuminance and irradiance measurements. Renewable Energy. 20:265-277.

[7] Lamm LO. 1981. A new analytic expression for the equation of time. Sol. Energy. 26(5):465.

[8] Meeus J. 1988. Astronomical formulae for calculators. 4th ed. Richmond, VA: Willman-Bell. 218 p.

[9] Gillette G, Pierpoint W, Treado S. 1984. A general illuminance model for daylight availability. J. lllum. Eng. Soc. 13(4):330-340.

[10] IESNA. 1989. IES recommended practice for the lumen method of daylight calculations, IES RP-23-1989. New York: IESNA.

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[11] Perez R, Seals R, Michalsky J. 1993. All-weather model for sky luminance distribution, preliminary configuration and validation. Solar Energy. 50(3):235-245.

[12] Perez R, Seals R, Michalsky J. 1993. Erratum: All-weather model for sky luminance distribution, preliminary configuration and validation. 51(5):423.

[13] Commission Internationale de l'Ec1airage. 2004. CIE S 011/E:2003. Spatial distribution of daylight- CIE standard general sky. Vienna: CIE. 7 p.

[14] National Solar Radiation Data Base: 1961- 1990: Typical Meteorological Year 2 [Internet]. National Renewable Energy Laboratory (US); [cited 2010 Jan 27]. Available from: http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/.

[15] National Solar Radiation Data Base: 1991- 2005 Update: Typical Meteorological Year 3. [Internet]. National Renewable Energy Laboratory (US); [cited 2010 Jan 27]. Available from: http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/.

[16] EnergyPlus Energy Simulation Software – Weather Data. [Internet]. Department of Energy (US); [cited 2010 Jan 27]. Available from: http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm.

[17] National Climate Data and Information Archive – Products and Services. [Internet]. Environment Canada; [cited 2010 Jan 27] Available from: http://climate.weatheroffice.gc.ca/prods_servs/index_e.html.

[18] Walkenhorts O, Luther J, Reinhart C, Timmer J. 2002. Dynamic annual daylight simulations based on one-hour and one-minute means of irradiance data. Solar Energy. 72(5):385-395.

[19] Fotios SA, Levermore GJ. 1997. Perception of electric light sources of different colour properties, Lighting Res. Technol. 29(3); 161-171.

[20] Fotios SA, Levermore GJ. 1995. Visual perception under tungsten lamps with enhanced blue spectrum. Lighting Res. Technol. 27(4); 173-179.

[21] McColgan MW, Van Derlofske J, Bullough JD, Shakir I. 2002. Subjective color preferences of common road sign materials under headlamp bulb illumination. SAE technical paper series: advanced lighting technology for vehicles (SP-1668). SAE 2002 World Congress. Detroit, MI.

[22] Guo X, Houser KW. A review of colour rendering indices and their application to commercial light sources. Lighting Res. Technol. 2004; 36(3): 183-199.

[23] Philips Lighting. 1995. LiDaC correspondence course. Module 8: incandescent lamps. 51 p.

[24] ANSI. 2002. ANSI C82.11 Consolidated-2002: American national standard for lamp ballasts—high frequency fluorescent lamp ballasts—supplements. 45 p.

[25] Eastman AA, Campbell JH. 1952. Stroboscopic and flicker effects from fluorescent lamps. Illum. Eng. 47(1): 27-35.

[26] Wilkins A, Lehman B, editors. 2010. IEEE Standard P1789. A review of the literature on light flicker: Ergonomics, biological attributes, potential health effects, and methods in which some LED lighting may introduce flicker. 26 p.

[27] Lehman B, Wilkins A, Berman S, Poplawski M, Miller NJ. 2011. Proposing measures of flicker in the low frequencies for lighting applications. Leukos. 7(3): 189-195.

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[28] IESNA LM-47-01. 2001. IESNA approved method for life testing of high intensity discharge (HID) lamps. New York: Illuminating Engineering Society. 5 p.

[29] Gibson RG. 2006. Investigations into LFSW ballast induced instabilities in ceramic metal halide lamps. 41st IAS Annual Meeting. Tampa, FL. 3:1372-1376.

[30] ANSI. 2007. ANSI C78.380-2007. American national standard for electric lamps–high-intensity discharge lamps, method of designation. 16 p.

[31] ANSI. 2005. ANSI C82.6-2005. American national standard for lamp ballasts-ballasts for high—intensity discharge lamps—methods of measurement. 29 p.

[32] Houser KW, Royer MP, Mistrick RG. 2010. Light loss factors for sports lighting. Leukos. 6(3):183-201.

[33] ANSI. 2007. ANSI-ANSLG C78.42-2007. American national standard for electric lamps: high pressure sodium lamps. 86 p.

[34] Ohno Y. 2004. Color rendering and luminous efficacy of white LED spectra. Proceedings of SPIE Fourth international conference on solid state lighting. Denver, CO. 88-98.

[35] Protzman JB, Houser KW. 2006. LEDs for general illumination: the state of the science. Leukos. 3(2): 121-142.

[36] ANSI. 2008. ANSI-NEMA-ANSLG C78.377-2008 American national standard for electric lamps: specifications for the chromaticity of solid state lighting products. 17 p.

[37] ANSI. 2001. ANSI C78.376-2001 American national standard for electric lamps: specifications for the chromaticity of fluorescent lamps. 16 p.

[38] US Department of Energy. 2008. Energy star program requirements for CFLs partner commitments. version 4.0, final version. Washington, DC: US Department of Energy. 38 p.

[39] Next Generation Lighting Industry Alliance with the US Department of Energy. 2010. LED luminaire lifetime: recommendations for testing and reporting. Washington, DC: US Department of Energy. 15 p.

[40] IEC 61000-6-3. 2006. Electromagnetic compatibility (EMC) – part 6-3: generic standards – emission standard for residential, commercial and light-industrial environments. 2nd edition. Geneva, Switzerland: International Special Committee on Radio Interference, International Electrotechnical Commission.

[41] National Fire Protection Association. 2008. NFPA 70: National electric code. Quincy, MA: NFPA. 822 p.

[42] Canadian Standards Association. 2009. C22.1-09: Canadian electrical code, part 1 (21st edition), safety standard for electrical installations. Mississauga, Ontario, Canada: Canadian Standards Association. 628 p.

[43] ANSI/UL 8750. 2009. Light emitting diode (LED) equipment for use in lighting products. Northbrook, IL: Underwriters Laboratory. 60 p.

[44] UL 1310. 2005. Standard for class 2 power units. Northbrook, IL: Underwriters Laboratory. 120 p.

[45] UL 1012. 2005. Standard for power units other than class 2. Northbrook, IL: Underwriters Laboratory. 162 p.

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[46] Nakamura S. 2009. Current status of GaN-based solid-state lighting. Materials Research Society Bulletin. 34(2):101-107.

[47] Crawford MH, Koleske DD, Lee SR, Tsao JY, Armstrong AM, Wang GT, Fischer AJ, Wierer JJ, Coltrin ME, Shea-Rohwer LE. 2009. Roadblocks to high efficiency solid-state lighting: bridging the "green-yellow gap". 2009 Quantum Electronics and Laser Science Conference. CLEO/QELS 2009. Baltimore, MD.

[48] Nakano Y, Tahara H, Suehara K, Kohda J, and Yaho T. 2005. Application of multi-spectral camera to color rendering simulator. Proceedings AIC Colour 2005. 1625-1628.

[49] Ohno Y. 2005. Spectral design considerations for color rendering of white LED light sources. Optical Engineering. 44: 111302.

[50] Sandor N, Schanda J. 2005. CIE visual colour-rendering experiments. Proceedings AIC Colour 2005. 511-514. ANSI.

[51] Commission Internationale de I'Ec1airage. 2007. CIE 177:2007 Colour rendering of white LED light sources. Vienna: CIE. 14 p.

[52] American Society for Testing and Materials. 2006. Standard solar constant and zero air mass solar spectral irradiance tables, ASTM E490-00a (Reapproved 2006). West Conshohocken: ASTM.

[53] IESNA. 2005. Nomenclature and Definitions for Illuminating Engineering, ANSI/IES, RP-16-2005. New York: IESNA.

[54] Stephenson DG. 1965. Equations for solar heat gain through windows. Sol. Energy 9(2):81-86.

[55] American Society of Heating, Refrigerating and Air-Conditioning Engineers. 2005. Fenestration, Chapter 31 in ASHRAE Handbook: 2005 Fundamentals. Atlanta: ASHRAE.

[56] Karayel M, Navvab M, Ne'eman E, Selkowitz S. 1984. Zenith luminance and sky luminance distributions for daylighting calculations. Energy Build. 6(3):283-29l.

[57] Kittler R. 1967. Standardisation of outdoor conditions for the calculation of daylight factor with clear skies. In Sunlight in buildings: Proceedings of the CIE Intercessional Conference, Newcastle-Upon-Tyne. Vienna: CIE.

[58] Commission Internationale de I'Ec1airage. 1994. CIE 110:1994 Spatial distribution of daylight - luminance distributions of various reference skies. Vienna: CIE. 33 p.

[59] Pierpoint W. 1983. A simple sky model for daylighting calculations. General proceedings: 1983 International Daylighting Conference, edited by T. Vonier. Washington: American Institute of Architects.

[60] Moon P, Spencer DE. 1942. Illumination from a non uniform sky. Illum. Eng. 37(12):707-726.

[61] Commission Internationale de l'Eclairage. 1970. CIE 16-1970 International recommendations for the calculation of natural daylight. Vienna: CIE. 87 p.

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7.9 Formulary: Daylight Availability from IES Standard Skies

For the purpose of conducting simple comparisons between designs for daylit spaces, standard sky conditions have been developed for representative clear, partly cloudy and overcast skies. The sun and sky contributions are each specified for these sky conditions based on solar position. These standard skies represent averages of a range of sky conditions, and are unlikely to represent conditions that would be measured at a particular site.

7.9.1 Sun Contribution

For the purpose of most basic daylighting calculations, the sun is considered to be a point source that produces collimated beam illuminance. The solar illumination constant is the solar illuminance at normal incidence to a surface at the earth's mean distance from the sun at the outer reaches of the earth's atmosphere. It is obtained from

$$E_{sc} = \int_{380}^{780} G_\lambda V_\lambda d\lambda \qquad \text{(F7.1)}$$

Where:

E_{sc} = solar illumination constant in klx
K_m = spectral luminous efficacy of radiant solar flux in lm/W
G_λ = solar spectral irradiance at wavelength λ, in W
V_λ = photopic vision spectral luminous efficiency at wavelength λ
λ = wavelength in nm (for photopic vision at 380 to 780 nm)

The following solar parameters are based on current standards [52] [53]:

- Solar illumination constant (E_{sc}): 133.1 klx (12,370 fc)
- Solar irradiation constant: 1366 W/m^2 (127.0 W/ft^2)
- Solar luminous efficacy (K_m): 97.4 lm/W

To calculate the sunlight reaching the ground, two conditions must be considered: the varying distance of the earth to the sun caused by the earth's elliptical orbit, and the effect of the earth's atmosphere. The extraterrestrial solar illuminance, corrected for the earth's elliptical orbit, is

$$E_{xt} = E_{sc}\left(1 + 0.034\cos\frac{2\pi(J-2)}{365}\right) \qquad \text{(F7.2)}$$

Where:

E_{xt} = extraterrestrial solar illuminance in klx
E_{sc} = solar illumination constant in klx
J = Julian date

The direct normal illuminance at sea level, E_{dn}, corrected for atmospheric attenuation, can be computed for a clear or partly cloudy sky via the following [54].

$$E_{dn} = E_{xt}e^{-cm} \qquad \text{(F7.3)}$$

Where:

E_{dn} = direct normal solar illuminance in klx
E_{xt} = extraterrestrial solar illuminance in klx
c = atmospheric extinction coefficient; clear sky = 0.21, partly cloudy sky = 0.80
m = optical air mass (dimensionless)

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Note that $E_{dn} = 0$ for an overcast sky, since the sun is completely obscured.

Values for the atmospheric extinction coefficient, discussed below, vary with sky condition. The simplest and most often used [55] representation for the optical air mass, m, is

$$m = \frac{1}{\sin a_t} \tag{F7.4}$$

Where a_t is the solar altitude in radians.

The direct sunlight on a horizontal plane is then expressed by

$$E_{dh} = E_{dn} \sin a_t \tag{F7.5}$$

Where:

E_{dh} = direct horizontal solar illuminance in klx
E_{dn} = direct normal solar illuminance in klx
a_t = solar altitude in radians

The direct sunlight on a vertical elevation is expressed by

$$E_{dv} = E_{dn} \cos a_i \tag{F7.6}$$

Where:

E_{dv} = direct vertical solar illuminance in klx
E_{dn} = direct normal solar illuminance in klx
a_i = incident angle in radians (see Equation 7.9)

7.9.2 Sky Contribution

Both a sky-ratio method and a sky-cover method have been used to classify sky conditions. The sky ratio is determined by dividing the horizontal sky irradiance by the global horizontal irradiance. Since the sky ratio approaches 1.0 when the solar altitude approaches zero (regardless of sky condition), this method is not accurate for low solar altitudes. The sky cover method applies an estimate of the cloud cover fraction (0 – 1.0) across the sky dome. Sky classifications based on these approaches are provided in Table F7.1, which summarizes the definitions for clear, partly cloudy, and overcast skies using the sky ratio and cloud cover fraction methods.

7.9.2.1 Sky Illuminance

The horizontal illuminance produced by the sky can be expressed as a function of solar altitude for a clear, partly cloudy and overcast sky, with the constants A, B and C listed in Table F7.2 [9]:

$$E_{kh} = A + B \sin^C a_t \tag{F7.7}$$

Where:

E_{kh} = horizontal illuminance due to unobstructed skylight in klx
A = sunrise/sunset illuminance in klx
B = solar altitude illuminance coefficient in klx
C = solar altitude illuminance exponent
a_t = solar altitude in radians

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7.9.2.1 Sky Luminance

For the purpose of computing the illuminance contribution from a portion of the sky, and for application in computer software tools, equations for sky luminance distributions are available. A different equation is used to represent the mean luminance distribution of each of the three sky conditions. The sky luminance at any position is a function of zenith luminance and the sun's position relative that direction. A zenith luminance factor is applied to calculate the zenith luminance from the horizontal sky illuminance:

$$L_Z = E_{kh}\ ZL \tag{F7.8}$$

Where:

L_Z = zenith luminance in kcd/m^2
E_{kh} = horizontal illuminance due to unobstructed skylight from Equation F7.7, in klx
ZL = zenith luminance factor at the same solar altitude as E_{kh}, in kcd/(m^2 klx)

Values for the zenith luminance factor can be found in Table F7.3. More detailed equations for the zenith luminance have been developed, which include effects such as differences in atmospheric turbidity [56].

The angles used in sky luminance determinations are shown in Figure F7.1. The position of the sun in this figure is given by the solar azimuth a_s and zenithal sun angle Z_o, which is the complement of the solar altitude:

$$Z_o = \frac{\pi}{2} - a_t \tag{F7.9}$$

The position of a point p in the sky (at which the sky luminance is to be determined) is given by angles, ζ, the zenith angle to the point, and γ, the angle between the point and the sun's position.

A standard clear sky luminance distribution function was developed by Kittler [57] and adopted by the CIE [8]:

$$L(\zeta,\alpha) = L_Z \frac{(0.91 + 10e^{-3\gamma} + 0.45\cos^2\gamma)}{(0.91 + 10e^{-3Z_o} + 0.45\cos^2 Z_o)(1 - e^{-0.32})} \tag{F7.10}$$

Where:

$L(\zeta,\alpha)$ = sky luminance at point p with spherical coordinates, ζ and α, in kcd/m^2
L_Z = sky zenith luminance in kcd/m^2
γ = angle between the sun and sky point p in radians (Equation F7.11)
ζ = zenith angle of point p in radians
α = azimuth angle from the sun in radians
Z_o = zenithal sun angle in radians

The angle, γ, between the sun and sky point p is given by

$$\gamma = \arccos(\cos Z_o \cos\zeta + \sin Z_o \sin\zeta \cos\alpha) \tag{F7.11}$$

where Z_o, ζ, α, and γ are defined as in Equation F7.10. This equation does not account for changes in the luminance distribution due to changes in atmospheric turbidity, which can substantially alter the sky luminance distribution.

Table F7.1 | Sky Classification Methods

Sky Type	Sky Ratio (SR = I_h / I_{global})	Cloud Cover Fraction (CCF)
Clear	SR ≤ 0.3	CCF ≤ 0.3
Partly Cloudy	0.3 < SR < 0.8	0.3 < CCF < 0.7
Overcast	SR ≥ 0.8	CCF ≥ 0.7

I_h = horizontal irradiance
I_{global} = global irradiance

Table F7.2 | Daylight Availability Constants

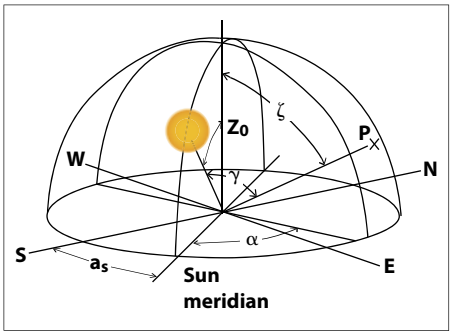
Sky Type	A (klx)	B (klx)	C
Clear	0.8	15.5	0.5
Partly Cloudy	0.3	45.0	1.0
Overcast	0.3	21.0	1.0

Table F7.3 | Sky Zenith Luminance Constants (ZL)

Solar Altitude (degrees)	Clear Sky ZL	Partly Cloudy Sky ZL
90	1.034	0.637
85	0.825	0.567
80	0.664	0.501
75	0.541	0.457
70	0.445	0.413
65	0.371	0.375
60	0.314	0.343
55	0.269	0.315
50	0.234	0.292
45	0.206	0.272
40	0.185	0.255
35	0.169	0.241
30	0.156	0.23
25	0.148	0.221
20	0.142	0.214
15	0.139	0.209
10	0.139	0.205
5	0.14	0.202
0	0.144	0.201

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Figure F7.1 | Sun and Sky Angles
The angles shown are used to denote sun and sky positions in sky luminance equations. See Equations F7.10 - F7.14.



The equation for a partly cloudy sky [13, 58] is similar in form to the clear-sky distribution but has different values for the constants based on mean data for partly cloudy skies.

$$L(\zeta,\alpha) = L_Z \frac{(0.526 + 5e^{-1.5\gamma})(1 - e^{-0.80/\cos\zeta})}{(0.526 + 5e^{-1.5Z_o})(1 - e^{-0.80})} \quad \text{(F7.12)}$$

where the symbols have the same meaning as in Equation F7.10.

The overcast-sky equation is

$$L(\zeta,\alpha) = L_Z (0.864 \frac{e^{-0.52/\cos\zeta}}{e^{-0.52}} + 0.136 \frac{(1 - e^{-0.52/\cos\zeta})}{e^{-0.52}} \quad \text{(F7.13)}$$

The form of the overcast-sky equation can be derived from first principles[59]. The first term provides the luminance contribution of the cloud layer, while the second term provides the luminance contribution of the atmosphere between the bottom of the cloud layer and the ground. Constants have been chosen to give a best fit to the original overcast sky data used by Moon and Spencer [60].

The empirical Moon-Spencer equation for the luminance distribution of an overcast sky is

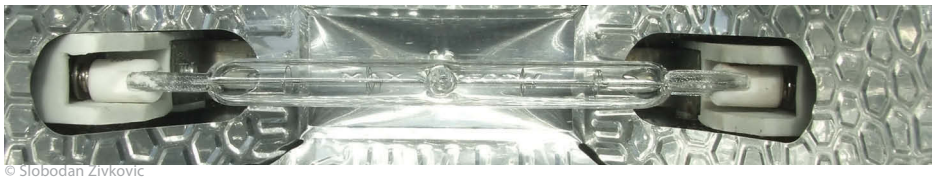
$$L(\zeta,\alpha) = \frac{L_Z}{3}(1 + 2\cos\zeta) \quad \text{(F7.14)}$$

Where:

$L(\zeta,\alpha)$ = sky luminance in kcd/m^2
L_Z = sky zenith luminance in kcd/m^2
ζ = zenithal point angle in radians

This equation has been almost universally used to represent overcast skies for the past 40 years and was adopted by the CIE in 1955 [61]. It is historically significant in that a large number of daylight calculation methods are based on it. There is very little numerical difference between Equations F7.13 and F7.14 for the appropriate constants.

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8 | LUMINAIRES
FORMS AND OPTICS

The hero is the one who kindles a great light in the world, who sets up blazing torches in the dark streets of life for men to see by.

Felix Adler, Early 20th Century Professor of Political and Social Ethics

Contents

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A luminaire is a device to produce, control and distribute light. It is a complete lighting unit consisting of one or more lamps and some or all of the following components:; optical control devices designed to distribute the light; sockets or mountings to position and protect the lamps and to connect the lamps to a supply of electric power; the mechanical components required to support or attach the luminaire, and various electrical and electronic components to start, operate, dim or otherwise control and maintain the operation of the lamps or LEDs. This chapter deals with the forms and optics of luminaires, ballasts and LED drivers are described in 7.3.6.5 Ballasts.

This chapter describes most common types of luminaires, how they are used, how their performance is evaluated, and gives a general classification system useful for understanding their application. Information for the specific applications of luminaires can be found in the appropriate application chapters.

8.1 General Description

8.1.1 Light Sources

Luminaires are designed and manufactured for all common types of electric lamps. Luminaires are commonly available for these lamps:

- Incandescent filament, including tungsten halogen and infrared (heating) lamps
- Fluorescent
- Compact fluorescent
- High intensity discharge, including metal halide and high-pressure sodium
- Light emitting diodes (LED)
- Organic light emitting diodes (OLED)
- Induction or electrodeless, including fluorescent and metal halide lamps

Less common are luminaires for these sources:

- Low pressure sodium lamps
- Xenon arc lamps
- Carbon arcs
- Microplasma
- Solid state - plasma

The size, materials, thermal properties, photometric performance, and power requirements of a luminaire depend on the lamp. For example, lamps that produce a large amount of infrared (IR) radiation require luminaires vented for convection, and fluorescent lamps that are sensitive to environmental temperature must be protected from low air temperatures.

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8.1.2 Light Control Components

The lamps used in some luminaires have integrated optical control components. These are usually filament and tungsten halogen lamps with a reflective coating and/or refracting prisms on the bulb and LEDs with integral refractor capsules. These integral lamp components produce useful beams and patterns of light without any auxiliary optical control. In these cases, most of the light control is provided by the lamp; the luminaire is simply an appliance to hold the lamp, deliver electric power, provide additional truncating of the lamp's beam, and perhaps permit the lamp to be aimed in different directions.

Most lamps without these optical control components emit light in virtually all directions and their efficient application is produced by light control components in the luminaire to collect and distribute the lamp light. Four types of light control components are commonly used: reflectors, refractors, diffusers, and louvers or shields. See 1.5 Optics for Lighting for a discussion of the optics of light control by reflection, refraction, and diffusion.

8.1.2.1 Shades, Baffles, and Louvers

Shades, baffles, and louvers are opaque or translucent materials shaped or configured to reduce or eliminate the direct view of the lamp from outside the luminaire. Shades are usually translucent and are designed to diffuse the light from the lamp and provide some directional control. Fully opaque shades provide directional control, but by design provide little diffuse light which may contribute to an overall dim look to the room or area and may introduce severe adaptation effects from foreground to background if these are the only luminaires in use.

Baffles are linear blades and are opaque or translucent media sized and configured to limit direct view of the lamp(s) from normal seated and/or standing viewing directions. Baffles typically are oriented perpendicular to the long axis of the lamp(s). Acrylic and metal are common materials. Typical finishes range from matte or specular black (least efficient) to white to aluminum although most can be factory-painted to any color available in powder coating. Specular finishes can create reflected lamp images visible at some viewing angles which may produce direct glare and veiling reflections on tasks. Baffles can be simple straight-blades or contoured to offer enhanced optical control.

Louvers are essentially baffles and are frequently arranged perpendicular to each other creating what is historically called an egg-crate pattern. Louvers can be configured with compound contours for a variety of distribution patterns and glare control limits. In large fluorescent lamp luminaires, typically 2′ by 2′ or larger, and where lamps may be high-output type or people and tasks are sensitive to direct light, lamps can be arranged to sit directly above louvers that are contoured and geometrically-designed to limit direct view of lamps. In other designs where lower-output lamps are used and where glare control is traded for efficiency, lamps can be arranged to sit directly between louvered cells.

8.1.2.2 Diffusers

Diffusers are light control elements that scatter and redirect incident light in many directions. Most diffusers scatter the light, a process that can take place in the material such as in bulk diffusers like white plastic, or on the surface as in etched or sandblasted glass. Diffusers are used to spread light and, since scattering destroys optical images, obscure the interior of luminaires, suppress lamp images, and reduce high luminances by increasing the area over which light leaves a luminaire.

Recently developed holographic diffusing material [1] permits much more control of the distribution of diffused light than just bulk or surface scattering. This material provides for the design of luminaires with highly tailored intensity distributions and very high luminous efficiencies [2].

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8.1.2.3 Reflectors

A reflector is a device, usually of coated metal or plastic that exhibits a high reflectance, shaped to redirect by reflection the light emitted by a lamp. The surface finish of luminaire reflectors is usually classified as specular, semi-specular, spread, or diffuse. See 1.5 Optics for Lighting.

Some applications require the reflector to control the light very precisely and specular or semi-specular reflecting material is used. Metal reflectors are formed and then polished or chemically coated to produce a specular finish. In some cases, metal reflectors are manufactured from metal stock that has already been treated to produce a specular finish. Plastic reflectors are molded and then coated with aluminum by vaporization. Examples of specular reflectors are those used to control the light from a metal halide lamp to produce a narrow beam of light for sports lighting and the parabolic louvers in some fluorescent lamp troffers.

In some luminaires the reflector does not have to control the light very precisely, and it is sufficient for the reflector to have a high but non-directional reflectance. An example of this is the white, slightly specular, coated metal reflectors in some large fluorescent lamp luminaires.

Diffuse reflectors generally cannot be used to control and redirect light from a lamp since light is reflected more-or-less uniformly in all directions. See 1.5.1 Important Optical Phenomena. Diffuse reflectors are thus uncommon in luminaires as shielding or beam shaping optical elements. However, diffuse material with very high reflectance can be used to produce highly efficient integrating chambers to capture and distribute light from high-power LEDs that would otherwise be difficult to use because of their very high luminance.

Other applications and lamps require reflectors with special surface finishes, such as semi-specular or peened materials (see 1.5.1.1 Reflectors), or coatings to reduce color separation upon reflection (iridescence) when using certain fluorescent and metal halide lamps. See 1.5.2.5 Thin Films.

In some cases, reflectors have properties varying with wavelength. Alternating layers of materials with differing indices of refraction are applied to glass. These layers have a thickness approximately that of the wavelength of light (500 nm). Interference effects produce reflection and (simultaneously) transmittance that changes with wavelength. See 1.5.1.4 Interference. This is useful if it desirable to reflect light but not reflect long wavelength thermal radiation or, conversely, reflect the long wavelength radiation and pass light. These reflectors are used when it is necessary to direct light and to control heat generated by the lamps.

For metal reflectors, surface treatments are used to increase hardness, improve corrosion resistance, and provide for coloring and reflective coating. Usually, these treatments are performed on the metal before it is formed into reflector parts and so is referred to as prefinishing. One of these processes is anodization; an acid-bath, electrolytic process commonly used with aluminum alloys to deposit a layer of aluminum oxide on the surface and increase corrosion resistance. The Alzak® process pretreats the metal surface to increase reflectance and, if required, specularity. This is often referred to as electrochemical brightening. The important characteristics of prefinished reflector material are its reflectivity, the degree of specularity, and its ability to maintain reflectivity. Some surface treatments involve the deposition of very thin layers that can produce dispersion of the lamp spectrum, causing iridescence. See 1.5.1.4 Interference.

8.1.2.4 Refractors

Refractors are light control devices that take advantage of the change in direction light undergoes as it passes through the boundary of materials of differing optical density, such

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as air/glass or air/plastic. A material, usually glass or plastic, is shaped so that light is redirected as it passes through it. This redirecting can be accomplished with linear extruded two-dimensional prisms or with three-dimensional prisms. These prisms can either be raised from the surface of the material or embossed into it. They are usually small enough to become a type of surface treatment on one side of an otherwise flat sheet of glass or plastic. The entire sheet is referred to as a prismatic lens.

A collection of small prisms, acting in concert, can be used to control the directions from which light leaves a luminaire. This redirection can be used to partially destroy images and therefore to obscure lamps and reduce luminance by increasing the area over which the light leaves the luminaire. In some cases, linear prisms, shaped ridges, or scallops are used to spread light or widen the beam produced by the luminaire.

In some cases the sheet containing prisms is shaped to provide additional control. In specialized applications, such as the refractors used for some street lighting luminaires, the prisms are on both surfaces of the material.

Another application of refracting material takes advantage of total internal reflection. In this case the refracting material is shaped so that light passes into it through its first surface and the second surface reflects much of the light back into the material and back out the first surface. See 1.5.2.3 Prisms and 1.5.2.1 Reflectors. Some glass and plastic industrial luminaires use this type of light control. This is also the basis for the operation of light pipes and fiber optic luminaires.

For some luminaires, the lamp and application require a transparent cover to prevent broken lamp components from falling out of the luminaire. Though providing little optical control, these cover plates are often referred to as lenses.

8.1.2.5 Filters

In some applications it is necessary to alter the spectral power distribution of the optical radiation produced by the lamp before it leaves the luminaire, without necessarily altering the spatial distribution of radiation. Filters can provide this alteration. For some medical and museum applications, filters are used to eliminate or block ultraviolet (UV) or infrared (IR) radiation. Glass or plastic materials that absorb UV radiation are used for these filters. Filters that limit the spectral power distribution of optical radiation leaving the luminaire to relatively narrow bands can be used to provide color filtration. Some of these are based on interference produced by thin films, others use bulk absorption. Interference filters generally have better spectral control and can produce transmission in very narrow spectral bands when necessary.

Filters of thin opaque material which have patterns cut into them are used with some accent and projection luminaires. Such filters interrupt the luminaire beam and thus project the patterns. These filters are called gobos.

8.1.3 Mechanical Components

The mechanical components of a luminaire consist of a housing or general structure to support other components of the luminaire and a mounting mechanism for the attachment of the luminaire to its support. In some luminaires the reflector is a separate component that is attached to the housing, as in a compact fluorescent lamp downlight. In some luminaires, the housing serves as the reflector, as in a fluorescent lamp troffer.

If the luminaire uses a refractor or transparent cover, then hinged frames or doors that hold the lens are provided. Access for cleaning and relamping is through this door.

In damp or wet applications it is necessary to provide adequate seals to prevent migration of water into the luminaire. In some hazardous locations the housing and seals must keep explosive or flammable vapors from contact with high lamp surface temperatures or electric

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spark. These luminaires are said to be explosion proof and have to have a specific listing (Class and Division) to ensure they are safe in specific types of hazardous environments.

In some applications, the luminaire is used as part of the building's heating, ventilating, and air conditioning system. Air is supplied to or removed from the room using the luminaire. In this case, airways are provided within the luminaire as well as attachments for air ducts and slots through which air enters or leaves the room.

8.1.4 Electrical Components

The electrical components of the luminaire provide for the operation of the lamp. One or more sockets provide mechanical support for the lamp and provide necessary electrical connections. For some lamps, usually single ended, mechanical support in addition to the socket is required.

If required by the lamp, the luminaire contains and supports ballasts, starters, igniters, capacitors, or drivers. See 7 | LIGHT SOURCES: TECHNICAL CHARACTERISTICS for a description of these components. The size and power handled by these components often determine the size of the luminaire and the requirement for proper thermal performance. In a few applications, these components are too heavy, too loud, or too large to be in the luminaire. In these cases, the ballast and other auxiliary equipment is mounted remotely from the luminaire and lamp. Luminaires may also have dimming control or data modules in addition to ballasts.

The luminaire also contains wiring and connectors to connect lamp socket, or ballast if present, to the external wiring that brings electrical power to the luminaire. These wire and electrical components must meet the thermal requirements of the area in which they are used. There may also be control or signal wiring for a ballast or a dimming control module. See 16 | LIGHTING CONTROLS.

8.1.5 Thermal and Air-handling Components

Some luminaires require heat sinks and heat dissipaters to conductively remove heat generated by the lamp. In other cases fins or openings are required to provide for the convective heat removal. LEDs require heat sinks to limit junction temperature thus maintain expected luminous efficacies. See 7 | LIGHT SOURCES: TECHNICAL CHARACTERISTICS. These heat sinks can be part of the structure that contains the LEDs themselves, or be part of the luminaire to which the LED structure is attached.

When building codes permit, some luminaires designed to be used as part of the air handling system in a building can be used to deliver or remove air. These luminaires may have an internal air plenum, an opening that is connected to the building's air handing system, and vents for air intake or distribution.

8.2 Classifying Luminaires

Luminaire classification helps specifiers and manufacturers describe, organize, catalog, and retrieve luminaire information. The nature of luminaire classification has changed with the advance of computer and information technology. Modern lighting design and specification practice relies on computer based luminaire databases, accessed on the Internet. This technology allows luminaire data to be updated frequently and easily. In such systems, a luminaire can be known by all of its characteristics, with any one being the path by which a search finds the luminaire in a database.

Luminaires can be classified according to application or photometric characteristics. Application refers to broad categories of use or project type, where the lighting tasks, environments, and activities are broadly similar. Within an application, luminaires can

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be classified according to source, mounting, or construction. Photometric characteristics usually refer to the distribution of light produced by the luminaire. This can be categorization based on the general shape of the distribution, on ratios of the amount of light sent is various directions, or whether the luminaire emits any light in certain directions at all.

Luminaires can also be classified by the quality of components: gauge of metal, lens thickness, type and quality of finishes, and assembly and construction methods. The degree of quality is usually stated as ranging from "commodity" to "specification" grade.

8.2.1 Classification by Application

One form of classification organizes luminaires by application. Many luminaire characteristics are determined by application, so this distinction proves useful in organizing luminaire information. Luminaires are usually classified according to these application areas:

- Residential
- Commercial
- Industrial
- Roadway
- Sports
- Floodlighting
- Emergency
- Landscape
- Special applications and custom

Within each application, luminaires can be classified by source, mounting, and construction. Examples of these classifications are:

- Residential ceiling mounted room luminaire with a filament lamp
- Commercial recessed troffer luminaire with fluorescent lamps
- Industrial high bay suspended luminaire with a metal halide lamp
- Sports narrow spot luminaire with a metal halide lamp

8.2.2 Classification by Photometric Characteristics

Another form of classification uses the luminous intensity or flux distribution of the luminaire. For luminaires used indoors, a method specified by the International Commission on Illumination (CIE) is frequently used. For luminaires used outdoors, the NEMA and IES methods are used.

8.2.2.1 CIE System

The International Commission on Illumination classifies luminaires based on the proportion of upward and downward directed light output. This system is usually applied to indoor luminaires. Figure 8.1 shows typical intensity distributions for these classes.

- Direct Lighting. When luminaires direct 90-100% of their output downward, they form a direct lighting system. The distribution may vary from widespread to highly concentrated, depending on the reflector material, finish and contour and on the shielding or optical control media employed.
- Semidirect Lighting. The distribution from semidirect luminaires is predominantly downward (60-90%) but with a small upward component to illuminate the ceiling and upper walls.
- Direct-Indirect Lighting. The distribution from direct-indirect luminaires has equal downward and upward components of flux, with very little flux at angles near horizontal. The upward distribution is often a mild bat-wing. This is a special category within General Diffuse
- General Diffuse Lighting. When the downward and upward components of flux from luminaires are about equal (each 40-60% of total luminaire output), the system is classified as general diffuse.

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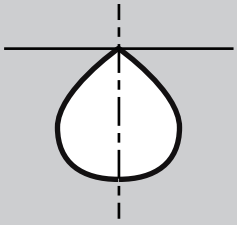
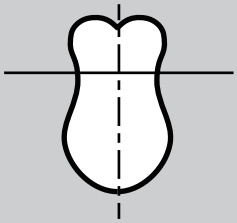
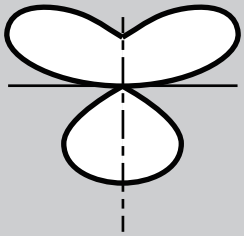
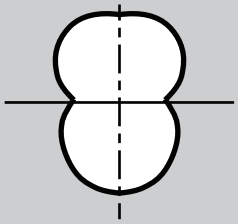
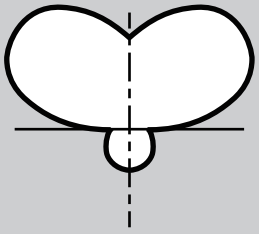
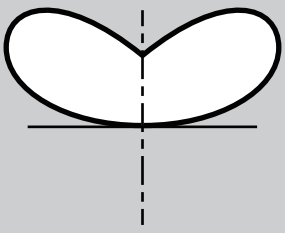
CIE Classification	Approximate Distribution of Light Emitted by Luminaire Upward Percent — Downward Percent
Direct	 0-10 — 100-90
Semi-direct	 10-40 — 90-60
Direct-indirect	 50 — 50
General Diffuse	 40-60 — 60-40
Semi-indirect	 60-90 — 40-10
Indirect	 90-100 — 10-0

Figure 8.1 | CIE Luminaire Classification System
Polar intensity distributions typifying six classes of luminaire distributions in the CIE System. The system is based on both the fraction of upward and downwar directed lumens, and the shape of the intensity distribution.

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- Semi-Indirect Lighting. Luminaires that emit 60-90% of their output upward are classified as semi-indirect.
- Indirect Lighting. Luminaires classified as indirect are those that direct 90-100% of the light upward to the ceiling and upper side walls.

8.2.2.2 Indoor Classification by Cutoff

There are several characteristics of indoor luminaire intensity distributions that are important for classification. This information can appear in the photometric report for a luminaire. See 8.4.2. Components of Luminaire Photometric Reports.

- Physical cutoff. The angle measured from nadir at which the lamp is fully occluded.
- Optical cutoff. The angle measured from nadir at which the reflection of the lamp in the reflector is fully occluded.
- Shielding angle. The angle measured from the horizontal at which the lamp is just visible. This is the complement of the physical cutoff angle.

8.2.2.3 NEMA Classification

The National Electrical Manufacturers Association (NEMA) has established a system of luminaire classification based on the distribution of flux within the beam produced by the luminaire. It is used primarily for sports lighting and floodlighting luminaires. Seven distributions are defined, types 1 through 7, from narrowest to widest beams. This and other classifications use beam angle and field angle to specify characteristics of the luminaire's distribution. Beam angle is defined as the greatest angle, measured from the center of the distribution, at which the intensity drops to 0.50 of the maximum. Field angle is defined as the greatest angle, measured from the center of the distribution, at which the intensity drops to 0.10 of the maximum. Figure 8.2 gives an example.

Figure 8.3 shows the projections of the NEMA beam types, their field angle ranges, and approximate projection distances.

8.2.2.4 IES Distribution Classification of Outdoor Luminaires

This system is based on the shape of the area that is primarily illuminated by the luminaire. It is used for roadway and area lighting luminaires where a complete analysis is required of how light is distributed. Though these luminaires can differ in the manner in which they are mounted, the type of intensity distribution they exhibit, and by the degree

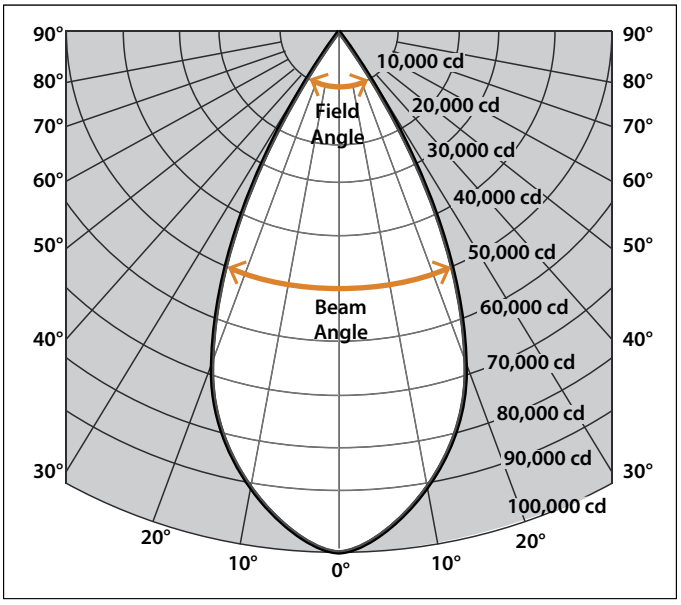
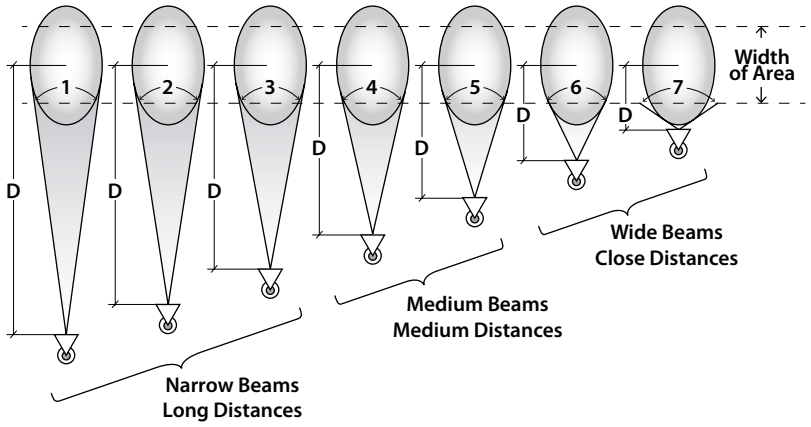


Figure 8.2 | Field and Beam Angles
Field and beam angles indicated on a polar plot of an intensity distribution. Field angle is at 0.10 of maximum intensity and beam angle is at 0.50 of maximum intensity.

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Beam Type	Field Angle Range (degrees)	Projection Distance (D)
1	10 to 18	240 ft and greater
2	> 18 to 29	200 to 240 ft
3	> 29 to 46	175 to 200 ft
4	> 46 to 70	145 to 175 ft
5	> 70 to 100	105 to 145 ft
6	> 100 to 130	80 to 105 ft
7	> 130 and Up	Under 80 ft

Figure 8.3 | NEMA Sports Luminaire Classification System
Diagram of the projections of luminaire beams in the NEMA field angle specification system.

to which they provide cutoff, these luminaires are often specified by the way in which they illuminate an area.

Following are the IES outdoor luminaire classifications by intensity distribution:

- Type I: Narrow, symmetric distribution, highest intensity usually at nadir
- Type II: Wider distribution than Type I, highest intensity between 10° and 20° from nadir
- Type III: Wide distribution, highest intensity between 25° and 35° from nadir
- Type IV: Widest distribution. Highest intensity at greater than 35° from nadir
- Type V: Symmetrical; produces circular illuminance pattern
- Type VS: Produces an almost symmetrically square illuminance pattern

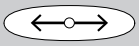
8.2.2.5 IES Luminaire Classification System for Outdoor Luminaires
The IES luminaire classification system (LCS) is based on the lumen distribution within the solid angles of a luminaire's distribution that are of specific interest in outdoor applications. [3]. These classifications are meant to be used in conjunction with the IES distribution classification defined above. The LCS supersedes the previous IES cutoff classifications of full-cutoff, cutoff, semi-cutoff, and non-cutoff [4].

This system is based on the fraction of either luminaire lumens or lamp lumens that are distributed into three primary solid angles. These solid angles are pieces of the entire 4π of solid angle around the luminaire. Each of these three primary solid angles are divided into secondary solid angles, as shown in Figures 8.5 to 8.8. The fractions of luminaire or lamp lumens that these secondary solid angles contain are also calculated.

Luminaires can be categorized, evaluated, and compared based on the fractions of luminaire or lamp lumens that are contained in the various solid angles.

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Figure 8.4 | IES Outdoor Luminaire Intensity Distribution Classification System
IES outdoor luminaire classifications and the approximate illuminance patterns they represent.

Type	Description	Plan View
Type I	Narrow, symmetric illuminance pattern	
Type II	Slightly wider, more asymmetric illuminance pattern than Type I	
Type III	Wide, asymmetric illuminance pattern	
Type IV	Asymmetric, forward throw illuminance pattern	
Type V	Symmetrical circular illuminance pattern	
Type VS	Symmetrical, nearly square illuminance pattern	

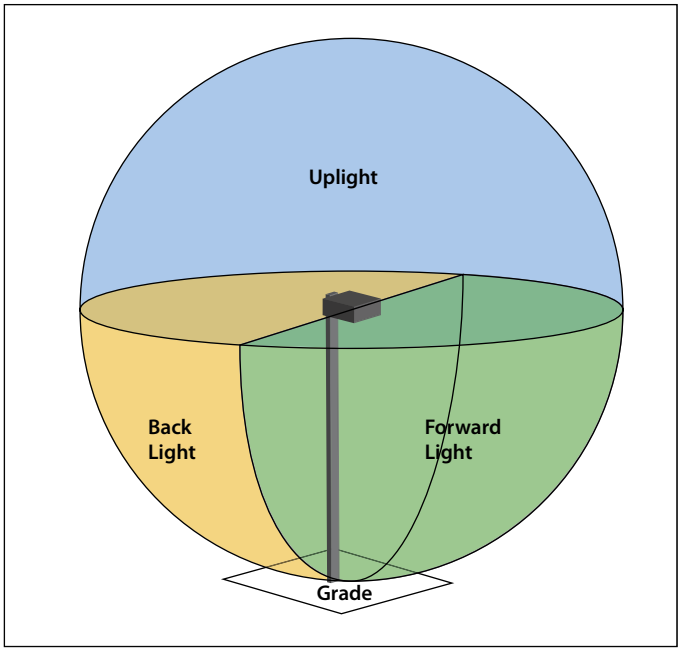


Figure 8.5 | Luminaire Classification System Solid Angles
Luminaire classification system principal solid angles for determining uplight, forward light, and back light from a luminaire.

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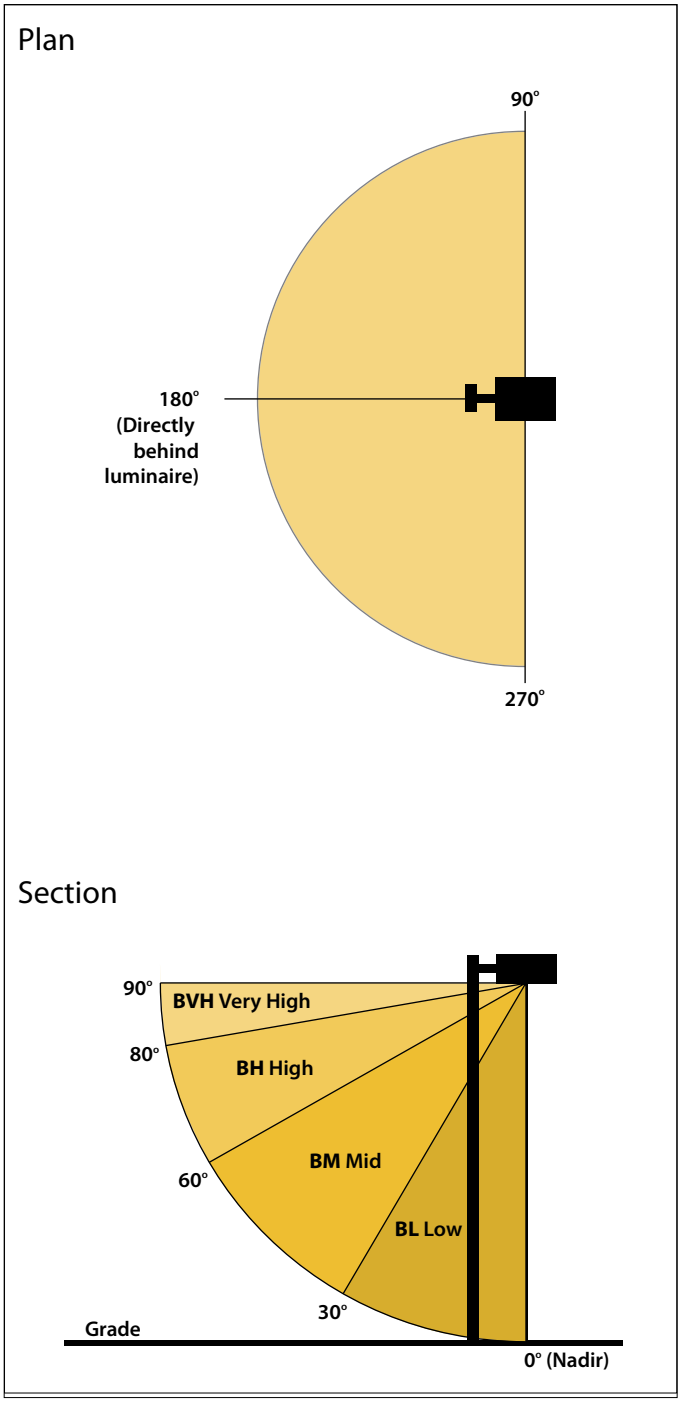


Figure 8.6 | Backward Solid Angle Extents
The subsections of the back light solid angle in the Luminaire classification system, ranging from BL low to BL very high. Note that the angular sizes of the subsections are not uniform.

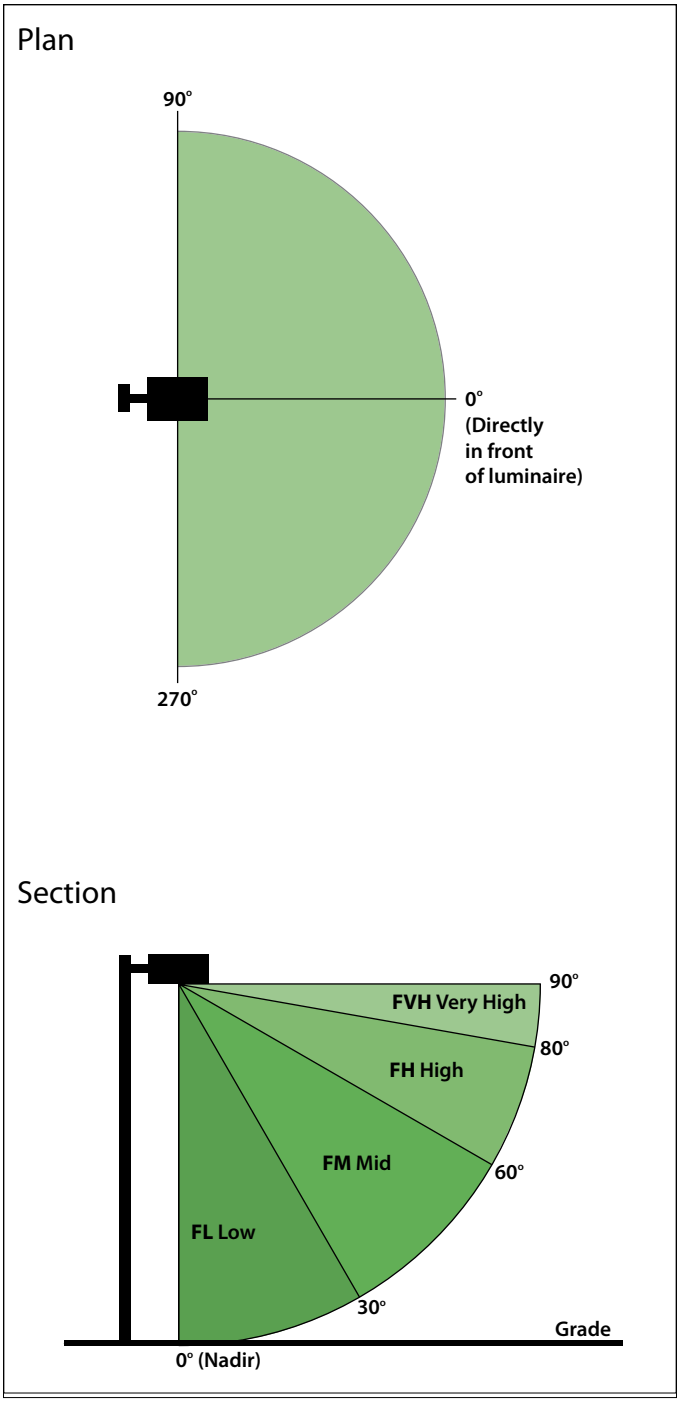


Figure 8.7 | Forward Solid Angle Extents
The subsections of the forward light solid angle in the Luminaire classification system, ranging from FL low to FL very high. Note that the angular sizes of the subsections are not uniform.

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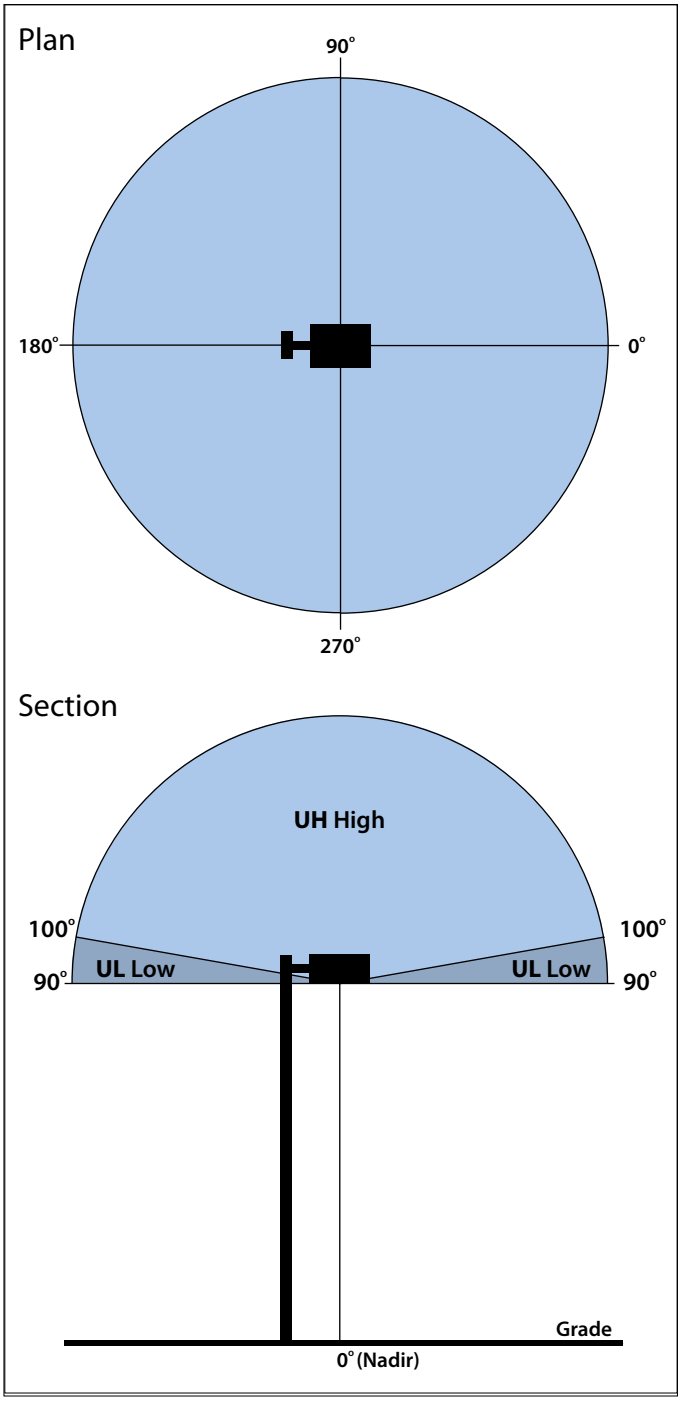


Figure 8.8 | Upward Solid Angle Extents
The two subsections of the uplight solid angle in the Luminaire classification system, ranging from UL low to HL high

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Table 8.1 | Backlight Ratings For each rating (B0-B5), the maximum lumens are shown for each secondary solid angle involved

Secondary Solid Angle	B0	B1	B2	B3	B4	B5
BH	110	500	1000	2500	5000	>5000
BM	220	1000	2500	5000	8500	>8500
BL	110	500	1000	2500	5000	>5000

Table 8.2 | Uplight Ratings For each rating (U0-U5), the maximum lumens are shown for each secondary solid angle involved

Secondary Solid Angle	U0	U1	U2	U3	U4	U5
UH	0	10	100	500	1000	>1000
UM	0	10	100	500	1000	>1000
FVH	10	75	150	>150		
BVH	10	75	150	>150		

Table 8.3 | Glare Ratings, Types I, II, III, and IV For each rating (G0-G5), the maximum lumens are shown for each secondary solid angle involved

Secondary Solid Angle	G0	G1	G2	G3	G4	G5
FVH	10	250	375	500	750	>750
BVH	10	250	375	500	750	>750
FH	660	1800	5000	7500	12000	>12000
BH	100	500	1000	2500	5000	>5000

Table 8.4 | Glare Ratings, Types V and Vs For each rating (G0-G5), the maximum lumens are shown for each secondary solid angle involved

Secondary Solid Angle	G0	G1	G2	G3	G4	G5
FVH	10	250	75	500	750	>750
BVH	10	250	375	500	750	>750
FH	660	1800	5000	7500	12000	>12000
BH	660	2800	5000	7500	12000	>12000

8.2.2.6 Outdoor Environmental Classification

The light trespass, sky glow, and high angle brightness potential of a luminaire is assessed and classified using the LCS described above. In these assessments the luminaire lumens in the backlight, uplight, and glare (BUG) solid angles and secondary solid angles are used to classify a luminaire's outdoor environmental characteristics. Lumen limits in each secondary solid angle establish a BUG rating for the luminaire. The B, U, and G ratings range from 0, the most limiting, to 5, the most lenient. Tables 8.1- 8.4 show the secondary solid angles, and the corresponding lumen limits for each of the various components of a BUG rating.

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8.3 Luminaire Types

This section gives a general description of different types of luminaires, including performance characteristics, typical applications, and images. Table 8.5 illustrates a variety of luminaires with some notable components and features identified.

8.3.1 Commercial and Residential Luminaires

8.3.1.1 Portable Luminaires

These are completely self-contained luminaires designed to be moved and placed near the task or surface to be lighted. They have a plug and outlet connection to electric power and usually contain integral switching and/or dimming. They usually contain low wattage filament, tungsten halogen, or compact fluorescent lamps.

Examples of portable luminaires are:

- Floor and table luminaires using filament lamps
- Desk luminaires using filament or compact fluorescent lamps, or LEDs
- Partition mounted luminaires using compact fluorescent lamps

8.3.1.2 Furniture Mounted

Permanently attached to furniture or other equipment surface, these luminaires are designed to be in close proximity of the task and produce localized lighting.

Examples of furniture mounted luminaires are:

- Under-cabinet office cubicle luminaire using fluorescent lamps
- Partition mounted luminaires using compact fluorescent lamps or LEDs

8.3.1.3 Recessed or Surface Mounted Downlights

These are general-purpose luminaires designed to provide general or ambient lighting in a space on a floor or workplane. Certain types have concentrated luminous intensity distributions designed for the luminous accenting. When recessed into the ceiling they have luminous apertures of various shapes. It is often necessary to augment these luminaires with other types that will raise wall luminances and add vertical illuminance to the space. Downlights use filament or compact fluorescent lamps, or LEDs and are often grouped by size and shape of aperture. Optical control is often provided by the lamp or by reflectors. Downlights using metal halide lamps may require open-rated lamps that are protected with arc tube enclosures to prevent lamp components from falling from the luminaire [5].

Examples of downlight luminaires are:

- Compact fluorescent lamp recessed downlight. These units usually have modest apertures and can exhibit very low luminances at high viewing angles.
- Filament lamp surface mounted downlight with opaque sides.
- LED downlight using a diffuse integrating chamber.

8.3.1.4 Recessed or Surface Mounted Troffers

These are general-purpose luminaires designed to provide general or ambient lighting in a space on a floor or workplane but may have distributions for lighting vertical surfaces as well. When recessed into the ceiling they have luminous apertures that are almost always rectangular. These luminaires are often fitted with a prismatic lenticular lens or set of louvers to provide optical control. Surface mounted versions may have open sides or lenses that wrap around the sides and provide a significant amount of light onto the ceiling. Optical control is provided by lenticular prismatic lenses or specularly reflecting louvers of aluminized plastic or metal.

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Examples of recessed or surface mounted troffer luminaires are:

- Recessed fluorescent lamp troffer. These units use large fluorescent lamps and are usually recessed into a suspended acoustical tile ceiling system.
- Recessed LED troffer. These units use lines of LEDs and are recessed into a suspended acoustical tile ceiling system.
- Surface mounted warp-around fluorescent lamp troffer.

8.3.1.5 Wallwasher

These are used to produce a distribution of illuminance/luminance on a wall that, though not necessarily uniform, usually changes gradually from high values at the top of the wall to lower values down the wall. Many wallwasher luminaires are designed to achieve an illuminance ratio from the top to the bottom of the wall of 10:1 or less. Wallwasher luminaires can be recessed or surface mounted. Wallwasher luminaires that use relatively small lamps such as filament or compact fluorescent lamps, or LEDs have relatively small apertures and are spaced at appropriate distances along the illuminated wall. Optical control in these luminaires is provided by reflectors and refractors. Wallwasher luminaires that use linear fluorescent lamps have relatively long apertures and are usually mounted continuously along the illuminated wall.

Examples of wallwasher luminaires are:

- Linear fluorescent wallwasher. These luminaires usually have a reflector that allows them to be placed close to the wall, when required. Recessed or surface mounted types are available.
- Compact fluorescent lamp, filament lamp, or LED wallwasher. These are small units that, if recessed, have a modest aperture and therefore can appear like other downlights in the space. They can also be surface mounted.

8.3.1.6 Accent

These luminaires are either designed to produce patterns of light that reinforce the design intent with respect to aesthetics and psychological setting or are themselves ornamental.

Accenting Artwork, Details, and Features

Accent luminaires for this type can be ceiling recessed or surface mounted, wall mounted, or suspended from pendants. These accent luminaires are sometimes equipped with lenses for spreading or concentrating the beam from the lamp, so-called barn doors and snoots for limiting the beam, color and ultraviolet/infrared filters, gobos for producing patterns, and diffusers.

Examples of this type of accent luminaire are:

- Ceiling mounted accent luminaires using filament, compact fluorescent or low wattage metal halide lamps, or LEDs. The lamps are adjustable or fixed.
- Pendent mounted accent luminaires using LEDs with color-changing and dimming control.

Decorative Accents

These accent luminaires not only produce a lighting pattern but are themselves decorative and often have a luminous body. Since they are often mounted low, they are often in the field of view, and therefore the designer should be aware of the potential for glare. Sconces with translucent shields, which vary in size or shape, are often used for lighting hallways, stairways, and surfaces around doorways and mirrors.

Examples of this type of decorative accent luminaire are:

- Sconces and other wall mounted accent luminaires using filament or compact fluorescent lamps, or LEDs.
- Decorative ceiling-recessed downlights with luminous trim.

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8.3.1.7 Wall-mounted Downlights and Uplights

Wall-mounted luminaires with opaque shielding completely conceal the source from normal viewing angles, and are strongly directional in light distribution. Downlight luminaires are sometimes mounted on the wall and used for accent and display lighting, whereas uplight luminaires can be used for general, indirect lighting.

The extent to which wall-mounted luminaires protrude from the wall is often subject to code restrictions such as the Americans with Disabilities Act [6].

Examples of wall-mounted luminaires are:

- Wall sconce with a compact fluorescent lamp or LEDs
- Tungsten halogen luminaire for illuminating wall-mounted art

8.3.1.8 Track

This refers to a system that includes small luminaires and a track or rail that is designed to both provide mounting and deliver electric power. Track is generally made of linear extruded aluminum, containing copper wires to form a continuous electrical raceway. Some varieties can be joined or cut, and others set into a variety of patterns with connectors. Track is available in line-voltage or low-voltage, with remote transformers available for the low-voltage equipment. Line voltage track systems are equipped with luminaires that use line voltage lamps or are equipped with integral transformers at each luminaire. Low voltage track uses remote power to provide low-voltage power along the entire length of track.

Track can be mounted at or near the ceiling surface, recessed into the ceiling with special housing or clips, or mounted on stems in high-ceiling areas. It can also be used horizontally or vertically on walls. It can be hard wired at one end or anywhere along its length. Flexibility can be added if a cord-and-plug assembly rather than hard wiring is used to supply power.

A variety of adjustable track-mounted luminaires are available for attachment at any point along the track. These luminaires come in many shapes and styles, housing a large assortment of lamps and LEDs, including line and low-voltage. In addition, a number of luminaires are designed to create special effects for decorative applications. Track luminaires are available that use filament, compact fluorescent, or metal halide lamps, LEDs, or high CRI variety of high-pressure sodium lamps.

8.3.1.9 Point Indirect

These luminaires are designed to provide general or ambient lighting by illuminating the ceiling with compact fluorescent or metal halide lamps, or LEDs. When necessary, optical control is provided by reflectors that help produce a wide distribution so that luminaires can be mounted close to the ceiling. Pendants or cable usually suspend these luminaires, but some types are post-mounted from the floor. Point indirect luminaires can also be mounted on the walls forming a perimeter lighting system.

8.3.1.10 Linear Indirect

These luminaires are designed to use linear or biaxial fluorescent lamps or LEDs to provide general or ambient lighting by illuminating the ceiling. When necessary, optical control by reflectors produce wide distributions and permit short suspension distances and wide spacings. These luminaires can be suspended from the ceiling by pendants or cable, or in the case of modest spans, mounted by their ends. Linear indirect luminaires can also be mounted on the walls forming a perimeter lighting system. Suspended linear indirect usually have a luminous intensity distribution that is symmetric about the lamps' axis, wall mounted linear indirect typically have a bilaterally symmetric distribution.

8.3.1.11 Linear Direct-Indirect

These are similar to the suspended indirect, but provide some downward directed light, thus changing the modeling of objects; that is, the shade, shadow and highlights with the space.

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8.3.1.12 Cove

These luminaires are design to be placed in an architectural cove or to have a shape such that when mounted on the wall their housing provides a cove and its lighting effect. The simplest form of this luminaire is a fluorescent striplight, providing ballast and lamp sockets. More elaborate forms provide reflectors to control near-wall and ceiling luminance.

8.3.2 Industrial Luminaires

8.3.2.1 Linear Fluorescent

These luminaires are often designed for high output fluorescent lamps, with the reflector often being part of the housing. A refractor or lens is uncommon. These luminaires are designed to minimize accumulation of dirt by providing for convection, or in areas with large amounts of airborne particles, dust-tight covers are used. Diffusers with gasketing are often used in wet locations.

8.3.2.2 Striplights

These luminaires have one or more fluorescent lamps mounted to a small housing large enough to hold ballasts and sockets. Reflectors are uncommon since these luminaires are used in areas where a large amount of general diffuse lighting is required and efficiency and budget are a concern. See | 30 LIGHTING FOR MANUFACTURING for a discussion of the potential poor quality lighting provided by these luminaires.

8.3.2.3 High Bay

These luminaires use HID lamps to produce general lighting in an industrial area. They are for applications with spacing-to-mounting height ratios of up to 1.0. They are surface or pendant mounted, depending on the structure and openness of the area. These luminaires use reflectors and refractors to produce luminous intensity distributions that vary from narrow to wide, depending on the application and the need for vertical illuminance.

In cleaner industrial environments, high-output linear and compact fluorescent lamps are used in open high bay luminaires with specular reflectors for optical control. Other environments often require an enclosed luminaire and the use of HID lamps with prismatic refractors for optical control.

8.3.2.4 Low Bay

These luminaires use HID lamps to produce general lighting in an industrial area. They are for applications with spacing-to-mounting height ratios greater than 1.0. As with high bay luminaires, they are surface or pendant mounted. These luminaires usually have wide luminous intensity distributions to provide greater horizontal and vertical illuminances in areas with restricted ceiling heights. HID and compact fluorescent lamps are often used in low bay luminaires.

8.3.3 Outdoor Luminaires

8.3.3.1 Street, Path, and Parking Lighting

Street and Roadway

These luminaires are designed to produce reasonably uniform illuminance on streets and roadways. They are usually mounted on arms on a pole. All types of HID lamps are used in street and roadway luminaires, as well as LEDs. Low-pressure sodium lamps are uncommon. Reflectors and refractors are used to produce the various types of luminous intensity distributions required in these applications when discharge lamps are used. LED luminaires of this type do not necessarily require additional optical control beyond the narrow directionality of the light emitted from the LED. Wide distributions permit large pole spacing, but may be more prone to discomfort and disability glare because of the high angle luminous intensity. Minimum horizontal illuminance and uniformity of horizontal illuminance are typical design criteria. For this reason, the luminous intensity distributions can have maximum values at angles above 75° from the nadir.

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Luminaires with dropped-dish, or ovate, refractors are frequently used in roadway applications with discharge lamps. Because of their appearance these luminaires are referred to as "cobra head" luminaires. Poles for roadway applications are usually mounted well back from the roadside to avoid damage to both the luminaire and oncoming traffic.

Pathway
Walkway and grounds lighting is often accomplished with bollards. These luminaires are mounted in the ground and have the form of a short thick post similar to that found on a ship or wharf; hence the name. The optical components are usually at the top, producing an illuminated area in the immediate vicinity. Bollards are used for localized lighting. Their size is appropriate for the architectural scale of walkways and other pedestrian areas.

Small sharp cutoff luminaires are also used on small poles to provide pathway lighting. Additionally, luminaires for lighting outdoor stairs and ramps are used. These can be mounted on poles or recessed into the structure near the stairs or ramp.

Parking Lot and Garage
Parking lot lighting often uses cutoff luminaires with flat-bottomed lenses. These luminaires are mounted on short arms and can be arranged in single, twin or quad configurations. Symmetric and asymmetric intensity distributions and mounting configurations are used to provide the necessary flexibility in pole placement for parking lots.

Wall-mounted luminaires are often used for small parking lots immediately adjacent to a building or in parking structures. Often referred to as "wall packs," wall-mounted luminaires have a bilaterally symmetric distribution necessary for lighting adjacent parking lots. There is significant potential for glare and light pollution with these luminaires. Additional optical control is usually available for wall-mounted luminaires to limit direct glare and light trespass.

Surface-mounted luminaires in parking structures are mounted on walls or ceilings and are designed to produce a considerable amount of interreflected light in the structure.

8.3.3.2 Sports Lighting
Some sport lighting luminaires have very narrow luminous intensity distributions and are typically mounted to the side and well above the playing area. Others have medium distributions and sharp cutoff and are mounted either over or to the side of the playing area in indoor applications. Metal halide lamps are common for sports lighting luminaires. Reflectors are used to produce the required luminous intensity distribution. Use of the narrow-intensity-distribution luminaires almost always requires careful design to ensure proper overlapping of beams as well as proper horizontal and vertical illuminances. Since aiming is a critical part of their application, these luminaires are usually provided with special aiming and locking gear. Indoor sports lighting luminaires using metal halide lamps may require lamps with arc tube enclosures to prevent lamp components falling from the luminaire [5]. Additionally, glare control louvers and visors are often required.

Sports lighting luminaires are usually classified using the NEMA field angle designation. Seven categories from very narrow to very wide are used to describe the luminous intensity distribution of these luminaires. See 8.2.2.3 NEMA Classification.

8.3.3.3 Floodlighting
These luminaires are often used for building lighting and other special applications. These applications can require luminous intensity distributions that range from very narrow to very wide, depending upon the angular size of the object being illuminated and the effect to be achieved. The luminous intensity distributions are usually not symmetric. Most types of HID lamps and LEDs are used in floodlight luminaires.

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Exterior building lighting uses luminaires with narrow and wide distributions, depending upon the portion of the building being illuminated and its distance from the luminaire mounting location. Column lighting, accent lighting and distant mounting locations require narrow distributions. Lighting large areas with near mounting locations requires very wide distributions. Floodlight luminaires often have luminous intensity distributions that produce an illuminance pattern that approaches square or rectangular.

8.3.4 Emergency and Exit Luminaires

Emergency lighting luminaires are designed to provide enough light for egress in emergent situations or when normal power fails. They typically operate from power provided by batteries or are powered by emergency lighting wiring and generators. Under normal conditions the batteries are continuously charged from line voltage. Exit sign luminaries are normally on and contain circuitry that operates them on battery power on whenever line voltage is not present.

Exit luminaires help building occupants identify directions to an exit. They can be considered a type of illuminated signage that is useful under normal conditions, but is designed to provide critical help in emergent situations. Like emergency lighting luminaires, exit luminaires often operate on batteries. Compact fluorescent lamps and light emitting diodes are common exit luminaires.

8.3.5 Security

Security luminaires are typically outdoor luminaires designed to help visually secure an area. This can mean providing sufficient illuminance for visual surveillance or security camera surveillance. These luminaires are typically mounted in inaccessible places, and have particularly strong housing and lenses to help make them vandal proof.

8.3.6 Landscape

Landscape luminaires are designed for use outdoors to light buildings, planting, water features, and walkways [7]. The can be mounted in the ground, on poles, on trees, or underwater. Typically they have special housing, gasketing, lenses, and electrical wiring hardware that protects against the effects of water and corrosion.

8.3.7 Special Applications

Some applications are unique, with uncommon photometric requirements or unusual environmental conditions that require very special luminaires. This kind of lighting equipment is usually provided by specialty manufacturers and is often customized.

Examples of special application luminaires are:

- Ceiling mounted surgery luminaires in a hospital operating room to produce a spectrally limited illuminance of 10,000 lux on the patient operating site [8].
- Light-pipe luminaires using remote metal halide lamps in an industrial environment with explosive gases or as a supplement for a daylight delivery system [9].

8.3.8 Custom Luminaires

In some cases, a project requires luminaires that are not available as commodity stock and must be specially manufactured. Custom luminaires may be required for reasons of aesthetics, size, special lamping requirements, unusual application mounting, or matching historical lighting equipment in projects of renovation or restoration [10].

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Table 8.5 | Examples of Various Luminaires

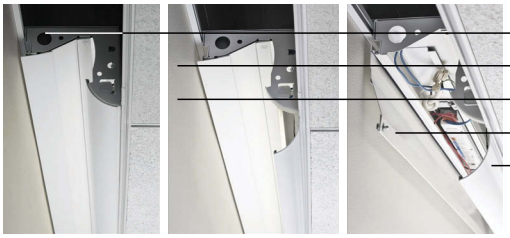
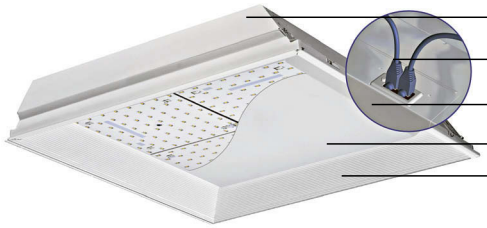
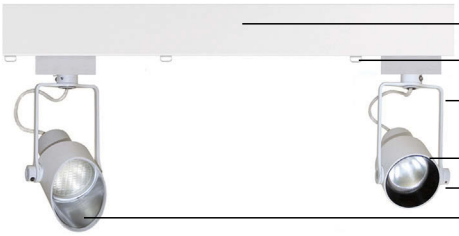
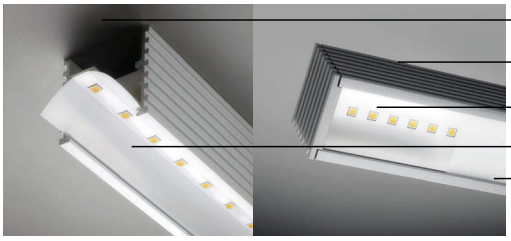
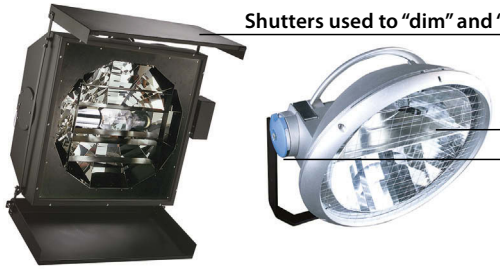
Luminaire Variety	Example	Some Notable Components and Features
Recessed Downlight: Metal Halide Open Direct	 » Image ©Acuity Brands	Heat sink Thermal protector Ballast box Luminaire trim frame
Recessed Downlight: LED Lensed Direct	 » Image ©Edison Price Lighting, Inc.	Heat sink Ceiling throat (to accommodate certain ceiling types and thicknesses) Semi-specular clear anodized aluminum reflector and matching trim flange
Recessed Downlight: CFL Open Direct	 » Image ©Acuity Brands	Adjustable mounting rails Junction box with knockouts
Recessed Linear: Linear Fluorescent Louvered Direct	  » Image ©US Energy Sciences	Formed steel housing Lamp and reflector chamber with accessible ballast compartment Matte anodized aluminum parabolic louvering and servicing Latches to access hinged louver for cleaning and servicing
Recessed Linear: Wallslot, Linear Fluorescent Open Direct	 » Image ©Litecontrol	Wiring compartment with knockouts to connect multiple luminaires Reflector and wiring compartment mount to mounting rail at wall Wall finish continues up into slot for "infinity" look Thumbscrews open hinged reflector for access to wiring and ballast Lamp shield hinges down for relamping
Recessed Luminaire: 2x2 LED Lensed Direct	 » Image ©Litecontrol	Formed steel housing Control connector for convenient control and commissioning LEDs arrayed as necessary for light output and optical distribution Bottom lens (cut-away visible) for distribution and glare control Ridged deep regress

Table 8.5 | Examples of Principal Luminaire Types and Their Components continued next page

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Table 8.5 | Examples of Various Luminaires continued from previous page

Luminaire Variety	Example	Some Notable Components and Features
Track Luminaires: Halogen IR MR16 Adjustable and Wallwasher		Two-circuit extruded aluminum busway Low voltage transformer integral to busway fitting (not visible) Rotating yoke lockable after aiming Integral snoot to limit spill light and glare Tilt mechanism lockable after aiming Wallwash snoot version » Image ©Edison Price
Pendant Luminaire: LED Linear Lensed Direct		Aircraft cables or stems (not shown) mount to ceiling Ridged extruded aluminum housing acts as heat sink LEDs arrayed as necessary for light output and optical distribution Reflector insert optimizes efficiency and eases future replacement Bottom lens (cut-away visible) for distribution and glare control » Image ©Litecontrol
Pendant Luminaire: Metal Halide Prismatic Refractor Direct (high bay and low bay)		Stems (not shown) mount to ceiling Die cast ballast aluminum heat sink enclosure Borosilicate glass refractor for efficient light distribution Wireguards (not shown) available for rough environments Low bay version (for lower ceiling applications) High bay version (for higher ceiling applications) » Image ©Acuity Brands
Pole Luminaire: LED Area Light Lens-control		Top side of light engine compartment open for ventilation and self-cleaning Die cast aluminum housing (transparency and cut-away shown for clarity) LED dies are fitted with individual precision-molded lenses for light control LED arrays (rows) are field replaceable » Image ©Acuity Brands
Pole Luminaire: LED Area Light Reflector-control		Tamperproof die cast latch for access Die cast aluminum housing LED dies are fitted with precision reflectors and fixed aimed for light control LED optical modules are field replaceable Clear tempered glass or polycarbonate flat bottom lens Top side of light engine compartment fitted with integral cooling ribs » Image ©Kim Lighting
Rack Luminaire: Metal Halide Sports Light		Shutters used to "dim" and "extinguish" luminaire and glare control without extinguishing lamp Segmented reflector with additional vane reflector for beam control Aiming and locking devices for precise adjustment » Image ©Philips Sports North America

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8.4 Luminaire Performance

Luminaire performance can be considered a combination of photometric, electrical, and mechanical performance. Photometric performance of a luminaire describes the efficiency and effectiveness with which it delivers the light produced by the lamp to the intended target. This performance is determined by the photometric properties of the lamp, the design and quality of the light control components, and any auxiliary equipment required by the lamp. Luminaire efficacy is determined by lamp efficacy and, if present, the ballast and its interaction with the lamp or by LEDs and their drivers.

Photometric performance, evaluated outside of a luminaire's application, may not describe the final effectiveness of light production at the task. Luminaire photometric reports should be evaluated in the context of the intended application. For example, a luminaire with high overall luminous efficiency but with a wide distribution may not be as effective at lighting a task as a luminaire that might be less efficient overall but has an intensity distribution better suited for the application: more narrow or with a skewed beam, for example . In this case, a lamp of lower power and fewer total lumens in the latter luminaire may achieve lower total lighting power density.

The electrical performance of a luminaire describes the efficacy with which the luminaire generates light and the electrical behavior of any auxiliary equipment such as ballasts. Electrical behavior, such as power factor, waveform distortion, and various forms of electromagnetic interference are properties of the lamp and ballast.

The mechanical performance of a luminaire describes its behavior under stress. This can include extremes of temperature, water spray or moisture, mechanical shock, and fire.

8.4.1 Photometric Performance

Luminaire photometric performance is summarized in a photometric report. Luminous intensity values are determined from laboratory measurements and are reported as the luminaire's luminous intensity distribution. Electrical and thermal measurements are made and often reported. These include input watts, and compliance with the input volts and ambient air temperature required of standard procedures. In addition, some calculated application quantities are usually reported. These include zonal lumens, efficiency, and coefficients of utilization. See 9 | MEASUREMENT OF LIGHT: PHOTOMETRY for a description of measurement procedures and 10 Calculation of Light for a description of the calculation procedures that produce the application data.

8.4.2 Components of Luminaire Photometric Reports

Luminaire photometric reports may consist of any of the following, depending on the type and application of the luminaire:

- Luminous intensity distribution
- Average luminance in various viewing directions
- Zonal lumens
- Efficiency
- Coefficients of utilization
- Spacing criterion
- Glare assessment
- Surface illuminance patterns

The content and format of most photometric reports follows applicable standards [11] though individual laboratories and manufacturers usually have a particular format for reporting photometric data. Figure 8.9 shows a typical and complete photometric report for an indoor luminaire: a recessed fluorescent troffer. Figure 8.10 shows a typical photometric report for an outdoor luminaire: a building floodlight luminaire.

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In most cases, relative photometry is reported; that is, all photometric quantities are scaled to the rated lumens of the lamp used in the luminaire. For luminaires using LED sources, absolute photometry must be used [12]. See 9 | MEASUREMENT OF LIGHT: PHOTOMETRY.

8.4.2.1 Luminous Intensity Distribution

The luminous intensity distribution of a luminaire specifies its light distribution characteristics. Luminous intensities in various directions are specified in an angular coordinate system appropriate for the luminaire and its customary application. Most luminaires have luminous intensity distributions specified by values in directions given by the elevation and azimuthal angles (θ,ψ) of the spherical coordinate system. For indoor luminaires, the origin of the elevation angle θ is down (nadir) and along the polar axis of the coordinate system, as shown in Figure 8.11. The origin of the azimuthal angle ψ is usually along a lamp axis. This is Type C photometry. The elevation (vertical) angle θ has the range $0° \le \theta \le 180°$. The azimuthal (horizontal) angle ψ has the range $0° \le \psi \le 360°$.

For some outdoor luminaires, usually floodlights, the origin of the two angles (V, H) is the primary aiming axis of the luminaire and passes through the equator of the coordinate system, as shown in Figure 8.12. This is Type B photometry. In this case the range of the two angles is -90° to 90°.

For indoor luminaires, the range of elevation angles, θ, depends on the distribution of the luminaire. The range is usually one of three: $0° \le \theta \le 90°$, $90° \le \theta \le 180°$, or $0° \le \theta \le 180°$; depending upon whether the luminaire emits light only downward, only upward, or both. Increments of 5° or 10° in θ are usually reported, though smaller steps are usually measured and sometimes reported if the luminous intensity distribution changes rapidly with elevation angle. See 9.14 Luminaire Photometry.

Indoor luminaires that exhibit axial symmetric distributions have luminous intensity reported for $\psi = 0°$. A downlight with a lamp base up is often luminaire with an axially symmetric distribution. If the luminaire exhibits quadrilateral symmetry in the azimuthal angle, ψ, it is customary to report luminous intensity values for $0° \le \psi \le 90°$. A fluorescent troffer with a prismatic lens is a luminaire with a quadrilaterally symmetric distribution. If the luminaire exhibits bilateral symmetry in ψ, then data is reported for $0° \le \psi \le 180°$. Some older photometric reports for linear fluorescent wall wash luminaires with report azimuthal angles for $90° \le \psi \le 270°$. A wall-mounted fluorescent indirect is a luminaire with a bilaterally symmetric distribution. In all cases the increments in ψ are usually 22.5°.

For outdoor luminaires the range and increments are variable, the limits of each depending upon the angular size of the beam.

The luminous intensity values reported for a luminaire are almost always from relative photometry. That is, the lamps in the luminaire are assumed to be emitting their rated lumens. Light loss factors can be applied to account for actual field conditions.

The measurements are always far-field; that is, the distance at which measurements are made is large enough to consider the luminaire to be a point source. It is assumed that all of the luminaire lumens are emitted from the luminaire photometric center. This point is usually at the center of the opening of the luminaire, in the center of its lens, or at the geometric center of its lamps.

For many small luminaires, such as filament and fluorescent lamp downlights, far-field measurements do not pose a problem in use. Far-field measurements can also be used when the distance between luminaire and illuminated point is large compared to luminaire dimensions, as in flood lighting. But for large luminaires located near to illuminated surfaces, calculating illuminances with these luminous intensity values must be done with care. Examples of this situation are under-cabinet luminaires or task lights. See 10.3 Photometric Data for Calculations.

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Figure 8.9 | Indoor Luminaire Photometric Report

Complete indoor luminaire photometric report using relative photometry for a recessed troffer using two biaxial fluorescent lamps.

❶ Report header information includes test number, luminaire, lamp, and ballast descriptive information, and testing conditiions. See Reference [11].

❷ Most reports show a simple drawing of the luminaire to show lamp position and photometric center. See Reference [11].

❸ The luminous intensities report here are usually only those required for calculating indoor coefficieints of utilization. These correspond to the centers of the standard solid angle zone used in that calculation. The azimuthal increment is 22.5º and the elevation increment is 10º, beginning at 5º. The intensities at 0º and 90º are included. This is often a subset of the full data set. See 10.10.3 Calculating Lumen Method Coefficients of Utilization.

❹ Zonal lumens are reported for the zones used in calculating indoor coefficients of utilization. See 9.14.16.1 Zonal Lumens.

❺ Luminaire luminous efficiency expressed as the fraction of total zonal lumens to rated lamp lumens.

❻ Spacing Criteria are reported in two planes if the distribution is very azimuthally asymmetric. One value is reported for azimuthally symmetric.

❼ Average luminaire luminance is reported in multiple planes for azimuthally asymmetric distributions, each at several angles measured up from photometric nadir. See 5.7.3 Luminance and 9.16 References, Reference [58].

❽ Coefficients of utilization are reported for a range of room cavity ratios and surface reflectance combinations. Good reports include values a RCR=0 at all reflectances and at surface reflectances of zero at all RCRs. See 10.9.1 Calculating Average Illuminance.

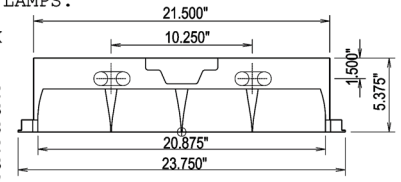
❾ This section is often added to give a complete recording of intensity distribution. Mosting indoor luminaire testing is done with elevation angle spacing no greater than 5º. Some test equipment records data every 2-1/2º

❿ The more detailed reporting of the intensity distribution is accompanied by a more detailed zonal lumen summary.

» Image ©Luminaire Testing Laboratories

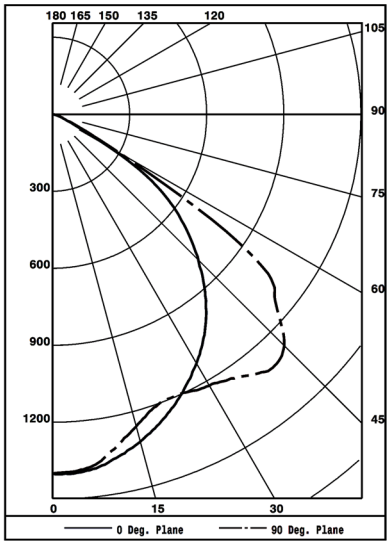
LTL NUMBER: 04983 DATE: 1-1-2000
PREPARED FOR: LUMINAIRE TESTING LABORATORY, INC.
CATALOG NUMBER: SAMPLE INDOOR TEST
LUMINAIRE: FORMED STEEL HOUSING, FORMED WHITE ENAMEL STEEL REFLECTOR, 16 CELL, 3" DEEP, FORMED SEMI-SPECULAR ALUMINUM LOUVER. ❶
BALLAST: ONE MAGNETEK B232I120RH
LAMPS: TWO SYLVANIA FBO31/31K RATED AT 2800 LUMENS EACH
MOUNTING: RECESSED
TOTAL INPUT WATTS = 54.7 AT 120.0 VOLTS
THE 0 DEGREE PLANE IS PARALLEL WITH THE LAMPS.

❷ #04983



❸ CANDELA DISTRIBUTION ❹ FLUX

	0.0	22.5	45.0	67.5	90.0	
0	1401	1401	1401	1401	1401	
5	1399	1396	1393	1391	1390	132
15	1321	1313	1283	1267	1260	363
25	1198	1156	1124	1170	1199	538
35	1034	977	1050	1177	1252	682
45	803	789	979	1167	1277	763
55	508	557	706	823	921	597
65	82	103	123	107	97	125
75	18	20	21	21	21	24
85	0	0	0	0	0	3
90	0	0	0	0	0	



ZONAL LUMEN SUMMARY

ZONE	LUMENS	%LAMP	%FIXT
0- 30	1034	18.5	32.0
0- 40	1716	30.6	53.2
0- 60	3076	54.9	95.3
0- 90	3228	57.6	100.0
90-180	0	0.0	0.0
0-180	3228	57.6	100.0

❺ TOTAL LUMINAIRE EFFICIENCY: 57.6%
TOTAL REFLECTANCE OF PAINT: 92.4%
CIE TYPE: DIRECT

PLANE:	0-DEG	90-DEG
❻ SPACING CRITERIA:	1.2	1.4
SHIELDING ANGLES:	30	35
LUMINOUS LENGTH:	20.875	20.875

❼ LUMINANCE IN CANDELA PER SQUARE METER

ANGLE IN DEG	AVERAGE 0-DEG	AVERAGE 45-DEG	AVERAGE 90-DEG
0	4983.	4983.	4983.
45	4039.	4924.	6423.
55	3150.	4378.	5711.
65	690.	1035.	816.
75	247.	289.	289.
85	0.	0.	0.

❽ COEFFICIENTS OF UTILIZATION - ZONAL CAVITY METHOD
EFFECTIVE FLOOR CAVITY REFLECTANCE 0.20

RC	80				70				50			30			10			0
RW	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
0	69	69	69	69	67	67	67	67	64	64	64	61	61	61	59	59	59	58
1	64	62	60	59	63	61	59	58	59	57	56	56	55	54	54	54	53	52
2	60	56	53	51	59	55	53	50	53	51	49	52	50	48	50	48	47	46
3	56	51	47	44	54	50	47	44	48	45	43	47	44	42	46	43	42	41
4	51	46	42	38	50	45	41	38	44	40	38	42	39	37	41	39	37	36
5	47	41	36	33	46	40	36	33	39	36	33	38	35	32	37	34	32	31
6	44	37	32	29	43	36	32	29	35	31	29	34	31	28	34	30	28	27
7	40	33	28	25	39	33	28	25	32	28	25	31	27	25	30	27	25	23
8	37	29	25	22	36	29	25	22	28	24	21	28	24	21	27	24	21	20
9	34	26	22	19	33	26	22	19	25	21	18	25	21	18	24	21	18	17
10	31	24	19	16	31	24	19	16	23	19	16	22	19	16	22	19	16	15

❾ CANDELA DISTRIBUTION

	0.0	22.5	45.0	67.5	90.0
0	1401	1401	1401	1401	1401
5	1399	1396	1393	1391	1390
10	1365	1363	1360	1343	1332
15	1321	1313	1283	1267	1260
20	1263	1245	1195	1199	1204
25	1198	1156	1124	1170	1199
30	1121	1067	1078	1173	1222
35	1034	977	1050	1177	1252
40	925	881	1019	1191	1307
45	803	789	979	1167	1277
50	668	694	898	1033	1133
55	508	557	706	823	921
60	248	322	391	352	298
65	82	103	123	107	97
70	38	43	44	44	42
75	18	20	21	21	21
80	10	10	10	9	10
85	0	0	0	0	0
90	0	0	0	0	0

❿ ZONAL LUMEN SUMMARY

0- 5	33.
5- 10	99.
10- 15	157.
15- 20	207.
20- 25	249.
25- 30	289.
30- 35	325.
35- 40	357.
40- 45	382.
45- 50	382.
50- 55	351.
55- 60	246.
60- 65	92.
65- 70	33.
70- 75	16.
75- 80	7.
80- 85	3.
85- 90	0.

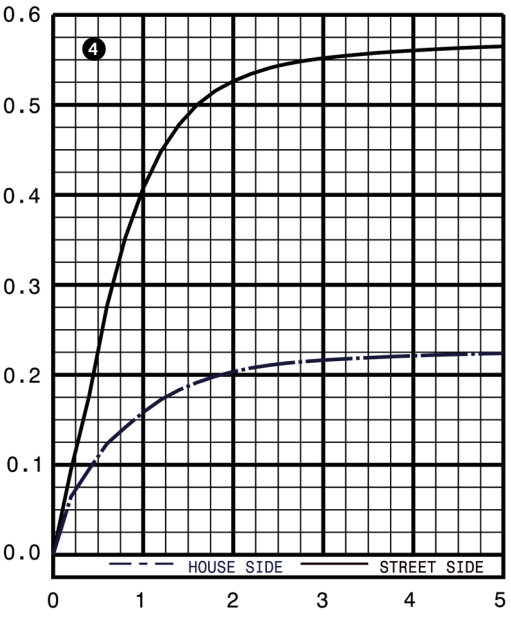
THIS TEST WAS CONDUCTED USING RELATIVE PHOTOMETRY TECHNIQUES ACCORDING TO STANDARD IESNA PROCEDURES.

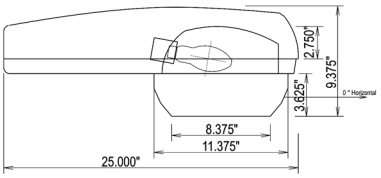
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LTL NUMBER: 04982 DATE: 01-01-2000
PREPARED FOR: LUMINAIRE TESTING LABORATORY, INC.
CATALOG NUMBER: SAMPLE ROADWAY TEST
LUMINAIRE: CAST ALUMINUM HOUSING, FORMED SEMI-SPECULAR ALUMINUM ❶
REFLECTOR, CLEAR ACRYLIC PRISMATIC LENS.
LAMP: ONE CLEAR HORIZONTAL S55 150 WATT ED17 HPS RATED AT 15,800 LUMENS.
LAMP CATALOG NUMBER: SYLVANIA LU150/55/MED
ARC TUBE VOLTAGE RISE: 0.9V

#04982

❷





IES CLASSIFICATION: **TYPE III**
LONGITUDINAL CLASSIFICATION: **MEDIUM**
CUTOFF CLASSIFICATION: **NON-CUTOFF**

❸

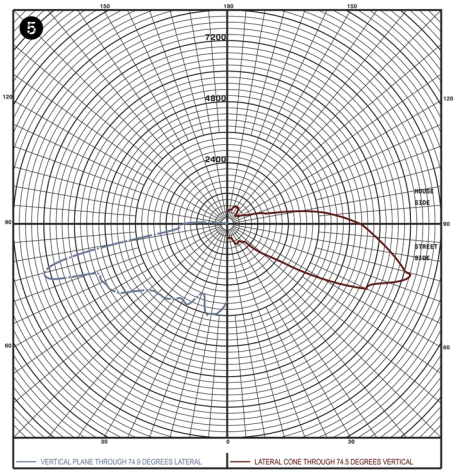
FLUX DISTRIBUTION

LUMENS	DOWNWARD	UPWARD	TOTALS
HOUSE SIDE	3632 (23.0%)	128 (0.8%)	3761 (23.8%)
STREET SIDE	9069 (57.4%)	248 (1.6%)	9318 (59.0%)
TOTALS	12702 (80.4%)	376 (2.4%)	13079 (82.8%)

STREET WIDTH / MOUNTING HEIGHT

MAXIMUM PLANE AND CONE PLOTS OF CANDELA

❺



❻

FLUX DISTRIBUTION TABLE BASED ON THE IESNA LUMINAIRE CLASSIFICATION SYSTEM

ZONE	LUMINAIRE LUMENS	% OF LAMP LUMENS
FORWARD LIGHT	9070	57.4
FL (0°-30°)	1555	9.8
FM (30°-60°)	4264	27
FH (60°-80°)	2793	17.7
FVH (80°-90°)	457	2.9
BACK LIGHT	3633	23
BL (0°-30°)	617	3.9
BM (30°-60°)	1674	10.6
BH (60°-80°)	1196	7.6
BVH (80°-90°)	147	0.9
UPLIGHT	377	2.4
UL (90°-100°)	229	1.4
UH (100°-180°)	148	0.9

Figure 8.10 | Ourdoor Luminaire Photometric Report
Outdoor photometric report for a building floodlighting luminaire.

❶ Report header information includes test number, luminaire, lamp, and ballast descriptive information, and testing conditiions. See Reference [11] and 9.16 References, reference [54).

❷ Most reports show a simple drawing of the luminaire to show lamp position and photometric center.

❸ Flux distribution gives house, stree, and total lumens.

❹ Roadway Coefficients of Utilization are plotting for stree and house side. See 9.14.6.5 Coefficients of Utilization.

❺ In addition to a listing of luminous intensities measured, polar plots are provided that show the characteristics of the principal beam of the luminaire. One plot is of intensities in a vertical plane, located azimuthally to pass through the maximum intensity. The other plot is of intensities in an azimuthal cone, located at the elevation angle of maximum intensity.

❻ Lumens in the zones and subzones required to determine the luminaire BUG rating. See 8.2.1.6 Outdoor Envrionmental Classification.

» Image ©Luminaire Testing Laboratories

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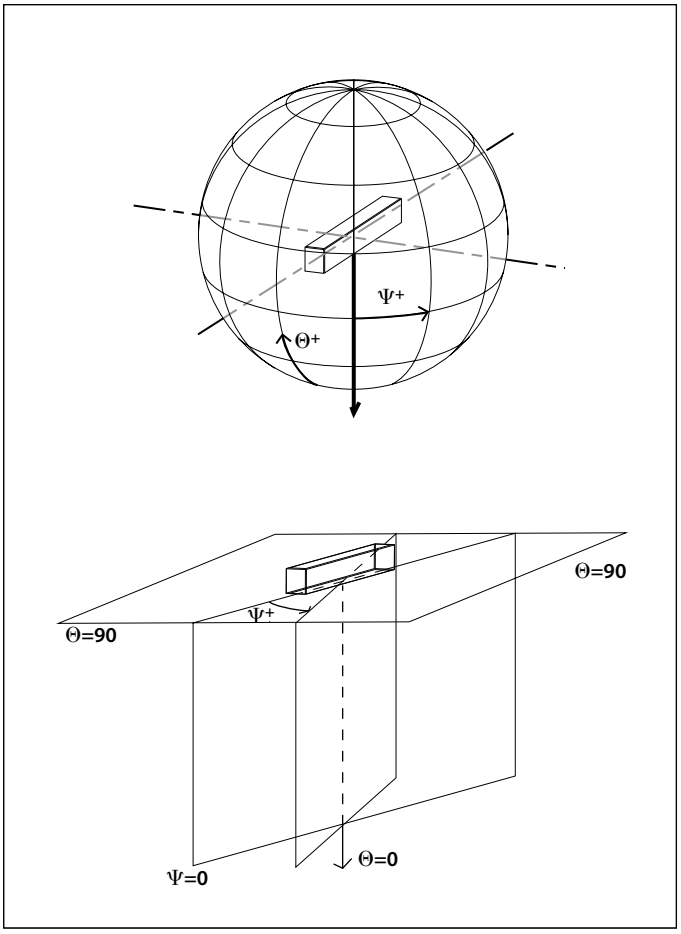


Figure 8.11 | Type C Goniometry
The angles and orientation for Type C photometry. The elevation angle is θ and the azimuthal angle is ψ.

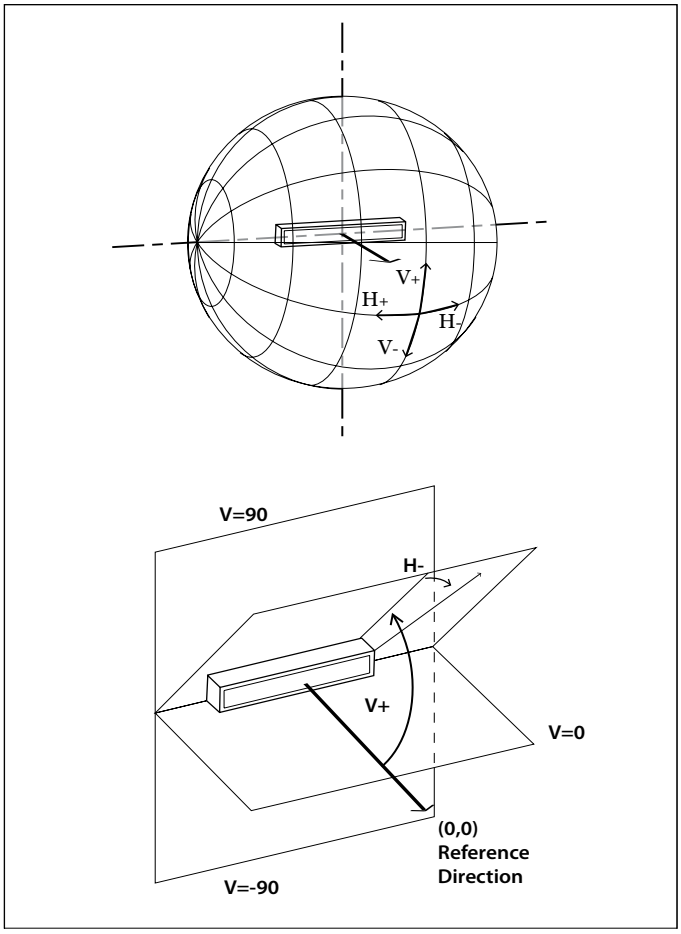


Figure 8.12 | Type B Goniometry
The angles and orientation for Type B photometry. The vertical angle is V and the horizontal angle is H.

In either case, the luminous intensity distribution always gives a general idea of how light is distributed by the luminaire. A convenient way to convey this information graphically is to produce a polar plot of the luminous intensity values. The azimuthal (horizontal) angle in the spherical coordinate system is kept fixed and the elevation (vertical) angle is allowed to move from 0° to 90° or to 180°, with the luminous intensity value at each elevation angle being plotted. This data line represents one plane of luminous intensity distribution data. Similar data lines can be plotted for other planes. Cutoff, uniformity of illuminance, and light patterns can be inferred from such plots.

For indoor luminaires, luminous intensity distributions are usually reported in two ways: an array of values and a polar plot. In the polar plot, luminous intensities in an azimuthal plane are plotted with a single line, labeled with the azimuthal angle or the plane's orientation. Each azimuthal plane is plotted as a separate line. See the polar plot in Figure 8.9.

For outdoor luminaires, luminous intensity distributions are reported in either Cartesian or polar plots. Luminous intensities in horizontal and vertical planes are reported. See Figure 8.10.

8.4.2.2 Average Luminance in Various Viewing Directions

As shown in section 5.7.3 Luminance, the definition of luminance can be extended to determine the average luminance of a surface. Equation 5.6 involves: $I(\theta,\psi)$, the luminous intensity from the entire luminaire in direction (θ,ψ); A, the luminous area of the

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luminaire ; and cos (θ), the cosine of the elevation angle from photometric nadir. This luminance gives a general idea of the luminaire's luminance and appearance but is meaningful only if the luminaire is homogeneous. In this case, average luminance can be used to assess the potential for discomfort glare.

If the luminaire exhibits large inhomogeneities in luminance, this value can significantly underestimate the luminance of some parts of the luminaire. Average luminance is sometimes reported in indoor luminaire photometric reports.

8.4.2.3 Zonal Lumens

The distribution of lumens emitted by a luminaire is described by discretizing the sphere or hemisphere of solid angle around the luminaire into smaller elements, called zones, and reporting the lumens contained in each zone.

Indoor Luminaires

Nested conic solid angle cones can be established with apexes at the luminaire photometric center. Given the size of these cones and the luminous intensity values in them, the number of lumens in each cone can be determined. Each cone defines a conic zone and the lumens within each are the luminaire zonal lumens. Any azimuthal asymmetry present in the luminous intensity distribution is not apparent, since only the number of lumens in each zone is reported. See the section labeled "Zonal Lumen Summary" in Figure 8.9.

Outdoor Luminaires

Many outdoor luminaires have intensity distributions that are very asymmetric or exhibit very high gradients of intensity. In terms of Type B photometry, the distribution in the vertical is very different than that in the horizontal. In addition, the change in intensity with angle can be very great, often having a gradient exceeding 1000 cd/degree. For these reasons the zones used to report zonal lumens are small and usually of different angular size in the horizontal and vertical. See Figure 8.10.

8.4.2.4 Efficiency

The total number of lumens emitted by the luminaire can also be calculated from the luminous intensity distribution. Dividing this value by the total number of lumens emitted by the lamps in the luminaire gives the luminous efficiency. This is a measure of how effectively the lamp and the reflector and/or refractor work to get the lamp lumens out of the luminaire. With lamps that are affected by operating temperature, thermal effects are also included in the efficiency. Efficiency is shown in Figure 8.9. Note that efficiency is not necessarily a measure of quality nor an indication of appropriate application. A bare lamp in a socket has an efficiency approaching 100%, but it is unsuitable for most applications because it has no controlling optics.

8.4.2.5 Efficacy

NEMA has established a procedure to determine a Target Efficacy Rating (TER) for luminaires [13]. TER is defined as the ratio of lumens emitted from a luminaire that contribute to the illumination of a generic target area based on the luminaire category, per watt of power consumed by the luminaire. This data is not yet required of photometric reports and is voluntarily provided by laboratories and equipment manufacturers.

8.4.2.6 Coefficients of Utilization

As described in Chapter 10, coefficients of utilization for indoor luminaires describe the effectiveness with which the luminaire puts lamp lumens onto the horizontal work plane of a rectangular room. Tables of these values for a range of room surface reflectances and room shapes are part of a photometric report for an indoor luminaire that can be used for general or ambient lighting. See section labeled "Coefficients of Utilization" in Figure 8.9.

Some indoor luminaires are not designed or intended to produce general lighting, and coefficients of utilization are not provided. Accent and wallwasher luminaires are examples.

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8.4.2.7 Spacing Criterion

Spacing criterion is a low precision indicator of how far apart general lighting luminaires can be spaced while providing acceptable uniformity of horizontal illuminance. It is based only on direct illuminance (interreflected illuminance is ignored) and cannot be applied to indirect luminaires.

8.4.2.8 Discomfort Glare Assessment

Data for discomfort glare assessment, independent of application, is limited to reporting the average luminance at typical viewing angles. This can be used to show compliance with luminance limits in certain applications [14]. Discomfort glare assessments are generally no longer made or reported for luminaires outside of specific applications and are usually project specific in the form of a calculation of UGR. See 10.9.2 Calculating Glare.

8.4.2.9 Other Components

Some luminaire photometric reports provide additional information, depending upon the application. Examples include wall illuminances for wallwasher luminaires, iso-illuminance contours for outdoor area luminaires, and roadway coefficients of utilization for roadway luminaires. See sections labeled “Iso-Illuminance Contour” and “Max. to Min. Uniformity” in Figure 8.10.

8.4.3 Thermal Performance

In general, the thermal performance of luminaires cannot be isolated from the way in which they are used. In most interior applications and some exterior applications, luminaires are thermally coupled to their environment. There are, however, some thermal issues that can essentially be isolated. Three of these are the effect of the luminaire on the operating temperature of the lamp, the effect of lamp heat on luminaire materials, and the effects of air handling.

8.4.3.1 Lamp Operating Temperature

The performance of LED sources is very dependent on junction temperature. See 1.4.5.4 Electroluminescence: Light Emitting Diodes, and 7 | LIGHT SOURCES: TECHNICAL CHARACTERISTICS. Luminaires that use LEDs must have adequate means to limit LED junction temperature. This is usually accomplished with heat sinks. For these to work properly, luminaires must be constructed and used so that any required convective airflow from the heat sink is maintained.

The performance of many discharge lamp types is dependent on the bulb wall temperature. This is particularly true for fluorescent lamps, for which both light output and electrical power input, and thus luminous efficacy vary with the temperature of the coldest spot on the bulb wall. The lamp temperature in turn is a function of the heat balance between the lamp and its surroundings. Electrical energy provided to the lamp is partly converted into light, the balance being dissipated through the mechanisms of thermal radiation, convection and conduction.

Even the most efficient lamps convert only a moderate fraction of their electrical power input into visible light. See 7 | LIGHT SOURCES: TECHNICAL CHARACTERISTICS. Efficiency (watts converted to light as a fraction of input watts) varies from a low of approximately 0.10 for filament lamps, to high of 0.3 for low-pressure sodium lamps. With the exception of low-pressure sodium lamps, the greatest percentage of energy converted by most lamps is dissipated as infrared radiation. The relative energy dissipation by convection and conduction depends on airflow conditions and the temperature around the lamp, and on the details of the lamp mounting and luminaire design.

8.4.3.2 Effects on Luminaire Materials

Since lamps emit energy in infrared as well as visible wavelengths, it is useful to examine the radiant properties of materials used in luminaires. The transmittance and reflectance of most materials are wavelength dependent. Thus, for example, a lens material can be selected which has high visible transmittance but low infrared transmittance, thereby re-

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ducing the amount of heat radiated from the luminaire. However, the heat that is trapped in the luminaire will cause the lamp temperature to be greater than it would be otherwise. This may be desirable if higher lamp temperatures are needed to boost efficiency, but consideration should be given to the possibility of increased thermal stresses within the luminaire.

8.4.3.3 Air Handling

The thermal performance of an indoor luminaires can also include its ability to deliver or extract air from a space. These heat transfer luminaires are often referred to as air-handling luminaires and are constructed to add or remove heat from a space by moving air. They are constructed to minimize the effect of the air on the lamp bulb temperature.

8.4.4 Testing and Compliance

Luminaires should be installed in accordance with regional safety regulations and be certified for safety by an organization that is accredited in the region in which the luminaire is installed. National and local electrical codes sometimes determine the type of lighting equipment that can be used and the method of installation. Typically, luminaires are tested in accordance with national or international safety standards. These establish a minimum level of safety to reduce the likelihood of fire or electric shock.

8.4.4.1 USA

Luminaire installation practices in the United States are dictated by the National Electrical Code (NEC), which is produced by the National Fire Protection Association. This code is revised at least every three years. The NEC requires that equipment be listed as meeting minimum safety standards by an organization that is acceptable to the municipal authority having jurisdiction over the installation. This authority is typically the local electrical inspector. The American National Standards Institute (ANSI) has accredited Underwriters Laboratories (UL) as the standards-making organization for luminaires in the United States [15]. Virtually all local authorities require luminaires to be tested to UL standards and so labeled by a Nationally Recognized Testing Laboratory (NRTL). They sometimes require other certifications as well.

The Occupational Safety and Health Administration (OSHA) accredits some laboratories to evaluate products using ANSI/UL standards. Such a laboratory is designated as NRTL [16]. In addition, the National Institute of Standards and Technology (NIST) operates the National Voluntary Laboratory Accreditation Program (NVLAP). This program covers metrology in general and photometric testing in particular [17].

8.4.4.2 Canada

Luminaire installation practices in Canada are dictated by the Canadian Electrical Code (CEC), published by the Canadian Standards Association (CSA). This code is revised every five years. The CEC requires that equipment be submitted for examination and testing by an acceptable certification agency. The CSA is the standards-making organization for luminaires in Canada. The Standards Council of Canada accredits laboratories in Canada to evaluate luminaires using CSA standards. The accredited laboratory labels equipment that meets these standards.

8.4.4.3 Mexico

Luminaire installation practices in Mexico are dictated by the Mexican government through a series of Mexican Governmental Obligatory Safety Standards. Products that comply with the Mexican requirements bear the mark NOM. Laboratories are accredited by the Mexican Board of Accreditation for Testing Laboratories.

8.4.4.4 EU

Luminaires that are exported to the European Community are required to bear the CE mark indicating that the manufacturer is in compliance with all assessment procedures required for luminaires. Essentially, luminaires are required to comply with applicable International Electrotechnical Commission requirements.

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8.5 Specifying and Using Luminaires

The successful use of luminaires requires an understanding of the lighting task they accomplish and the environment in which they operate. An appropriate luminaire for the lighting task has the proper photometric characteristics and is compatible with the environment. Table 8.6 lists many of the factors that may be involved in considering and specifying luminaires. Photometric characteristics are considered in the sections above. Electrical, thermal, mechanical, acoustical, and maintenance aspects of a luminaire's environment can affect its performance and are considered in the following sections.

8.5.1 Electrical

Every luminaire, as part of a lighting system, should also be considered part of an electrical wiring system. Branch-circuit panel boards and the feeders that serve them must be designed to carry the lighting electrical load. The characteristics of the electrical system, such as voltage, phases and capacity, must be known in order to design circuits or to choose any controls such as switches, dimmers or occupancy sensors.

Designers should know the fundamentals of electrical systems design to ensure that they can optimize flexibility and cost. All electrical systems in the United States must be designed and installed in accordance with the provisions and requirements of the NEC as well as state and local codes. To assure that these requirements are met, the electrical system should always be designed by a licensed professional engineer.

Designing a coordinated lighting and electrical system begins by determining the utilization voltage of the system. For new buildings, building feed voltage may be obtained from the utility company or from the engineer. This affects considerations of supply transformers. In existing buildings, the information may be obtained from the maintenance engineer by measurement, or by reading the name plate data on existing panel boards.

The electrical characteristics most often encountered in the United States are:

- 120/240 V, single phase, three wire for residential buildings
- 208/120 V, three phase, four wire for older or small commercial buildings
- 208/120 V, three phase, four wire for some new commercial buildings
- 480/277 V, three phase, four wire for newer and larger commercial buildings

In Canada, the voltages are:

- 120/240 V, single phase, three wire for residential buildings
- 347/600 V, three phase, four wire for commercial buildings
- 277/480 V, three phase, four wire for commercial buildings

In Mexico, the electrical characteristics are:

- 127/220 V, three phase, four wire for residential and commercial buildings
- 220/440 V, three phase, four wire for industrial buildings

It should be noted, however, that branch-circuit wiring for lighting in residential and commercial applications in Mexico utilizes 127 V, single phase.

When the designer is faced with a 277/480 V source of power, step-down transformers, to obtain 120/208 V, will be required for use with filament lamps. Some buildings will have two main transformers and special step-down transformers will not be required. The designer must exercise caution, as these step-down transformers may also be used for power

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to appliance and receptacle circuits, leaving little or no power for filament lamp lighting. If involved in a project early enough, the designer may wish to request that a portion of the transformer capacity be held in reserve for "special lighting."

The location(s) of the panel boards and transformers will probably be dictated by the architecture of the building. To exemplify, a high-rise office building will probably have one electrical room per floor, with vertical electrical distribution of 277/480 V and a step-down transformer for 120/208 V on each floor.

Very often, the lighting designer will be required to state the allowed power density prior to the completion of the design process. There are several sources of information available to assist in obtaining an answer; they include, in addition to past experience, the NEC, ASHRAE/ANSI/IESNA 90.1, and state and local codes.

Due to the need for effective energy utilization, controls have become a more integral part of lighting design. Various techniques for control are at the disposal of designers. These lighting control tools include two- or three-level switching of three- or four-lamp fluorescent lighting luminaires, photoelectric control for daylight and occupancy/motion sensors, and controls that are integral to the luminaire. See 16 | LIGHTING CONTROLS, for a discussion of control strategies and equipment.

High-power-factor ballasts are recommended. There are code restrictions on the use of 480-V lighting equipment. The use of high-power-factor ballasts not only reduces VA demand but also often permits more luminaires to be operated from a single circuit.

Caution is required in the use of square wave inverters for emergency power with high power-factor, compact fluorescent ballasts. The power-factor-correcting capacitor used in the ballast may look like a short circuit to the square wave output of the inverter and create circuit breaker problems.

Electronic ballasts have an inherent harmonic distortion that may damage the neutral conductor(s) of the electrical system. In some cases, it may become necessary to oversize the neutral conductor. See 7 | LIGHT SOURCES: TECHNICAL CHARACTERISTICS, for information on electronic ballasts.

8.5.2 Thermal

The interactions between building systems, and the response of the building to exterior conditions and occupant activities, influence the performance of each of the building components. In this regard, lighting system performance is also dependent on the building's thermal environment.

The major thermal considerations related to the performance of a lighting system are the dependence of its light output and efficiency on lamp temperature, and the cooling load due to energy dissipated by it. The effects of the thermal environment on light output and efficiency fall primarily within the realm of the lighting designer; the cooling load due to lighting is of more interest to the mechanical systems designer.

Essentially all of the electrical power provided to the lighting system is dissipated into the building space as heat, the exception being any light radiated directly out of the building through transparent surfaces. This building space heat is directly proportional to the amount of time the lighting system operates. Clearly, using higher efficacy sources can produce the required light with reduced watts, and thus less heat.

The heat gain from the lighting system contributes to the cooling load, or helps satisfy the heating requirements, depending on the building conditions. Most large commercial buildings have large interior heat sources, such as computers and other electrical equip-

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Table 8.6 | Factors Involved in Considering and Specifying Luminaires

Aspect	Parameter	Significance
Dimensions	• Length/width/depth/diameter	US Customary vs. metric
		Integration with modular systems
		Interferences in room space or in walls/ceilings
		Scale appropriate to architecture and/or occupants
	• Projection	US Customary vs. metric
		ADA-compliance
		Comfort
	• Maintenance access	Accessibility vs. comfort vs. frequency
Mounting	• Recessed	Necessary clear depth in ceilings/walls/floor/ground
		Mounting surface (smooth, rough, very rough, articulated, flat, angled)
	• Surface mounted	Necessary clear space around luminaire
		Mounting surface (smooth, rough, very rough, articulated, flat, angled)
	• Suspended	Mounting surface (smooth, rough, very rough, articulated, flat, angled)
		Desired overall suspension vs. overall available height
		Stem, aircraft cable, chain
		Safety cable
	• Furniture or millwork mounted	Wire management/routing
		Exposed (visible) or hidden (detail)
		Control (at luminaire or remotely)
	• Freestanding (floor or furniture)	Hardwired or cord+plug
		Control (at luminaire or remotely)
Ceiling Type	• Lay-in Grid-type	Standard T, narrow T, screw-slot T, concealed T
	• Hard Flange-type	Drywall, plaster, plaster-on-lathe, wood
	• Metal	Standard T or concealed T, linear
	• Other	Concrete, special modular, special fabric (e.g, Barrisol®), special acoustic (e.g., BASWAphon)
Flange	• Overlap trim	Self-flanged/same metal finish as reflector (best for most all ceiling colors/types)
		Self-flanged/white paint (best for white ceilings)
		Self-flanged/custom paint (best for other-than-white ceilings where custom look is desired)
		White acrylic/polymer flange (two-piece, less attractive, but quick and cheap)
	• Flangless (or trimless)	Cleanest, most minimal look, but requires precision drywall/plaster work
Reflector	• Optics	Precision formed and finished
		Diffuse
	• Finish	Anodized/low-irridescent (matte vs. specular vs. semi-specular)
		Painted
	• Material	Metal (for best durability)
		UV-stabilized acrylic
		Glass
Shielding	• Baffles	Visual cutoff in one viewing direction
		Material and finish
	• Louvers	Visual cutoff in two viewing direction
		Material and finish
Lensing	• Glass	Tempered vs. laminated vs. untreated (application and/or lamping dependent)
		Optically-active (prisms) or diffuse (opal) or decorative (colored, faux stone)
	• Acrylic	UV-stabilized
		Optically-active (prisms) or diffuse (opal) or decorative (colored, faux stone)
Door/Access	• Flush frame	Formed metal
		Extruded
	• Regressed	Shallow or deep
		Angled/straight edge
		Reveal

Table 8.6 | Factors Involved in Considering and Specifying Luminaires continued next page

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Table 8.6 | Factors Involved in Considering and Specifying Luminaires continued from previous page

Aspect	Parameter	Significance
Function	• Fixed	Narrow, medium, wide spread
	• Adjustable	Narrow, medium, wide spread
		Max rotation, max tilt angle, friction or locking mechanisms, hot aim
	• Wallwash	Narrow, medium, wide spread
Photometric	• Luminances	Maximum, average
	• Candlepower	Center beam
		Maximum
		Beam spread
	• Luminaire lumens	Luminaire efficiency
	• Power	Number of lamps and lamp wattage
		Total wattage with ballast/driver/transformer losses
Lamping	• Configuration	Layout and number of lamps
		Base type (universal, dedicated)
	• Type	halogenIR, CFL, fluorescent, CMH, LED
	• Internal Circuiting	Number of internal luminaire control circuits for mutliple-lamp units
	• Color	CCT
		CRI
	• Lamp lumens	Lumens
	• Lamp life	Hours
	• Lamp lumen depreciation	Anticipated reduction over time
Drivers, Ballasts, Transformers	• Voltage	Specific voltage or universal voltage
	• Lamps	Quantity of lamps controlled
	• Operating characteristics	Ballast factor (for fluorescent)
		Total harmonic distortion (<0.1)
		Power factor (>0.95)
	• Control method	Non-dimming
		Dimming
		DALI
	• Start method	Instant start, program start, rapid start (fluorescent options)
	• End method	End-of-life shutdown protection
	• Protection	Thermal fuse (required)
		Electrical fuse (may protect more costly lamps/ballasts)
	• Location	Internal to luminaire
		Remote from luminaire
	• Auxiliary	Black-box devices or other equipment necessary to start, operate, or dim equipment
Lamp Containment		Required for some halogen, halogenIR, and HID lamps (consult lamp vendor)
Environment	• Dry	UL/NRTL listed/labeled for Dry
	• Damp	UL/NRTL listed/labeled for Damp
	• Wet	UL/NRTL listed/labeled for Wet
	• Hazardous	Vapor/dust-proof, explosion proof, marine, etc. UL/NRTL listed/labeled
HVAC	• Static	Door frame appearance (reveal or no reveal)
	• Air handling	Supply
Thermal	• Insulation contact	IC rated or maintain at least 3" clear all around housing (or as otherwise required by code)
	• Insulation nearby	IC rated or maintain at least 3" clear all around housing (or as otherwise required by code)
	• No insulation	IC rated or non-IC rated (both are acceptable)
	• Air infiltration or loss	Air tight housing

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ment, and need to be cooled throughout the year. Exterior zones in large buildings, and smaller buildings with high ratios of surface area to volume, may require heating in winter. In buildings without air conditioning, the heat from lighting systems can overheat occupant spaces.

Lighting can account for 20-50% of building electrical energy usage. Electrical energy to meet the cooling loads imposed by lighting can add another 10-20%. Another important factor is that the time of day when the lighting load is greatest corresponds to the time of peak building cooling load demand and electric utility demand and of greatest electrical energy unit cost. Thus, any improvement in lighting system efficiency can save lighting energy, cooling energy and energy costs, and also reduces cooling equipment capacity requirements.

8.5.2.1 Lighting Energy Distribution Fractions

In general, the electrical energy input to a luminaire will be dissipated via the following mechanisms:

- Downward visible light
- Upward visible light
- Downward infrared radiation
- Upward infrared radiation
- Downward convection
- Upward convection
- Convection to return air
- Conduction

The magnitude of each of these components depends on the type of lamp and luminaire, HVAC design and the design of the building space, particularly the presence or absence of a ceiling plenum. Some of the fractions may be zero for some configurations [18].

Several test methods have been employed to assess the total energy distribution from a particular luminaire. One involves an adaptation of photometric techniques. Two others involve calorimetry, including the use of continuous-water-flow [19] and continuous-air-flow [20] [21] calorimeters. In one study, though procedures and equipment varied widely, the test results were of the same order of magnitude [22].

Testing guides for determining the thermal performance of luminaires have been published by IES, the Air Diffusion Council (ADC) and NEMA. The IES issues an approved test method that considers the effect of plenum temperature and air return on the light output. The test also provides data on the manner in which heat distribution and power input depend upon the return airflow through the luminaire [23].

8.5.2.2 Lamp Temperature as a Function of Lighting System Design

Fluorescent lamps are widely used in commercial and industrial spaces, and their performance is strongly dependent on lamp wall temperature. The type of luminaire and its location relative to supply and return air ducts influence the lamp temperature and therefore performance. A convenient way of characterizing lamp thermal performance is in terms of the elevation of lamp temperature above ambient air temperature for each luminaire and HVAC configuration. This allows the determination of the lamp temperature for any ambient air temperature by adding the lamp temperature elevation to the air temperature.

For example, an unvented four-lamp luminaire with an acrylic lens will usually have hotter lamps than the same luminaire if vented, or than a similar luminaire with two lamps, or than a luminaire with an open-cell diffuser. For each luminaire type and airflow configuration, the possible lamp temperatures span a fairly narrow range, approximately 3-6°C. Some variation in lamp temperature can be obtained by changing the airflow rate,

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but this has a limited effect unless lamp compartment extract is used. Some lamp and ballast systems have better performance in hotter environments such as an unvented lensed troffer. Higher ambient temperatures may adversely affect T8 fluorescent lamps, but not T5 HO fluorescent lamps.

8.5.2.3 Cooling Load Due to Lighting

The ASHRAE Fundamentals Handbook covers the calculation of the space load due to lighting for various luminaires and ventilation arrangements [24].

Luminaire mounting has an important role in the distribution of thermal energy. The total energy distribution involves all three mechanisms of heat transfer: radiation, conduction and convection.

Heat transfers from the surface-mounted semidirect luminaires involve radiation, conduction and convection. Assuming good contact with the ceiling, upper surfaces of the luminaire will transfer energy to or from the ceiling by conduction. Since many acoustical ceiling materials are also good thermal insulators, it may be assumed that temperatures within the luminaire will be elevated. Thus, lower luminaire surfaces will tend to radiate and convect to the space below at a somewhat higher rate. Unless the ceiling material is a good heat conductor and can reradiate above, essentially all of the input energy will remain in the space.

A different situation exists when components of the system are separated from the space. Recessed luminaires distributes some portion of its input wattage above the suspended ceiling. The actual ratio is a function of the luminaire design and plenum and ambient conditions. For most recessed static luminaires, the ratio is very nearly 50% above the ceiling and 50% below.

For recessed luminaires, the convected and radiated components to the space are reduced considerably, while the upward energy is increased correspondingly. Under certain conditions it is possible for the space load to consist almost entirely of light energy. The majority of the power input to the luminaire is directed upward, where it can be captured by the system and be subject to some form of control. Laboratory tests conducted in accordance with IES procedures [23] will provide energy distribution data for evaluative purposes. However, the total system must be evaluated, because heat removal to the plenum may raise plenum temperatures, causing conductive heat transfer back through the ceiling and floor to the space below and above, and thereby adding thermal load back to the space.

Task-ambient lighting systems have a different lighting energy distribution and the lighting designer may need to work very carefully with the building mechanical system designer. Care must be exercised in the selection of the cooling load factor (CLF) used in calculations of space load. Depending on the installation, it may be necessary to calculate task and ambient heat loads separately. It is possible to have both systems completely within the space. This will be the case if suspended or surface mounted or furniture mounted luminaires are used for ambient lighting, with task lighting being incorporated into the furniture or with suspended or surface-mounted luminaires being used for both. In this case, the entire input power is an instantaneous space load.

With recessed luminaires utilized for ambient lighting and either suspended or furniture-mounted ones for task lighting, the heat loads must be figured separately, as only the task lighting load is entirely instantaneous space load. The recessed luminaire heat contribution may be considerably less, depending upon the CLF.

Systems can also utilize recessed luminaires for both task and ambient lighting. Here, both will impose a heat load that will be reduced by the CLF.

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8.5.3 Mechanical

The mechanical aspects of a luminaire that should be taken into account are typically determined by the application and environment.

Ceiling mounted luminaire must have a compatibility with the ceiling system. This includes appropriate size, weight, and mounting mechanism. Luminaires intended for outdoor use should incorporate mounting and design features suitable to withstand high winds and rain and snow accumulation. Luminaires recessed in poured concrete should have an enclosure of suitable strength, tightness and rigidity for the application. Surface-mounted luminaires should be strong enough so that they will not bend excessively when mounted on uneven ceilings. Suspended luminaires should have adequate strength to limit vertical sag between supports as well as lateral distortion and twist. Provision must be made for attachment of supports at suitable locations. Mounting and leveling devises should allow for easy and fast installation, which can reduce construction labor costs. Certain locations may require vandal proof luminaires of heavy construction. This may, in turn, require additional or heavier mounting equipment. Locations subject to seismic activity may have codes that dictate that luminaires be securely fastened to the true ceiling at four points.

8.5.4 Acoustical

Undesirable sound generation is sometimes a problem with fluorescent or other discharge lamps ballasted with electromagnetic or solid-state devices. Luminaires can transmit this sound to the rest of the space and, in some cases, add luminaire vibration to it. Large, flat surfaces and loose parts amplify the sound. Steps taken to minimize transmission of sound from the ballast to the luminaire may affect heat transfer characteristics.

Where luminaires are used as air supply or air return devices, the air-controlling surfaces should be designed with full consideration for air noise. In this case, there are well-accepted criteria for permissible sound levels [25].

Electronic ballasts are essentially silent. Some ballast hum from magnetic ballasts is inevitable in view of the electromagnetic principle involved, and each ballast type has a different sound rating. Where low noise levels are necessary, consideration should be given to mounting the ballasting equipment remotely or using light sources having inherently quieter operation. Remote locations of ballasts may involve complications of wiring, voltage, and thermal considerations and code restrictions.

8.5.5 Maintenance

Maintaining luminaire performance requires periodic cleaning and relamping. If luminaires are mounted in places normally out of reach, consideration should be given to how they will be accessed. If special equipment is required or if lamps are used that have a short life, luminaire placement should be reconsidered. Doors and frames should be hinged to permit easy access to the lamps and cleaning of reflectors. If luminaires are aimed, it may be necessary to specify locking hardware to prevent them from moving.

The presence of dirt and insects should be considered when choosing a luminaire. Enclosed luminaires or gasketed doors can reduce dirt and insect penetration and accumulation, reduce required maintenance, and result in higher light loss factors.

8.6 References

[1] Santoro S, Crenshaw M, Ashdown I. 2002. Kinoform diffusers. J Illum Eng Soc. 31(1):9-19.

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[2] Pelka D, Patel K. 2003. An overview of LED applications for general illumination. In: SPIE Proceedings, Design of efficient illumination systems. San Diego CA. 5186:15-26.

[3] [IES] Illuminating Engineering Society. 2007. TM-15-07(revised). Luminaire classification system for outdoor luminaires. 11 p.

[4] Rea M, editor. 2000. IESNA Lighting Handbook. 9th edition. New York NY. IESNA

[5] [NFPA] National Fire Protection Association. 2005. National Electric Code.

[6] Americans with Disabilities Act. 1990/2008. Title 42, Chapter 126, United States Code.

[7] Moyer JL. 1992. The landscape lighting book. New York. Wiley. 282 p.

[8] [IEC] International Electrotechnical Commission. 2002. MEDICAL ELECTRICAL EQUIPMENT - PART 2-41: PARTICULAR REQUIREMENTS FOR THE SAFETY OF SURGICAL LUMINAIRES AND LUMINAIRES FOR DIAGNOSIS. IEC. (and Surgery lighting Leukos)

[9] Roseman A, Kaase H. 2006. Combined daylight systems for lightpipe applications. Int. J Low Carbon Tech. 1(1):10-21.

[10] Steffy GR. 2004. Design problems associated with aisle lighting. Leukos. 1(1):25-42.

[11] [IES] Illuminating Engineering Society. 2003. IESNA guide for reporting general lighting equipment engineering data for indoor luminaires.7 p.

[12] [IES] Illuminating Enginering Society. 2007. LM-79-08. Approved Method: Electrical and photometric measurement of solid-state lighting products. 16 p.

[13] [NEMA] National Electrical Manufacturers Association LE-6. 2008. Procedure for determining Target Efficacy Ratings (TER) for commercial, industrial and residential luminaires. Rosslyn VA. NEMA. 13 p.

[14] [IES] Illuminating Enginering Society. 2004. RP-1-04. Office lighting. 63 p.

[15] [UL] Underwriters Laboratories. 2000. The standard of safety for luminaires. UL-1598 CSA 250. 3rd edition. Northbrook IL. Underwriters Laboratories. 322 p.

[16] US Dept of Labor. 2009. Nationally recognized testing laboratories (NRTLs). http://www.osha.gov/dts/otpca/nrtl/

[17] {NIST] National Institute of Standards and Technology. 2006. http://ts.nist.gov/standards/accreditation/index.cfm

[18] Treado SJ, Bean JW. 1988. The interaction of lighting, heating and cooling systems in buildings: Interim report. NISTIR 88-3860. National Institute of Standards and Technology. Gaithersburg MD.

[19] Bonvallet GG. Method of Determining Energy Distribution Characteristics of Fluorescent Luminaires. Illum Eng. 58(2):69-74.

[20] Mueller T, Benson BS. Testing and Performance of Heat Removal Troffers. Illum Eng. 57(12):793-802.

[21] Ballman TL, Bradley RD, Hoelscher EC. Calorimetry of Fluorescent Luminaires. Illum Eng. 59(12):779-785

[22] [IESNA] Illuminating Engineering Society Committee on Lighting and Air Conditioning. Lighting and Air Conditioning. Illum Eng 61(3):123-147.

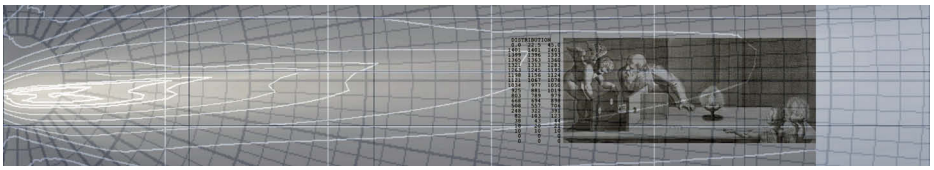
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[23] [IESNA] Illuminating Engineering Society Committee on Testing Procedures. IES Approved Guide for the Photometric and Thermal Testing of Air Cooled Heat Transfer Luminaires,. J Illum Eng Soc. 8(1):57-62.

[24] [ASHRAE] American Society of Heating, Refrigeration, and Air-Conditioning Engineers. 2009. ASHRAE Handbook of Fundamentals. ASHRAE. Atlanta.

[25] [ASHRAE] American Society of Heating, Refrigeration, and Air-Conditioning Engineers. 2009. ASHRAE Standard 36-72. Methods of testing for sound rating heating, refrigerating, and air-conditioning equipment. ASHRAE. Atlanta.

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9 | MEASUREMENT OF LIGHT
PHOTOMETRY

When you can measure what you are speaking about, and express it in numbers, you know something about it . . .

Lord Kelvin 1883, Engineer and Mathematical Physicist

Lighting is anchored to meaningful visual phenomenon by way of the definition of light it adopts: the joining of radiant power, a physical quantity, with visual response, a psychphysically quantity. The utility of the definition allows light to be measured and calculated; that is, light has the aspects of *quantity* that permit the engineering activities of measurement and prediction by calculation. This analytic aspect of light and lighting allows successful experience to be recorded and become quantity recommendations for other lighting projects, allows lighting equipment to be characterized in ways useful to designers, and allows predictions of likely outcomes of proposed lighting designs

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9.1 Introduction

The measurement of optical radiation, called radiometry, is the science of measuring radiant quantities and is part of the general science of measurement, metrology. Photometry, a special branch of radiometry, is the measurement of radiation accounting for human visual response. The Commission Internationale de l'Eclairage (CIE) standard observer, defined in part by the photopic luminous efficiency function of wavelength, V(λ), quantifies this response and defines the spectral response that photometric measurement equipment must exhibit. See 5.4.2 Photopic Luminous Efficiency.

This standard observer response curve is used as a weighting function applied to a spectral power distribution (SPD) of the optical radiation being measured. The summation across all wavelengths of the weighted SPD defines luminous flux. See 5.5 Luminous Flux. The weighting and summation is the very core of photometry. Though it is globally accepted and used, V(λ) is a compromise that always assumes the same predictable correlation of physical measurements with visual response. But there are circumstances where photometric quantities are poor predictors of visual response. See 4 | PERCEPTIONS AND PERFORMANCE. Thus, a basic understanding of photometry is essential to the balance that must be struck by a lighting designer between measurement on one hand, and visual experience on the other.

Photometry and radiometry are used to determine properties of lighting equipment and materials and aspects of the performance of lighting systems. Some of these measurements required photometric standards (either sources or detectors) and are usually performed in a photometric laboratory, some are accomplished with equipment designed for field use. Table 9.1 shows the most common types of photometric and radiometric measurement, along with the equipment and usual place of measurement.

Photometry is a word first used by Johann Heinrich Lambert as the title to his 1760 Latin treatise on the measurement of light. He coined it by combining the Greek words for Light (φωσ) and Measure (μετρον). Lambert's word soon found its way into European languages.

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Table 9.1 | Radiometric and Photometric Measurements

	Characteristic	Dimensional Unit	Equipment	Technique
Light	Wavelength	Nanometer	Spectrometer	Laboratory
	Color	None	Spectrophotometer and colorimeter	Laboratory
Light Sources	Energy radiated	Joule per square meter	Calibrated radiometer	Laboratory or field
	Color temperature	Kelvn	Colorimeter or filtered radiometer	Laboratory or field
	Luminous intensity distribution	Candela	Photometer and goniometer	Laboratory
	Luminance	Candela per unit area	Photometer or luminance meter	Laboratory
	Spectral power distribution	Watts per nanometer	Spectroradiometer	Laboratory or field
	Power consumption	Watt	Watt meter or voltmeter and ammeter	Laboratory or field
	Total lumen output	Lumen	Integrating sphere or photometer and goniometer	Laboratory
	Lumen distribution	Lumen	photometer and goniometer	Laboratory
Lighting Condition	Illuminance	Lumens per unit area	Illuminance meter	Laboratory or field
	Luminance	Candela per unit area	Luminance meter	Laboratory or field
Materials	Reflectance	Rods begin	Reflectometer	Laboratory or field
	Transmittance	saturation	Transmitometer	Laboratory or field
	Spectral reflectance	Percent	Spectrophotometer	Laboratory
	Spectal transmittance	Percent	Spectrophotometer	Laboratory
	Bidirectional reflectance	Inverse steradian	Luminance meter and goniometer	Laboratory
	Bidirectional transmittance	Inverse steradian	Luminance meter and goniometer	Laboratory

9.2 Photometric Standards

Photometric standards are objects or detectors designed to provide a uniform basis for all photometric measurement, and are important for several practical reasons:

- Standards permit fair and competitive comparison between lighting equipment performance, based on photometric measurements, regardless of the place of manufacture or final use.
- Standards permit the expectation of a reasonable correlation between predicted performance of lighting equipment (as determined in the laboratory) and that performance observed in application (as measured with field measurement equipment).
- Standards permit private and government laboratories to calibrate photometric measurement equipment, to evaluate lighting products, and guide the development and application of new source and material technologies in lighting.

9.2.1 Types of Standards

International metrology vocabulary distinguishes between types of standards based on quality, importance, and intended use [1]. The following types are based on that vocabulary.

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9.2.1.1 Primary Standards

A primary standard is a standard that is designated or widely acknowledged as having the highest metrological quantities and whose value is accepted without reference to other standards of the same quantity. The candela, maintained by the Bureau International des Poids et Mesures (BIPM), is a primary standard.

9.2.1.2 National (Measurement) Standards

National standards that define radiometric and photometric quantities are maintained by national standard laboratories [2].These standards typically are developed from international standards through a specified, usually complex, experimental procedure. In North America, measurement standards for lighting, including the candela, are maintained by the National Institute of Standards and Technology (NIST) in the United States, and the National Research Council (NRC) in Canada, the Centro Nacional de Metrologia in Mexico, the Physikalisch-Technische Bundesanstalt in Germany. National measurement standards are not directly accessible by other laboratories.

9.2.1.3 Transfer Standards

Transfer standards are necessary to link the measurement systems of one laboratory to another (for example, a national measurement laboratory and an industrial laboratory). They are defined simply as intermediaries used to compare standards. They can be called traveling standards when intended for transport between different locations.

9.2.1.4 Reference Standards

Reference standards are standards having the highest metrological quantity available at a given location or in a given organization, from which the measurements made there are derived. Reference standards can be derived directly from a national measurement standard or from the reference standards of other laboratories in the calibration chain. They usually are prepared with precise electrical and radiometric measurement equipment.

9.2.1.5 Working Standards

Working standards are used for routine measurements in a laboratory and usually are prepared and calibrated by that same laboratory from its own reference standard

Other nomenclatures have evolved from historical usage, but do not represent the internationally accepted definitions, and they are not all consistent. For example, the term “primary standard” often is used to designate a standard source that was obtained from a national standards laboratory and that is used only to make other working standards for everyday use in that laboratory. Sometimes, a primary standard is called a “master standard” The term “secondary standard” is also commonly used in private laboratories to distinguish a standard from the one called primary, and sometimes the terms “secondary standard” and “working standard’ are used interchangeably. The term “tertiary standard” is used if there are three levels of standards deployed.

9.3 Visual Photometry

The earliest instruments for measuring luminous quantities depended on visual appraisal [3] [4]. Such methods lacked both precision and accuracy, largely because the results were dependent on the individual observers making the measurement. Even for a particular observer, measurement reproducibility was limited because a number of variables influencing the measurements could not be controlled or explained. These visual methods are now rarely used, having been replaced with photometric measurements made using calibrated physical instruments that respond to optical radiation. However, visual assessment is still a fundamental part of the psychophysical investigation of visual perception, and forms the foundation of the process that leads eventually to quantification of perceptual effects.

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9.4 Physical Photometry

The development and standardization of the V(λ) function has allowed visual assessment to be replaced with a physical one: radiometric detection, spectrally modified to mimic the V(λ) function. Devices with a spectral response like that of V(λ) provide the basis for physical photometry.

9.4.1 Detectors

There is a broad range of detectors available and the best detector for an application depends on the requirements of spectral response, geometry, and quality. The characteristics of the signal, such as signal-to-noise ratio, amplitude, time response, and frequency bandwidth, all influence the suitability of a detector. The detector system's linearity range, field of view, noise equivalent power, and window transmission, as well as other factors, affect the measurements it can reliably make.

9.4.1.1 Phototubes

A phototube is a vacuum- or gas-filled glass tube containing a photoemissive surface as the source of electrical current. Photons striking the photoemissive surface release electrons by the photoelectric effect, and those electrons are collected by an anode having a higher voltage. The most useful form of phototube for photometry is the photomultiplier tube (PMT).

PMTs employ a photocathode, which emits electrons when irradiated. The spectral sensitivity of a photomultiplier tube depends on the entrance window and photocathode material, for which many choices are available. When photons strike the photocathode, electrons are emitted and then accelerated through a series of electron multipliers (dynodes), where the signal is greatly multiplied. The electrons are collected by an anode, where the output current is measured. A voltage divider chain connects the elements in the PMT in such a way that electrons are accelerated from one stage to the next. Typical PMT designs employ several to 15 stages of dynodes and produce signal gains from several thousand to hundreds of millions. The voltage required to operate the PMT can vary from 500 to 2000 V, depending on the tube construction and number of dynodes. The overall gain of the PMT is controlled by the voltage applied between elements. A high degree of voltage regulation is required for accurate operation. PMT offer the highest sensitivity and are used when extremely low amounts of light are measured.

PMT detectors produce an output signal (dark current) in the absence of light, due to thermionic emission. The dark current can be reduced by lowering the temperature of the PMT. Most PMTs exhibit gain differences when exposed to magnetic fields or when their orientation in the earth's magnetic field is changed. Magnetic shielding is required in most applications. Most PMTs are shock sensitive, and rough handling can cause failure or loss of previous calibration. All phototubes have highly selective spectral response characteristics. Depending on the photoemissive cathode material used, a phototube can be used for UV, visible, or near-IR measurement; however, a single phototube cannot cover this entire spectral range.

9.4.1.2 Solid-State Detectors

Solid-state detectors comprise a very large category of detectors incorporating semiconducting materials. All exhibit similar spectral response characteristics; their sensitivity to longer wavelengths increases up to a photon energy limit, where the detector response drops to zero. The useful spectral ranges of solid-state detectors extend from the UV to the far IR region. Photodetectors may be used in the photovoltaic mode, where the short-circuit current is measured, or in the photoconductive mode where a reverse bias voltage is applied and the device is treated as a radiation-sensitive variable resistor.

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Silicon photodiodes are commonly used in laboratory and commercial photometers. They offer a broad spectral range and the ability to measure low levels of radiant power. A silicon photodiode is combined with a glass filter to match its spectral response to the V(λ) function. Silicon detectors are also used in self-scanning linear arrays, facsimile (fax) machines, spectral measuring instruments, and two-dimensional charge-coupled devices (CCDs).

Photodiodes perform best when operated as current sources into zero-impedance amplifier circuitry. The linearity of silicon photodiodes has been shown to extend over 10 decades with appropriate amplification. Because very small currents are involved (typically 10^{-13} to 10^{-3} A), proper amplifier design is essential for the performance of these photometric instruments. Test methods, classes, and performance characteristics have been standardized [20].

9.4.2 Detector Spectral Response

The detector is the primary component affecting the spectral response of a radiant-power-measuring instrument. Photomultiplier tubes (PMTs) and silicon photodiodes are the most commonly used detectors in radiometers and photometers. These detectors respond differently to different regions of the spectrum. The spectral range of the detector is matched to the spectral region to be measured. This significantly improves sensitivity and relieves the burden of filtering. Photometers require suppression of UV and IR.

The native relative spectral response of detectors does not match the V(λ) function and so they cannot directly determine photometric quantities. Spectral filtering is used to produced a combined detector-filter response that closely matches the V(λ) function. A measure of the closeness of this match can be calculated using the CIE parameter f_1'. See 9.6.1.1 Spectral Correction Error, f_1' and 1.2.2 Spectral Power Data.

Some instruments are designed to measure CIE tristimulus values and calculate chromaticities. They use detectors that must be filtered to produce combined detector-filter responses that match the X(λ), Y(λ), and Z(λ) color matching functions [5]. See 6.1.5.5 XYZ Color Matching Functions.

Spectral response is particularly important when relatively narrow wavelength band sources are involved [6] [7] [8], such as the LEDs that radiate saturated colored light.

9.4.3 Environmental Factors

The environment and conditions of use affect detector performance. Temperature, magnetic and electric fields, and pulse or transient effects can change detector sensitivity, noise and dark current, cause drift.

9.4.3.1 Temperature Effects

Temperature variations affect the performance of all photodetectors. Silicon photodiodes are affected only slightly by temperature; however, problems can arise from the effects of temperature on detector response. The transmission of the spectral correction filters can also be affected by temperature. Hermetically sealed detectors provide protection against the effects of humidity and some insulation against temperature cycling. Care should be taken that the effects of high temperature or temperature cycling do not damage cemented layers of the detector filter.

PMTs are quite temperature sensitive. Both dark current and noise increase at higher temperatures. Also, the spectral response can vary significantly with temperature changes. Thermoelectric temperature control is frequently used to control the dark current, noise, and spectral characteristics of PMTs.

9.4.3.2 Transient Effects

Silicon photodiodes typically exhibit microsecond rise times and no fatigue. The rise and fall times for most photometers employing silicon photodiodes are usually limited by the am-

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plification circuitry. PMTs have nanosecond rise times but exhibit hysteresis, that is output overshoot or undershoot, requiring from seconds to minutes to adapt to large light-level changes. Precision radiometers and photometers usually employ PMTs with minimum hysteresis.

9.4.3.3 Effect of Pulsed or Cyclical Variation of Light

Electric discharge sources flicker when operated on alternating current (AC) power supplies. Precautions should be taken with regard to the effects of frequency, pulse rate, and pulse width when measuring the luminous properties of lamps [9]. It cannot be assumed that an instrument will treat modulation of a light source in the same way as the human eye. The internal capacitance of the detector and the response time of the amplifier to pulsating signals must be considered. Special metering circuitry for the integration of pulsed light is available for the measurement of flashing sources [10].

9.4.3.4 Magnetic Fields

As previously noted, radiometers and photometers containing PMTs can be affected by strong magnetic fields. Commercial instruments containing PMTs use magnetic shielding adequate to protect them from most ambient magnetic fields; however, it is advisable to keep them away from heavy-duty electrical machinery.

9.4.3.5 Electrical Interference

With electronic instrumentation, electrical interference can be induced in the leads between the detector and the instrumentation. This effect can be minimized by using filter networks, shielding, grounding, or combinations of the above.

9.5 Absolute, Relative, and Substitution Photometry

The photometric properties of equipment and materials can be absolute or relative, and determined directly or by the method of substitution.

9.5.1 Absolute Photometry

Absolute photometry measures and reports quantities as they are actually produced by the equipment being measured, in whatever state that equipment might be, or whatever the operating or measurement conditions. No corrections, other than instrument calibration, are used. Measurements are made with instruments calibrated from standards to report absolute photometric units. It is recommended that all LED luminaires be photometred using absolute photometry [38].

9.5.1 Relative Photometry

Relative photometry scales measurements to some presumed level of lamp output or other per-unit basis. In this case, instruments or detectors need not be calibrated absolutely. Rather, relative measurements of the equipment under test are made. Another (often just one) separate measurement is then made with the same instrument using a source with an assumed output. The relative measurements are then scaled based on this second measurement.

9.5.2 Substitution Photometry

Substitution photometry is the sequential measurement of a photometric property of a standard and then of the same property of the object being tested, using the same (to the extent possible) measurement instrument and geometry. The instrument does not have to be calibrated in absolute units. Knowing the photometric property of the standard and the ratio of the two measurements, determines the photometric property of the object being tested. Luminous flux, intensity, reflectance, and transmittance are often measured by substitution photometry.

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9.6 Instruments and Accuracy

Instruments for photometric and radiometric measurement are defined by their application. An instrument can be used as a stand-alone system such as an illuminance or luminance meter, or combined with auxiliary equipment such as an integrating sphere to form a lamp flux measurement photometer. Instruments exhibit a considerable range in precision and accuracy; from custom built equipment in a national metrology laboratory, to commercially available, inexpensive, portable meters used for field measurements. The most common types of instruments are:

- Spectroradiometers
- Illuminance meters
- Spot and image luminance meters
- Integrating spheres
- Distribution goniophotometers
- Reflectometers

Of these instruments, spectroradiometers, integrating spheres, and distribution goniophotometers are specialized instruments usually used in a laboratory. Others are much more common and often used by lighting professionals in various aspects of their work. Accuracy assessments have been developed for these instruments and occasionally a comparison survey is conducted and reports [7] [8] [20]. The accuracy measures important for these instruments are as follows, designated by the CIE as f1 through f5. Other factors have been defined but are less common.

9.6.1 Factors for All Instruments

Some factors affecting accuracy are common to all photometric instruments. Those that have standardized are spectral correction, linearity, display error, and fatigue. These are designated f_1', f_3, f_4, and f_5 respectively.

9.6.1.1 Spectral Correction Error, f_1'

f_1' is an error determined with respect to CIE Standard llluminant A (a blackbody radiator at 2856K). The f_1' is evaluated by adding the absolute values of the deviation of the detector's relative spectral responsivity from the V(λ) function. That is, if a detector is more sensitive in the blue and less sensitive in the red than the V(λ) curve, the respective positive and negative errors do not cancel out when summed. CIE Publication No. 69 characterizes f_i' as "the degree to which the relative spectral responsivity curve $s(\lambda)_{rel}$ [of the detector] matches the spectral luminous efficacy curve V(λ) of the human eye for photopic vision." The spectral correct error f_1' is defined as:

$$f_1' = \frac{\int_{\lambda} |s^*(\lambda)_{rel} - V(\lambda)| d\lambda}{\int_{\lambda} V(\lambda) d\lambda} 100 \qquad (9.1)$$

Where:

$s^*(\lambda)_{rel}$ = normalized relative spectral responsivity of the detector

The normalized relative spectral responsivity of the detector is determined by an assessment that compares it to CIE Illuminatn A:

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$$s^*(\lambda)_{rel} = \frac{\int_{\lambda} S(\lambda)_A \, v(\lambda) d\lambda}{\int_{\lambda} S(\lambda)_A \, s(\lambda)_{rel} d\lambda} s(\lambda)_{rel} \tag{9.2}$$

Where:

$S(\lambda)_A$ = spectral distribution of illuminant A
$s(\lambda)_{rel}$ = relative spectral responsivity of the detector
$v(\lambda)$ = photopic luminous efficiency function of wavelength

9.6.1.2 Linearity Error, f_3

The linearity of a detector is a property describing how constant the ratio of light input to detector output is over a measuring range of the photometer. An illuminance meter that measures from 0.1 to 100 lx could have three such measuring ranges: 0.1-1 lx, 1-10 lx, and 10-100 lx. For each range of measurement, the error term $f_3(Y)$ is calculated; the largest of the three terms is then given as the nonlinearity error, f_3, for the photometer. Generally, most detectors are linear over a specific range and become nonlinear outside set limits. That range should be stated. Also, the linearity of a detector may be affected by the electronic circuitry to which the output is being fed.

For each range of the photometer, the nonlinearity is characterized by linearity error f_3 defined as:

$$f_3(Y) = \left(\frac{Y_{output} \, X_{limit}}{Y_{limit} \, X} - 1 \right) 100 \tag{9.3}$$

Where:

$f_3(Y)$ = nonlinearity of a specific range
X_{limit} = maximum illuminance level of the range
X = (typically) 1/10 maximum illuminance level of the range
Y_{output} = photometer reading for input X
Y_{limit} = photometer reading for input X_{limit}

Then $f_3 = f_3(Y)_{max}$.

9.6.1.3 Display Error, f_4

For digital meters display uncertainty (usually ±1 digit), the maximum value of the display (1999 for a 3½-digit display), and the analog-to-digital (A/D) converter error are considered. Display error f_4 is defined as:

$$f_4 = \left(|f_{display}| + \frac{|k \, d|}{|P_{max}|} \right) 100 \tag{9.4}$$

Where:

$f_{display}$ = A/D readout display error (from manufacturer)
k = range change factor (that is, 10 for one decade)
d = display uncertainty
P_{max} = maximum value of the display

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9.6.1.3 Fatigue Error, f_5

Fatigue is a change in the detector's responsivity, usually decreasing with higher levels of incident light but recovers at lower levels. Fatigue is prominent in selenium detectors. Silicon photodiodes normally do not have fatigue other than by temperature effects. The changes are temporal and reversible. Other factors are at work when considering fatigue:

- Spectral responsivity may change.
- Detector heads suffer from temperature effects (a) as well as fatigue when irradiated at high levels.
- Thermostatic control of the detector head does not necessarily eliminate fatigue or temperature effects.

To calculate f_5, the detector first should be kept in the dark for 24 hrs before the test. The photometer is then set at a distance from a source (stabilized illuminant A) such that the maximum allowable level of illuminance is falling on the sensor. Detector output measurements are then made after 10 s and 30 min. Fatigue error f_5 is defined as:

$$f_5 = \left(\frac{Y_{30\ \mathrm{min}}}{Y_{10\ \mathrm{s}}} - 1\right)100 \tag{9.5}$$

Where:

$Y_{30\ \mathrm{min}}$ = detector output after 30 min
$Y_{10\ \mathrm{s}}$ = detector output after 10 s

9.6.2 Illuminance Meter Cosine Response Error, f_2

Cosine response means that the detector's output is in direct proportion to the cosine of the angle at which the optical radiation is incident on the photometer head. Standard illuminance measurements at a plane typically are made using a detector head having cosine response. With the detector placed in front of a stable point source, the procedure for calculating f_2 is a matter of rotating the detector from 0 to 85 degrees, measured with respect to the normal to the face of the detector, and recording data at, say, 5-degree intervals. The cosine correction error f_2 is defined as:

$$f_2 = \sum_{\theta\,=\,0^\circ}^{85^\circ} \left| \frac{Y(\theta)}{Y(0^\circ)\cos(\theta)} - 1 \right| 100 \tag{9.6}$$

Where:

$Y(\theta)$ = signal output as a function of angle of incidence
$Y(0^\circ)$ = signal output at normal incidence
θ = angle of incidence measured from the perpendicular to the detector plane
Angular increments depend on the precision of determination of f_2

9.6.3 Luminance Meter Surround Field Error, $f_2(u)$

Luminance meters are designed to measure light within a specified acceptance angle. However, no optical system can completely eliminate all stray light, or flare, outside that acceptance angle. The stray light splashing into the acceptance angle represents another source

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of error. $f_2(u)$ is a measure of how well the luminance meter baffles light from outside the acceptance angle. The method for determining this error involves a measurement with and without a gloss trap (opaque, diffuse, black material) in front of a uniform luminance source, which is at least 10 times as large as the acceptance area. The gloss trap is 10 percent larger than the acceptance angle. The surround field error $f_2(u)$ is defined as:

$$f_2(u) = \frac{Y(\text{surround})}{Y(\text{total}) - Y(\text{surround})} 100 \tag{9.7}$$

Where:

Y(surround) = detector output for measurement with gloss trap in place
Y(total) = detector output of total field

For luminance meters, detector response is also characterized by $f_2(g)$, which defines the uniformity of response of the detector (that is, it's spatial symmetry). Some areas of the detector surface may be more or less sensitive than the whole of the rest of the sensor.

9.7 Measuring Spectra

Spectral measurements refer to assessments made that account for the wavelength of the optical radiation involved and are among the most fundamental measurements that can be made of the optical radiation from light sources and of the optical properties of materials that interact with optical radiation.

There are different types of spectral measuring systems to suit specific applications, but they all generally incorporate the following elements:

- Collection optics to receive and limit the radiation to be measured,
- A monochromator that disperses radiation coming through an entrance slit and selects a narrow range of wavelengths that it sends to a detector,
- A detector or detector array,
- Electronics to process the detector or array signal, and
- Some type of display and electronic data output connection.

All together such a system is called a spectroradiometer. The monochromator houses a dispersing element, often a diffraction grating, which separates the various wavelengths of the input spectrum. The monochromator has an entrance aperture, usually in the form of a rectangular slit, through which the collected radiation enters; maybe some optical elements that image the entrance slit onto the dispersing element(s); and an exit slit through which selected wavelengths of the dispersed radiation pass.

In most spectroradiometers an array of irradiance detectors is positioned at the exit slit to measure the radiant power of the source at wavelengths throughout the optical spectrum.

Detector array spectrometers acquire spectral data simultaneously without mechanical moving parts. In modern instruments, photodiode arrays [11] are used in which each diode element, or line of diode elements, detects incident radiation in a narrow wavelength band, responding to the irradiance produced by the monochromator in that band. The wavelength resolution depends on the sensitivity of the detector and the narrowness of the bands. High dispersion gratings and narrow array elements permit spectral resolutions to ½ nm.

Silicon photodiodes do not exhibit a spectrally flat response and so array detector spectroradiometers have internal data processing capabilities to account for the varying

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sensitivity of the array diode elements through the optical spectrum. Other calibration parameters are handled electronically as well. Electronically scanned silicon photodiode arrays provide nearly instantaneous determination of a spectral power distribution [12]. Figure 9.1 shows a schematic diagram of a diffraction spectroradiometer and array detector.

In some high precision, high sensitivity instruments, the detector is a photomultiplier tube that is fixed at the exit slit of the monochromator. The spectrally dispersed output of the monochromator is swept across the exit slit by mechanically rotating the dispersion element. Industry guidelines and standards exist for spectroradiometric measurements, covering instrumentation, calibration and measurement procedures, and data reduction [13] [14] [15].

9.7.1 Using Spectroradiometers

Spectroradiometers are used in several ways:

- Measure relative and absolute spectral power distribution (SPD) of sources, spectral radiance and irradiance, spectral reflectance and transmittance, and spectral scattering [16]. In each case the basic components are those outlined above, the difference being how radiation is sampled and what type of spectral comparison standard is required.
- Measure the relative spectral responsivities of detectors. Radiometric detectors should exhibit a spectrally flat response over a stated range of wavelengths. Photometric detectors should exhibit a spectral response defined by the photopic luminous efficiency function. In both cases, measurement equipment can be tested and/or components designed using spectroradiometric measurements.
- Used as spectrophotometers. In this case the spectral response is not flat but should be the photopic luminous efficiency function. In most modern spectroradiometers, this conversion from radiometric to photometric assessment is performed electronically, no adjustment or filtering is performed on the flux falling on the array detector. Although called a spectrophotometer because of its principal application to measurements in the visible spectrum, this type of instrument is often

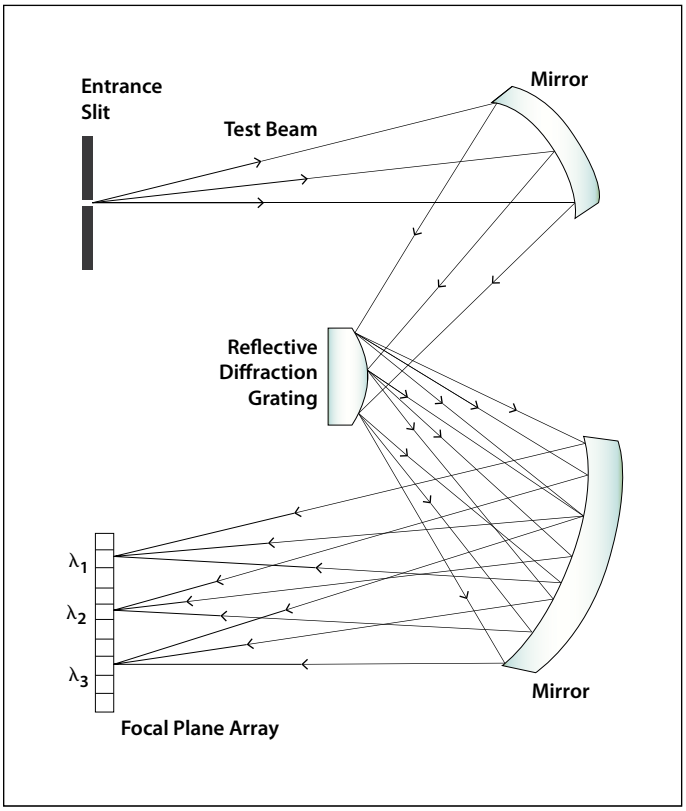


Figure 9.1 | Spectroradiometer
Schematic diagram of a spectroradiometer using mirrors and a diffraction grating as a monochromator and an array of silicon photodiodes as the full spectrum detector. Some implementations use only one mirror, others use a lens for spreading or focusing.

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designed for measuring UV and near-IR radiation. Some spectrophotometers are, in fact, designed specifically for UV or IR measurements.

The reduction in cost and size of electronic components and the increase in precision and reliability of diffraction gratings has permitted the development of very compact spectroradiometers. Portable spectroradiometers of for determining spectral radiance and luminance are now common.

9.7.1.1 Measurement of SPDs

A spectroradiometer is used to measure the SPD of light sources. Two methods are usually employed. In the first, the collection optics of the system directs optical radiation into a small integrating sphere or diffuser plate positioned in front of the entrance slit of the monochromator. This geometry is typically used to measure the spectral irradiance of a light source. In the second method, the optics of the system directs radiance from a uniform source integrating sphere, an irradiated highly reflecting diffuse target, or a diffusely emitting lamp, into the entrance slit of the monochromator.

By convention, relative SPD graphs are normalized so that their peak power is equal to 100, though in some cases relative SPD graphs are normalized so that the value at 560 nm is equal to 100 [17]. The wavelength bandwidth depends on the instrument used and the requirements of the data. See 1.4.2 Spectral Power Data for a discussion of the SPD data significance and presentation.

9.7.1.2 Spectral Reflectance and Transmittance

A spectrophotometer is used to determine spectral reflectance and transmittance properties of materials. In some reflectance instruments, standards are used to permit comparison of optical radiation reflected from a standard to that of a measurement sample, through individual wavelength bands.

Spectral transmittance is often done by splitting the beam of narrow band optical radiation from a monochromator into two and passing one through the sample to be measured. Comparison of the two beams reveals the absorption of the sample in that narrow wavelength band. See 1.5.1.1 Reflection and 1.5.1.2 Transmission for examples of spectral reflectance and transmittance data.

Spectral reflectance may vary with incidence and exitant directions. Standards have been developed for spectral reflectance and transmittance measurement conditions and procedures [18], specifically when these quantities are used in determining object color and to provide a means of examining the color of a material for analysis, standardization, and specification [19]. See 6.1.3 Object Color.

9.8 Measuring Illuminance

Because illuminance recommendations are a common and important part of lighting design, illuminance is the most common type of photometric measurement made. They are also common because illuminance is conceptually simple. Illuminance measurements are used to verify lighting system performance and achievement of design goals.

9.8.1 Illuminance Meters

Since illuminance measurements are relatively common, commercial illuminance meters are available in a wide range of quality and capability. The simplest illuminance meters consist of a photodiode with a photopic correction filter. The photodiode is connected to an operational amplifier with a display. These can be bench top, rack mountable, or portable. They can be enclosed in one case, or, as is more common with laboratory photometers,

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the detector and filter can be in one module that is connected by a cable to a console, at a convenient distance, containing the amplifier and display. The electrical scheme can be anything from a simple amplifier with manual controls to a programmed microprocessor with routines for calibration, measurement, and conversion of display units. Some meters include communication ports for remote operation and data manipulation. Examples of commercial instruments are shown in Figure 9.2.

9.8.2 Angular Response

By definition, illuminance meters should exhibit a response to incident flux that decreases as the cosine of the angle of incidence. Flat detectors and response-correcting filters do not have this type of response, and so the detector of an illuminance meter is usually specially configured to come close to the so-called cosine response. Detectors used in most illuminance photometers now have diffusing covers or some means of correcting the readings to a true cosine response. Solutions to the cosine problem include placing over the detector a flashed opal glass, diffusing acrylic disk, or an integrating sphere with a knife edge entrance port. With flashed opal glass and the diffusing acrylic disk at high angles of incidence, however, light will reflect specularly, so that the readings remain too low. This can be compensated by allowing light to enter through the edges of the diffuser. The readings at very high angles will then be too high but can be corrected by using a screening ring. The addition of auxiliary optics to improve cosine response can affect the photometric and directional response. CIE [20]

Illuminance meters of low quality can exhibit inaccurate response at large angles from the normal, with errors as much as 25% below the true illuminance value. This can be important when making illuminance measurements in a daylight space with strong sidelighting. Measurements of illuminance produced by light from high incidence angles can be in serious error if the illuminance meter has poor spatial response correction at high angles. Similar problems can arise in measurements of roadway and sports field illuminance from distant luminaires.



Figure 9.2 | Illuminance Meters
Commercial handheld illuminance meters. Integral detector head (right) and external remote detector (left).
» Image ©Konica Minolta

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Even with good spatial response correction, the illuminance meter head must be level or accurately parallel to the intended measurement plane. This is particularly important during photometry of lighting systems where light is received from one or a small number of discrete sources, such as in roadway lighting. Instruments are available in which the detector is gimbal mounted and self-leveling. This removes problems when trying to measure horizontal illuminance on uneven or sloping surfaces.

9.8.3 Spectral Response

Most illuminance meters alter the spectral response of the detector element with specially constructed spectral filters that, when combined with the detector produce a system with a spectral response that approaches the V(λ) function. See 9.4.2 Detector Spectral Response.

9.9 Measuring Intensity

Luminous intensity is almost always determined in an indirect manner: a value of intensity is inferred using the inverse square cosine law, an illuminance measurement, and the distance at which the illuminance measurement is made. That is, the effective luminous intensity is determined. See Equation 5.4 in section 5.7.2.1 Equivalent Luminous Intensity. For almost all equivalent luminous intensity determinations

$$I = E D^2 \tag{9.8}$$

Where:

E = illuminance measured as produced by the source
D = test distance from source to the plane of the illuminance measurement

This assumes that the plane of the illuminance measurement is perpendicular to a line from the source to the illuminance detector, and that the source is essentially a luminous point. For large sources this process gives the equivalent luminous intensity. See 5.7.2 Luminous Intensity and 10.3.1 Luminaire Photometry for Calculations.

In most cases, far-field luminous intensity is determined and this requires a test distance significantly larger than the largest luminous dimension of the source. For architectural luminaires, this can involve test distances greater than 8 m (25 ft).

9.9.1 Optical Bench Photometry

Sources can be measured on an optical bench photometer if either the luminous intensity in a particular direction or a mean horizontal luminous intensity is desired. Optical bench photometers provide a means for mounting sources and detectors in proper alignment and a means for easily determining these relative distances between them. If the source is of unknown luminous intensity is distant enough from a calibrated detector so that its radiation can be treated spatially as if it were emanating from a point, the inverse square law can be used to compute the unknown intensity from the illuminance determined by the calibrated detector. This is a determination of absolute luminous intensity.

9.9.2 Distribution Photometry

A series of luminous intensity measurements around a source characterize its intensity distribution. These measurements are made with a combined photometer and goniometer, usually referred to as a goniophotometer. The source can be a lamp or a luminaire. The intensity is determined at a series of positions around the source at a set

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of angles spanning directions appropriate for the source, and at sufficiently small intervals to provide a density of information consistent with the intended use of the data and the nature of the source. The coordinate system used for these angles depends on the construction of the goniophotometer and the types of sources it is intended to measure.

As described in 8.4.2.1 Luminous Intensity Distribution, there are three common types of angular coordinate systems used in distribution photometry, Type A, Type B, and Type C [21]. As a practical matter, most distribution photometers involve the coordinate system of Type C and if photometric data is required in Type B form, it is provided by interpolating the Type C data. The Type A system is widely used for automotive device photometry.

Distribution photometers for relatively small sources require concomitantly small test distances and the instruments can be relatively compact and fit into small laboratory

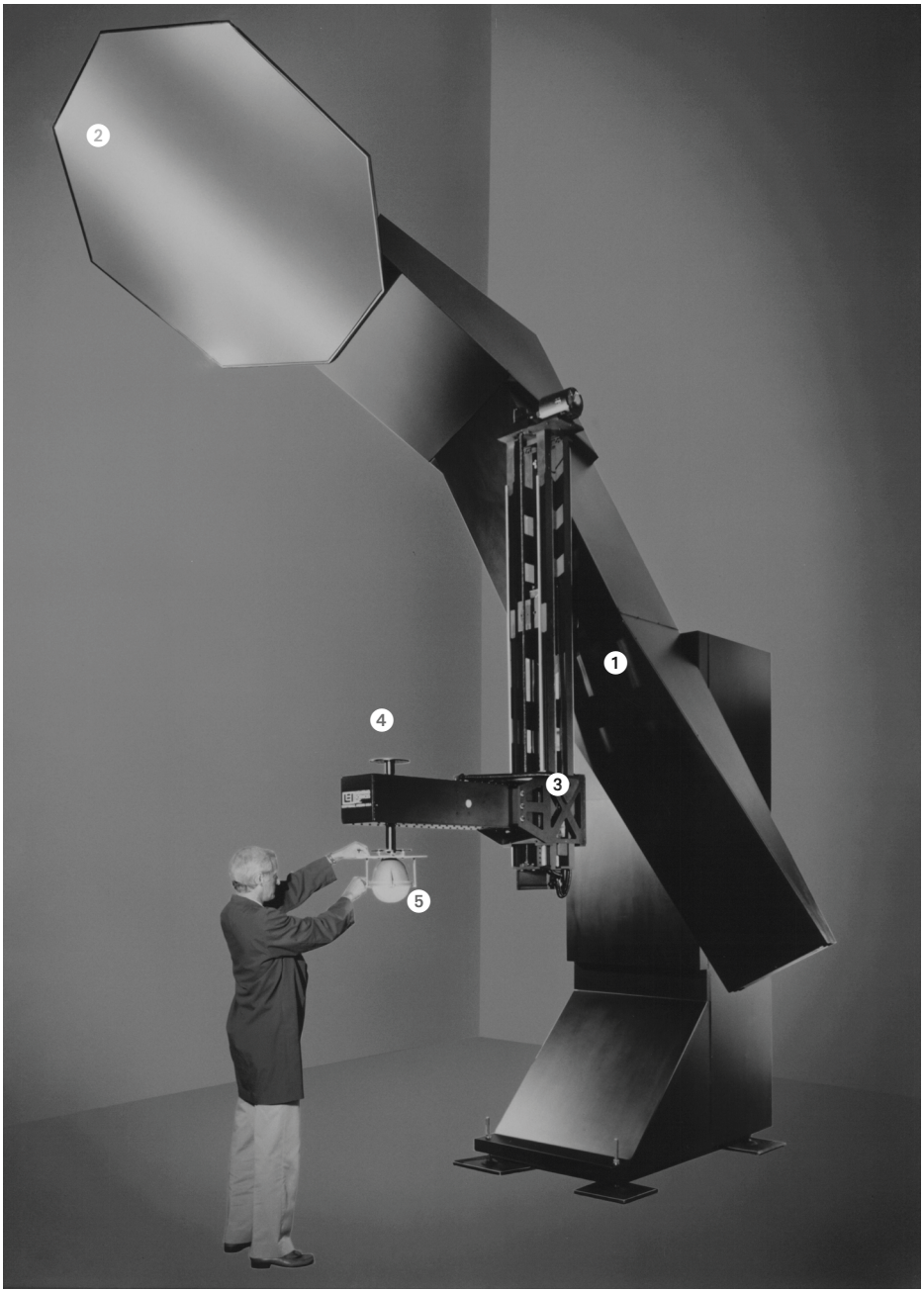


Figure 9.3 | Goniophotometer
Commercial goniophotometer with fixed luminaire position and rotating mirror. The operator is adjusting a luminaire on the mount, which is lowered for servicing. During measurements, the mount is raised along the vertical track to bring the photometric center of the luminaire in line with the rotation axis of the mirror.

1. Principal mirror rotation axis
2. Mirror
3. Luminaire mount, moves luminaire horizontally and vertically to position luminaire at the intersection of the two centers of rotation of the goniometer; which is the photometric center.
4. Azimuthal rotation axis of the luminaire
5. Test luminaire

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spaces. Architectural lighting equipment is often large and requires large test distances. For this reason, the most common type of distribution photometry used for the photometry of architectural lighting equipment is the moving mirror goniophotometer. In this instrument, the lamp or luminaire has a fixed position and rotates only about a vertical axis. This keeps the lamp or luminaire position with respect to gravity and thermal air motion fixed. An illuminance detector is in another fixed position. A mirror rotates about the lamp or luminaire to one of the required distribution directions, folding the optical path from the lamp or luminaire to the fixed detector. Figure 9.3 shows a commercial goniophotometer.

The use of mirrors in distribution photometers permits the positions of source and detector to remain fixed, and folds the optical path so that large test distances can be accommodated in relatively small spaces. The use of mirrors can be a source of error if the source being measured produces strongly polarized light, since the mirror reflectance can change significantly with the incident direction of strongly polarized light. Back surface mirrors can also introduce refraction and spatial errors that front surface mirrors do not.

9.10 Measuring Flux

Luminous flux measurements are used in lamp and luminaire photometry. Lamp lumens, luminaire lumens, and luminaire efficiency are equipment parameters requiring the determination of flux. Flux can be measured directly, as described in this section, or determined indirectly from a luminous intensity distribution, as described in 9.13.6.1 Zonal Lumens.

9.10.1 Integrating Sphere

The integrating-sphere photometer is used to measure the total luminous flux from a source. The most common type is the Ulbricht sphere [22]. The theory of the integrating sphere assumes an empty sphere whose inner surface is perfectly diffusing and of uniform nonselective reflectance. Every point on the inner surface then reflects to every other point, and the illuminance at any point is therefore made up of two components: the flux coming directly from the source and that reflected from other parts of the sphere wall. With these assumptions, it follows that the illuminance, and hence the luminance, of any

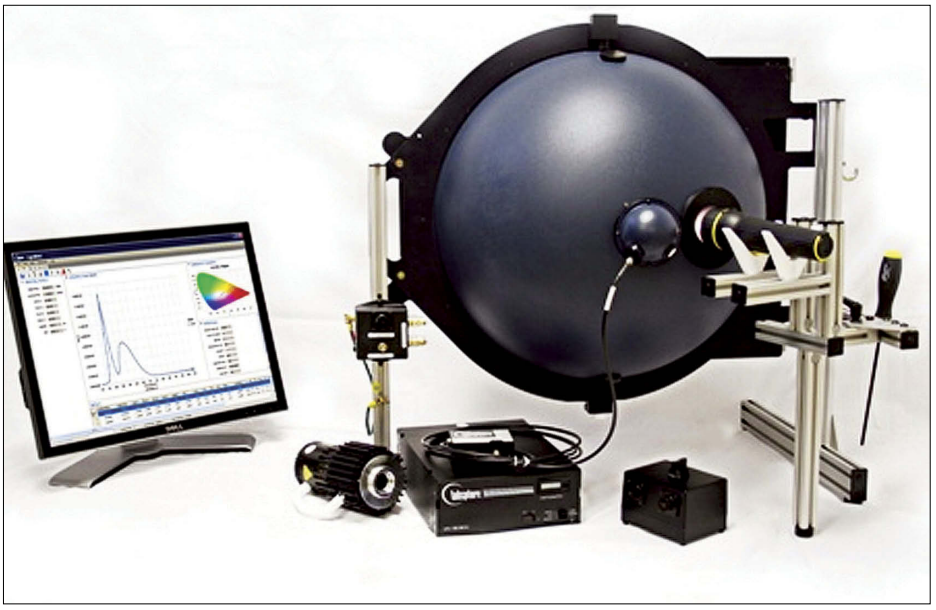


Figure 9.4 | Integrating Sphere
Commercial integrating sphere with remote source power and measurement display.
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part of the wall due to reflected light only is proportional to the total flux from the source, regardless of its distribution. The luminance of a small area of the wall, or the luminance of the outer surface of a uniformly diffuse transmitting window in the wall, when carefully screened from direct light from the source but receiving light from other portions of the sphere, is therefore a relative measurement of the total luminous flux from the source. Figure 9.4 shows the Ulbricht-type integrating sphere with a high-reflectance, diffuse white interior.

The presence of a source having finite dimensions, its supports and electrical connections, the necessary baffles or shields, auxiliary accessories, and the exit window or ports are all departures from the basic assumptions of the integrating-sphere theory. While durable high-reflectance diffuse material and coatings are now available for sphere interiors, none exhibits the ideal properties of perfect diffusivity and spectral nonselectivity. Despite these limitations, if the reference source and the test source are similar in shape, size, surface reflectance characteristics, and light distribution patterns, the errors introduced by an imperfect integration can be small. For accurate measurements of sources dissimilar from the reference source, corrections must be applied for self absorption, spectral mismatch, and spatial nonuniformity, which are inherent with integrating sphere lamp measurement photometry [23] [24].

An alternative to the substitution method uses an integrating-sphere with an external source, as shown in Figure 9.5 [25]. In this geometry the total luminous flux of a source in the integrating sphere is calibrated against an external reference source calibrated for illuminance, at an aperture outside the integrating sphere. The total luminous flux of the external source can be determined from the known illuminance produced by the external standard and aperture area. Additionally, other detectors can be connected to the exit port of the integrating sphere, creating integrating-sphere spectroradiometer, for example.

9.11 Measuring Luminance

Luminance meters are essentially illuminance meters with the addition of suitable optics to image an object onto the detector. They operate on the principle embodied in the equation relating illuminance, luminance, and solid angle:

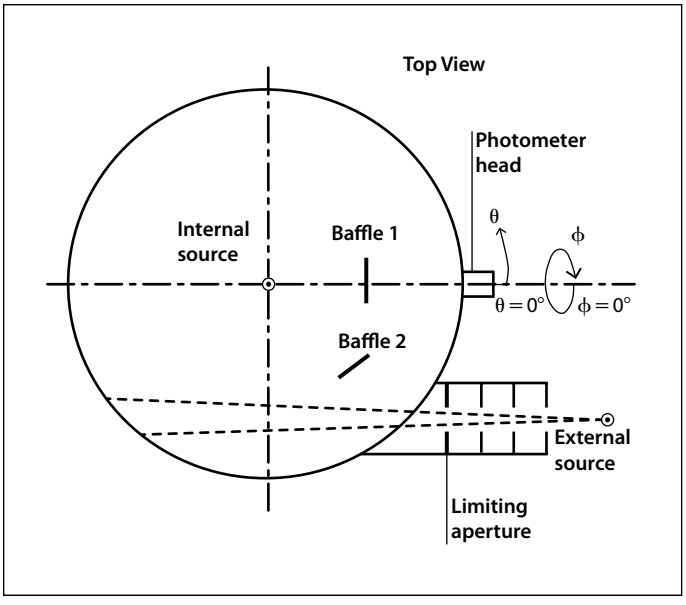


Figure 9.5 | Flux Measurement Using an Integrating Sphere
Research Standard integrating sphere using an external source of to measure flux from a source inside the sphere.

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$$E = L\,\Delta\omega\cos(\xi) \tag{9.9}$$

Where:

L = object luminance
$\Delta\omega$ = solid angle subtended by the source to the illuminance measurement point
$\cos(\xi)$ = cosine of angle between direction of object solid angle and perpendicular of the illuminance plane
E = illuminance produced by the object

If the plane of the illuminance measurement is perpendicular to the source, equation 9.9 can be rearranged as

$$L = \frac{E}{\Delta\omega} \tag{9.10}$$

That is, luminance can be determined from an illuminance measurement made through a limiting aperture of known solid angle.

In many luminance meters, a means of viewing the object is provided so that the user can see the area that is being measured as well as the surrounding field. Because of the similarity of this optical system to a telescope, these instruments are also called telephotometers.

Changing the focal length of the objective lens changes the field of view and the size of the measurement field. Some systems have apertures of various sizes to further define the measured area. Angular measurement fields from seconds of arc to several degrees can be selected.

Typically, modern luminance meters use silicon photodiodes or PMTs. The amplifier sensitivity may be either manually selected or automatic. Color filters can be incorporated for color measurements, and neutral density filters to extend the dynamic range.

Photodetectors are typically photodiodes for portable and low-sensitivity instruments and PMT for high-sensitivity instruments. Most instruments have at least a sensitivity dynamic range of four, and many incorporate attenuation screens or neutral-density filters for additional range. The electrical scheme can be anything from a simple amplifier with manual controls to a programmed microprocessor with routines for calibration, measurement, and conversion of display units. Some meters include communication ports for remote operation and data manipulation.

9.11.1 Spot Luminance Meters

A common type of luminance meter determines the luminance over a relatively small area, typically subtending 3° or less to the observation point.

9.11.1.1 Beamsplitter Spot Meters

This type of photometer employs a beamsplitter behind the objective lens which divides the incoming radiation into two paths. Approximately half of the radiation passes through the beamsplitter and is focused on an aperture defining the measurement field. The radiation passing through the aperture can be measured with either a PMT or a solid-state detector. The radiation reflected from the beamsplitter is focused on a reticle having an etched pattern with the same dimensions as the measurement aperture. A viewing system with an eyepiece allows the user to see the field of view and an outline of the area being measured. The reticle must be carefully aligned with the measuring field. Readings are usually in cd/m^2 or cd/ft^2. Some instruments may include colorimetric filter options. Field-of-view capabilities may range from 0.25° to 10°, with sensitivity ranging from 10^{-2} to 10^6 cd/m^2. Figure 9.6 shows a commercially available beamsplitter spot luminance meter.

Although good measurements can be made with this type of instrument, it does have some noteworthy disadvantages. Among these are loss of illumination to both the detector

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Figure 9.6 | Commercial Luminance Meters
A commercial beam-splitter spot luminance meter (left) and a commercial aperture mirror spot luminance meter (right). Both luminance meters require proper focusing to produce accurate measurements.
» Left Image ©Konica Minolta
» Right Image ©Photo Research

and the viewer; introduction of polarization, which affects the measurement of polarized sources; and the difficulty of changing apertures and reticles for different measurement fields. In general, a low-cost instrument using a beamsplitter will provide adequate but not exact location of the measured spot.

9.11.1.2 Aperture Mirror Photometers

Most of the problems of the beamsplitter spot meter are addressed by the aperture mirror photometer. There is no beamsplitter to introduce polarization error or reduce the brightness at either the measuring aperture or the viewed image. The image formed by the objective lens falls on an angled first surface mirror with a through hole for the measuring aperture. The viewing optics are focused on the aperture, which appears as a black circle. The field around the measurement aperture is clearly seen in the eyepiece. This arrangement allows apertures to be changed without the need to change precisely aligned reticles as well. A disadvantage of the aperture mirror photometer is that if a small source is imaged within the measuring aperture, it cannot be seen in the viewing optics. Instruments of this class usually employ high-quality detectors, one or more neutral-density range-multiplying filters, lens options, and some degree of colorimetric capability. They are available with internal microprocessor control and direct reading capability for luminance in several units, for color chromaticity coordinates, and for color temperature. The full-scale sensitivity for the best laboratory instruments ranges from 10^{-4} to 10^{8} cd/m^2. Figure 9.6 shows a commercially available aperture mirror spot luminance meter.

9.11.2 Digital Luminance Meters

Developments in imaging devices have provided a powerful tool for luminance measurements of complete scenes. Cameras equipped with a charge-coupled device (CCD) array are able to capture and digitize electronic images of visual scenes [26] [27] [28]. Providing the proper controls are applied, the digital image can be used to determine the luminance at every point in the scene, corresponding to the pixels of the camera's CCD array. Figure 9.7 shows an example of a commercial CCD-based luminance meter.

A complete photometric capture can be carried out and saved. As the information is provided in digital form, complicated functions of luminance images can be analyzed and reported for uniformity, contrast, spatial characteristics, and other photometric values. Some systems also provide chromaticity values.

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Figure 9.7 | Commercial Imaging Luminance Meter
A commercial imaging luminance meter.
» Image ©Photo Research



This form of photometry requires many factors to be controlled in the instrument and software if accurate results are to be obtained. The CCD and optical attachments must be of high quality. "Field flattening" adjustments are required for all lenses that spatially distort the image to at least some degree. To measure the complete dynamic range of luminances in most interior scenes, earlier 8-bit systems required capture of multiple images at different exposure settings. Today, 16-bit systems are available that cover a dynamic range of over 65,000:1. Cooling the CCD array may be needed for low luminances to reduce noise and dark current, to increase the detection limit, and to minimize effects of ambient temperature.

Applications for imaging photometers include the energy distribution of lamps (for example, floodlamps and automobile headlights), production line quality control, luminance uniformity of a projected scene, and complicated analyses of scene illumination.

9.12 Measuring Reflectance and Transmittance

Reflectance and transmittance are basic properties of architectural materials and are usually used to express the bulk properties of a material: total flux reflected or transmitted, in ratio to the flux incident. See 5.8.1 Reflectance and 5.8.2 Transmittance.

This section discusses spectrally integrated reflectance and transmittance. See 9.7.1.2 Spectral Reflectance and Transmittance for spectral measurements.

Generally, reflectance and transmittance are not simply a property of a material. Rather, they also depend on the measurement geometry, that is, the spatial relationship between the source and the detector. In some cases, bidirectional reflectance or transmittance is measured and specified, in others spatially integrated values are measured and reported.

9.12.1 Reflectometers and Transmitometers

Reflectometers are reflectance measurement photometers. Reflectance measurements typically fall under three categories: diffuse, specular, and a mix of specular and diffuse reflectances. The design of the reflectometer and the method of measurement depend on the reflectance properties of the sample material and what kind of the reflectance one desires to measure [29].

The fraction of the incident light reflected can be difficult to determine directly, particularly for diffuse reflection, and so in some cases reflectance is expressed as a *reflectance factor*:

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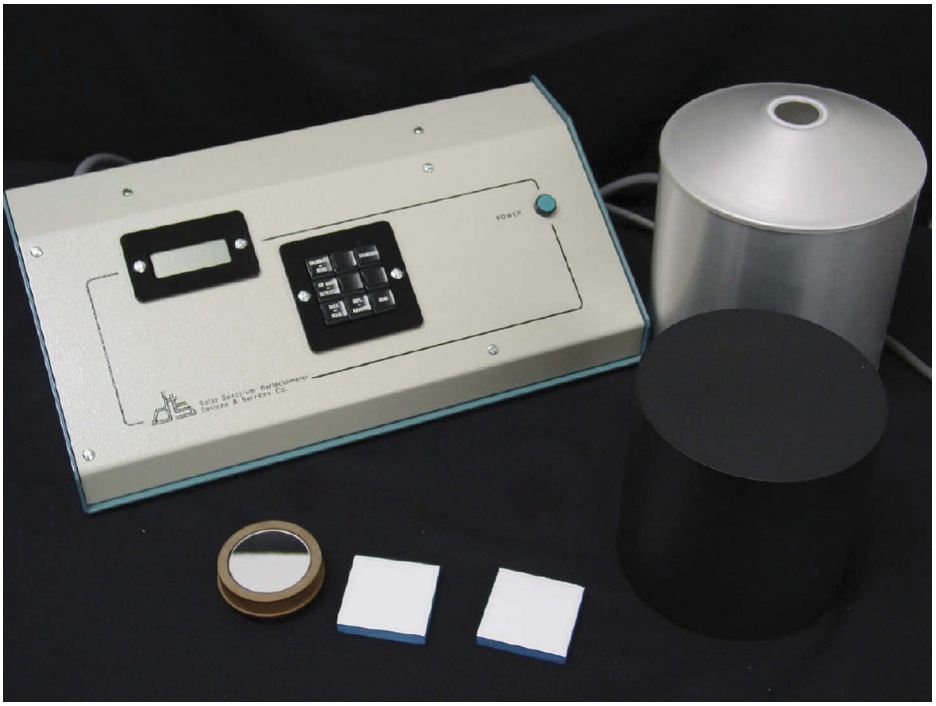


Figure 9.8 | Commercial Reflectometer
Reflectometers are often designed specifically for surface and finish measurements. This is a a Solar Reflectometer with multiple sources and fileters for the measurement of reflectance in the broad spectrum of optical radiation produced by the sun.
» Image ©Devices and Services

the ratio of the reflectance of a sample to that of a reflectance standard under the same measurement geometry. Three commonly used reflectance standards are a polished front surface mirror, a polished black glass having a specified index of refraction, and a total diffuse reflector (for example, $BaSO_4$).

In one method commonly used for measuring total reflectance, the sample is illuminated by a narrow cone of light from a given angle, typically 10° or less from the normal to the sample surface, and the reflected light is collected over the entire hemisphere surrounding the sample. Instruments of this type are said to employ a conical-hemispherical geometry. See 5.8.1 Reflectance. Figure 9.8 shows an example of a commercial reflectometer. The hemispherical flux collection is often accomplished by means of an integrating sphere with a detector, arranged so that it does not receive light reflected directly from the sample, but rather views the sphere wall. In this way the signal is proportional to the total flux reflected from the sample. A similar technique can be used to measure transmittance.

The same type of instrument also can be used to measure only that part of the light that is diffusely reflected. One example of a sample that one might measure in this way is one with a very smooth dielectric surface that reflects strongly by scattering from pigments or other inclusions beneath the surface. In this case, light specularly reflected from the sample is allowed to escape through an specular subtraction port in the sphere wall, where a light trap can be positioned to absorb the specular reflected beam.

For measuring color, a 45/0 reflectometer is often used to evaluate the spectral character of diffusely reflected light. The source and the detector are mounted in a fixed relationship in the same housing. Light is incident on the surface from an angle of 45°, and the detector is positioned above and normal to the sample surface.

Reflectances from plane samples can be measured in many ways. One method employs a reflectometer that compares, with the aid of an auxiliary mirror, the incident flux with the flux after two reflections from the sample. Such a reflectometer is often available as an accessory to commercial spectrophotometers. Another method employs a goniophotometer that allows the user to position the light source and detector at any known angle. In some

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models, the sample holder can also be repositioned Applications of the goniophotometer include measurements of gloss, luster, and haze.

Another type of instrument, the Taylor Baumgartner sphere reflectometer, measures total reflectance. It consists of an integrating sphere, light source, and a photodiode. The sample is placed at the sample port of the integrating sphere. A collimated beam of light is directed onto the sample from approximately 30° to the normal, and the total reflected light, integrated by the sphere, is measured by the photodiode mounted in the sphere wall. The collimated light source is then rotated so that the light is incident on the sphere wall, and a second reading is taken. The sample is in place during both measurements, so that the effect on both readings of the small area of the sphere surface it occupies is the same. The ratio of the first reading to the second is the reflectance of the sample for the conditions of the test. Samples of translucent materials should be backed by a light trap.

9.12.2 Field Measurement of Reflectance

The reflectance of an architectural surface in the field can be determined by the method of substitution and a standard reflectance card. Luminance measurements are made of a spot on, say, a wall. The standard reflectance card is placed over the same spot and its luminance is measured. The wall reflectance at that spot is approximately equal to the reflectance of the standard card times the ratio of the two luminance measurements, as shown in equation 9.11.

$$\rho_{surface} = \rho_{standard} \frac{L_{surface}}{L_{standard}} \tag{9.11}$$

Though useful, this approximation is subject to large error if the surface being measured is very specular or the illumination at the spot is highly directional.

9.13 Lamp Photometry

Lamp photometry is the measurement of various photometric properties of lamps operating under conditions usually consistent with typical applications. These properties can include total emitted lumens, intensity distribution, and spectral power distribution. Since lamps are electrical devices and their photometric properties are sometimes sensitive functions of electrical supply [30], the electrical operating characteristics and conditions of lamps are carefully noted and controlled during testing. Similarly, some lamps have photometric properties that are dependent on their operating temperature and therefore the operating temperature must be carefully noted and controlled during testing [31]. For these reasons, "lamp photometry" usually involves a considerable amount of electrical and thermal monitoring, testing, and reporting, in addition to the photometric testing.

Some lamps require auxiliary equipment such as starters, ballasts, or drivers. There is often, though not always, reference versions of this equipment that operates with reference performance and provides reference electrical conditions for the lamp being tested.

9.13.1 Characterizing Lamps

Lamps are characterized by their electrical, radiant, luminous, and life performance properties. See 7 | LIGHT SOURCES: TECHNICAL CHARACTERISTICS. Depending on the lamp type and the intended use of the data, lamp testing can include the following.

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Electrical properties:

- Operating, starting, and restrike voltages
- Electrode voltages
- Current
- Power
- Power factor

Radiant properties:

- Total efficiency
- SPD
- CRI, CCT, chromaticity coordinates

Photometric properties:

- Total flux
- Efficacy
- Intensity distribution
- Beam and field flux
- Flicker index

Life performance properties:

- Life
- Lumen depreciation

9.13.2 Lamp Testing

Lamp testing is usually intended to describe the photometric, radiometric, electrical, and thermal performance characteristics of a typical individual lamp from a relatively large population of commercially produced lamps of a single type. To the extent that all lamp manufacturing processes, however closely controlled, produce lamps of slightly varying characteristics, lamp testing is performed on a sufficiently large sample of lamps so that the resulting average performance can be reliably used as rated performance for that lamp type.

Many industry standard lamp types are produced by several different manufacturers, each using different materials, components, processes, procedures, and monitoring and test methods. Thus, lamps of the same type may have systematically different characteristics depending on the manufacturer not revealed by nominal lamp data. An example is a systematically different intensity distribution but with nearly the same total lumens.

Radiometric testing of lamps requires equipment beyond the instruments necessary for photometric testing and though not always the case, making ultraviolet radiation measurements can be hazardous when using sources designed for germicidal applications. Standards for spectroradiatometric and ultraviolet radiation describe the equipment, safety precautions, and test conditions for these measurements. [13] [32].

Most lamp types used in architectural lighting have an appropriate standard governing the equipment, procedures, test conditions, instrumentation, and test report contents to be used or provided in lamp photometric testing. In addition, proper lamp handling and seasoning before testing (expect for LEDs) is always part of good practice [33]. Standards governing all these issues are available for most lamp types. These include:

- Filament [34]
- Fluorescent [35]
- Compact fluorescent [36]
- High intensity discharge [37]
- LED [38]

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- Fiber optics [39]
- Low pressure sodium [40]

The determination of life performance properties for different lamps have appropriate standards governing, equipment, testing conditions, auxiliary equipment, lamp selection and sampling, pre-test procedures, lamp operating cycles, and report content. These include:

- Filament [41]
- Fluorescent [42]
- Compact fluorescent [43]
- High intensity discharge [44]
- Low pressure sodium [45]
- LED [46]

9.14 Luminaire Photometry

Luminaire photometry is the measurement of the properties of a luminaire, operating under standard test conditions, intended to provide data adequately describing the luminaire's performance and permitting its evaluation as part of the lighting design process. Some data are the direct result of photometric, electric, or thermal measurement; others are determined indirectly, using standard calculation procedures involving the primary data, and provide necessary application information.

9.14.1 Far-field and Near-field Photometry

Virtually all commercial luminaire photometry provides intensity distributions that are far-field. That is, the test distance used is greater than 5 times the largest luminous dimension of the luminaire. Though not usually noted, intensities produced this way are equivalent intensities. See 5.7.2 Luminous Intensity.

Near-field photometry has several forms, though it is commercially uncommon since its use for lighting calculations requires specialized application software, or special handling when incorporated into standard software [47]. Standards exist for near-field photometry of luminaires [48].

9.14.2 Absolute Luminaire Photometry

Absolute luminaire photometry involves luminous measurements made with detectors calibrated to provide direct assessment in absolute units. For example, the determination of absolute luminous intensity is made with an illuminance detector calibrated absolutely in lux. Thus, the determination of intensity, I, using the inverted inverse-square law, as in Equation 9.8, involves an absolute determination of the test distance, D, in meters and the illuminance, E, produced by the source in lux.

9.14.3 Relative Luminaire Photometry

Relative luminaire photometry provides an intensity distribution on a per unit basis. The basis is an assumed total lumen output of the lamp or lamps usually used in the luminaire. In this case, equivalent luminous intensities are determined from measurements made with detectors that are not absolutely calibrated. Instead of using 9.11, equivalent luminous intensity is determined from:

$$I = \mu\, k_{scale} \qquad (9.12)$$

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In this case, the detector generates an output signal, μ, that is assumed to be proportional to the luminous intensity of the source which, in turn, is proportional to the illuminance produced by the source and the square of the distance from the photometric center to the detector. Though not calibrated, it is necessary that the detector exhibit a linear response to the incident flux density. If relative intensities are determined from a series of measurements at a set of angular directions, then in general there will be a different scaling factor, k, for each measurement. If the test distance is constant and other operating factors are unchanged measurement to measurement, a single scaling factor can be used for all the data.

$$I(\theta,\psi) = \mu(\theta,\psi)\, k(\theta,\psi)_{scale} = \mu(\theta,\psi)\, k_{scale} \qquad (9.13)$$

Where:

$I(\theta,\psi)$ = equivalent luminous intensity in angular direction $(\underline{\theta,\psi})$
$\mu(\theta,\psi)$ = signal from the detector in angular direct (θ,ψ) at a fixed distance
k_{scale} = scaling factor for entire set of measurements

After the measurement of a set of relative values $\mu(\theta,\psi)$, the scale factor, k_{scale}, is determined by isolating the lamps used in the luminaire and assessing their actual (in distinction to their rated) lumen output. The combined effect of photometer calibration and unknown actual lamp lumen output is accounted for in k_{scale} [49]. Isolating lamps with sensitive thermal properties complicates this process considerably, sometimes making it difficult to determine other derived characteristics from this primary data [50]. For luminaires using LEDs, relative photometry should never be used [38].

9.14.4 Characterizing Luminaires

Luminaires are characterized by their luminous and application properties. Some luminous properties are measured directly, others derived by calculation from these basic measurements. Properties that can be aspects of luminaire testing include the following.

Photometric properties:

- Total flux
- Bare lamp output
- Intensity distribution
- Luminances

Derived photometric properties

- Zonal lumens
- Luminous efficiency
- Coefficients of utilization
- Spacing Criterion
- Beam and field flux
- Beam and field angles
- Various luminaire classifications

Other measured or tested properties

- Thermal performance
- Construction
- Water and vapor sealing
- Air-handling performance

9.14.5 Luminaire Photometric Testing

Luminaire photometric testing is usually intended to describe the photometric or radiometric performance characteristics of a typical individual from a relatively large

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population of commercially produced luminaires of a single type. Though it is ideal to photometrically test a sample of luminaires of a given type, this is rarely done. Luminaires submitted for photometric testing should be representative, but as a practical matter there is no way to be certain of this, other than extensive testing. Nevertheless, commercial luminaire photometry is usually a useful representation of how a large number of the same type of luminaire will perform. Most luminaire types used in architectural lighting have an appropriate standard governing the equipment, procedures, test conditions, instrumentation, and test report contents to be used or provided in luminaire photometric testing. These include:

- Indoor fluorescent [51]
- Outdoor fluorescent [52]
- Indoor HID [53]
- Indoor incandescent [53]
- Roadway [54]
- Floodlights [55]
- Searchlights [56]
- LED [38]

9.14.6 Derived Photometric Characteristics

Luminaire photometric reports usually contain performance data that is not measured directly, but calculated by standard procedures and listed as part of the photometric report.

9.14.6.1 Zonal Lumens

Zonal lumens describe the flux distribution of the luminaire using solid angle elements sized and shaped to the needs of the typical application for the luminaire and the coordinate system used for distribution photometry. Standards governing luminaire photometry define these sizes and shapes. Generally the lumens, Φ_{zone}, in a zone are calculated from

$$\Phi_{zone} = \int_{\Omega_{zone}} I(d\omega)\, d\omega \tag{9.14}$$

Where:

Ω_{zone}= solid angle of the zone, in steradians
$d\omega$ = differential element of solid angle in the zone
$I(d\omega)$ = luminous intensity in the direction of $d\omega$, in candela

Generally the lumens, Φ_{zone}, is almost always approximated by

$$\Phi_{zone} = \bar{I}\, \Omega_{zone} \tag{9.15}$$

Where:

Ω_{zone} = solid angle of the zone, in steradians
$\bar{I}$ = appropriate average luminous intensity over the zone

9.14.6.2 Luminaire efficiency and Photometric Efficiency

Luminaire efficiency is usually defined as the ratio of lumens emitted by the luminaire to the lumens emitted by the lamps. If relative photometry is used, then the lumens emitted by the lamps are, by definition, rated lumens. In some cases of relative photometry, lamp output is assumed to be 1000 lm. When relative photometric testing procedures are followed to determine rated lumens with the lamps outside the luminaire, the bulb wall temperature may be significantly below rated bulb wall temperature. Consequently, during

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this determination the lumen output is lower than rated lumens and lower than when the lamps are operating in the luminaire. This can produce a ratio of luminaire lumens to procedure-determined rated lamp lumens greater than 1.0 [57]. Thus, it is sometimes necessary to determine and use a luminaire thermal factor and the total photometric efficiency of the luminaire is the luminaire efficiency times the luminaire thermal factor.

9.14.6.3 Average Luminance

Depending on the form of the luminaire being tested, determining the apparent area to be used in the calculation of average luminaire luminance may require special attention to calculate and may not be simply a planar luminous aperture under foreshortening [58].

9.14.6.4 Beam Type and Characterization

Based on the intensity distribution and the subsequent determination of zonal lumens, the test luminaire can be assigned a classification for outdoor applications [59].

9.14.6.5 Coefficients of Utilization

Indoor

Coefficients of utilization are performance indicators used to predict average illuminances produced by luminaires typically arranged in uniform arrays. See 10.9.1 Calculating Average Illuminance for details concerning the determination of these coefficients.

Roadway

Coefficients of utilization are calculated for roadway luminaires for use in determining the average illuminance on a roadway. The calculations that use these value usually assume a uniform pole spacing [54].

9.15 Field Measurements

Evaluating a lighting installation in the field usually involves illuminance and luminance measurements at the site of the installation. The purpose of such measurements can be

- Validate design calculations
- Isolate problems in, and apparent differences between, expected and observed illuminance
- Complete a post-occupancy evaluation
- Assess an existing installation in advance of upgrading or retrofitting lighting equipment
- Provide a benchmark for renovation or expansion.
- Determine compliance with specifications or codes
- Reveal the need for maintenance, modification, or replacement

The purpose usually determines the type and extent of the measurements.

These evaluations usually take the form of a survey with illuminance (and less frequently luminance) being measured at enough carefully chosen positions in an installation to reliably determine averages and assess typical maxima and minima. Less frequently, measurements are required at essentially a single location. Good practice requires recording a complete detailed description of the surveyed area and all factors that might affect results, such as interior surface reflectances, presence of daylight from either sky or sun, ambient temperature, spot temperature of lamp or luminaire, stabilization time, presence of objects in the space, lamp type and age, voltage, and instruments used in the survey.

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Precautions and preparations common to most measurement surveys are:

- Using illuminance meters with adequate cosine and spectral correction
- Meters used at a temperature above 15°C (60°F) and below 50°C (120°F)
- Avoid casting shadows on the detector
- Stand far enough away from the detector, especially when wearing light-colored clothes, to prevent light from the source from being reflected onto it.
- A high-intensity discharge or fluorescent system must be lighted for at least 1 h before making measurements.
- Lamps should be seasoned before the survey is made: At least 100 h of operation for gaseous sources, and 20 h or less for common sizes of filament lamps.

9.15.1 Interior Measurements

Measurements in interior spaces are usually made for the purpose of evaluating an existing condition or to verify the performance of a new lighting installation. Average illuminance over large open areas is determined from measurements made at selected points. Illuminance at a point or small neighborhood of points is usually measured at specific task areas. Luminance measurements in interiors, though less common, are made to verify design ratios or investigate conditions that may lead to glare and veiling reflections.

9.15.1.1 Average Illuminance

Determination of Average Illuminance on a Horizontal Plane

The measuring instrument should be positioned so that when readings are taken, the surface of the detector is in a horizontal plane and 760 mm (30 in.) above the floor, or at whatever height is of interest. The area should be divided into approximately equal-sized squares, taking a reading in the center of each square and calculating the arithmetic mean. A measurement grid of 0.6 m (2 ft) is suitable for many spaces. Using a relatively dense rectangular grid of measurement locations is usually necessary in spaces that are obstructed, lack orthogonal geometry, or have highly nonuniform illumination. For spaces with unusual room cavity ratios or highly nonuniform illumination, as in corridors under emergency lighting conditions a denser grid of measurement points may be necessary.

For more uniform and symmetric rooms and luminaire positions, a uniform survey method for measuring and reporting the necessary data for interior applications as been developed [60]. The method has been found generally reliable to within an accuracy of 10%. It has the advantage of using weighted average of measurements made at select locations to minimize the number of measurements required. The room types suited for this survey method is shown in Figure 9.9.

Regular Area with Symmetrically Spaced Luminaires in Two or More Rows.

The average illuminance, $\bar{E}$, in such a space (See Figure 9.9a) can be determined from

$$\bar{E} = \frac{R(N-1)(M-1) + Q(N-1) + T(M-1) + P}{N\,M} \tag{9.16}$$

Where:

N = number of luminaires per row
M = number of rows
R = Average of measurements at: stations r-1, r-2, r-3, and r-4 for a typical inner bay and at stations r-5, r-6, r-7, and r-8 for a typical centrally located bay
Q = Average of measurement at: stations q-1, q-2, q-3, and q-4 in two typical half bays on each side of the room
T = Average of measurements at: stations t-1, t-2, t-3, and t4- in two typical half bays at each end of the room

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P = Average of measurements at: at stations p-1 and p-2 in two typical corner quarter bays

Regular Area with Symmetrically Located Single Luminaire

The average illuminance, $\bar{E}$, in such a space (See Figure 9.9b) can be determined from

$$\bar{E} = P \tag{9.17}$$

Where:

P = Average of measurements at: stations p-1, p-2, p-3, and p-4 in all four quarter bays

Regular Area with Single Row of Individual Luminaires

The average illuminance, $\bar{E}$, in such a space (See Figure 9.9c) can be determined from

$$\bar{E} = \frac{Q(N-1)+P}{N} \tag{9.18}$$

Where:

N = number of luminaires
Q = Average of measurements at: stations q-1 through q-8 in four typical half bays located two on each side of the area
P = Average of measurements at: stations p-1 and p-2 for two typical corner quarter bays

Regular Area with Two or More Continuous Rows of Luminaires

The average illuminance, $\bar{E}$, in such a space (See Figure 9.9d) can be determined from

$$\bar{E} = \frac{R(N-1)(M-1)+Q\,N+T(M-1)+P}{M(N+1)} \tag{9.19}$$

Where:

N = number of luminaires per row
M = number of rows
R = Average of measurements at: stations r-1 through r-4 located near the center of the area
Q = Average of measurements at: stations q-1 and q-2 located at each midside of the room and midway between the outside row of luminaires and the wall
T = Average of measurements at: stations t-1 through t-4 at each end of the room
P = Average of measurements at: stations p-1 and p-2 in two typical corners

Regular Area with Single Row of Continuous Luminaires

The average illuminance, $\bar{E}$, in such a space (See Figure 9.9e) can be determined from `

$$\bar{E} = \frac{Q(N-1)+P}{N} \tag{9.20}$$

Where:

N = number of luminaires
Q = Average of measurements at: stations q-1 through q-6
P = Average of measurements at: stations p-1 and p-2 in typical corners

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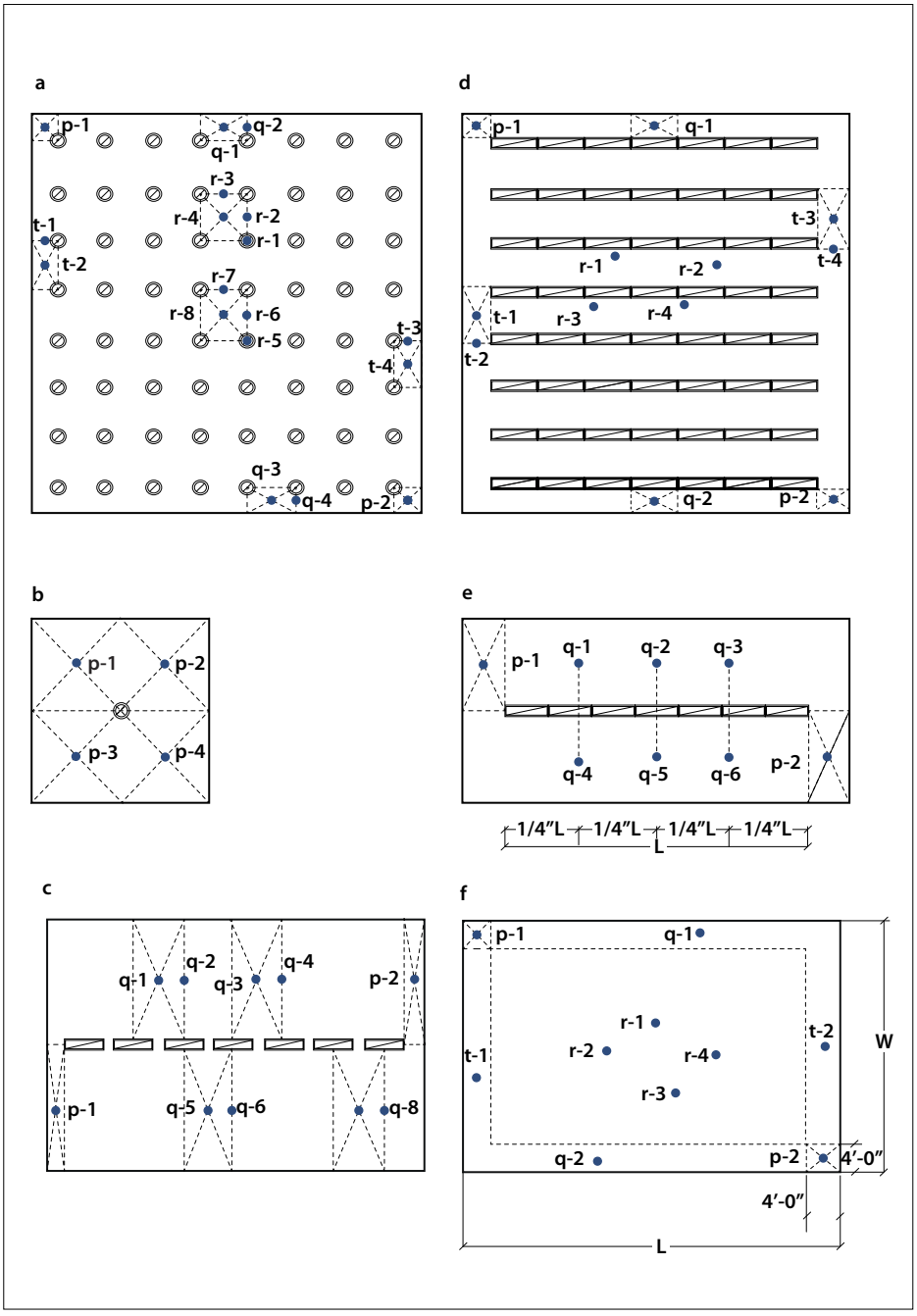


Figure 9.9 | IES Survey Measurement Stations
Locations of illuminance measurement locations for various rooms. a) regular area with symmetrically located luminaires. b) regular area with symmetrically located single luminaire. c) regular area with single row of continuous luminaires. d) regular area with two or more continuous rows of luminaires. e) regular area with single row of continuous luminaires. f) regular area with uniform indirect lighting.

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Regular Area with Uniform Indirect Lighting
The average illuminance, Ē, in such a space (See Figure 9.9f) can be determined from

$$\bar{E} = \frac{R(L-8)(W-8) + 8\,Q(L-8) + 8\,T(W-8) + 64\,P}{W\,L} \qquad (9.21)$$

Where:

W = number of luminaires per row
L = number of rows
R = Average of measurements at: stations r-1 through r-4 located at random in the central portion of the area
Q = Average of measurements at: stations q-1 and q-2 located 0.6 m (2 ft) from the long walls, at random lengthwise of the room
T = Average of measurements at: at stations t-1 and t-2 located 0.6 m (2 ft) from the short walls, at random crosswise of the room
P = Average of measurements at: stations p-1 and p-2 located at diagonally opposite corners 0.6 m (2 ft) from each wall

9.15.1.2 Illuminance at a Point

With task, general, and supplementary lighting in use, the illuminance at the point of work should be measured with the worker in his or her normal working position. Notice that this will generally not correspond to an illuminance prediction at that point, since body shadow is rarely taken into account in illuminance calculations. The measuring instrument should be located so that when readings are taken, the surface of the light-sensitive cell is in the plane of the visual task or of that portion of the visual task on which the critical visual processing is required—horizontal, vertical, or inclined.

9.15.1.3 Luminance

Luminance surveys should be made under actual working conditions with measurements at specified work point location with the combinations of daylight and electric lighting facilities available. Consideration should be given to sun position and weather conditions, both of which can have a marked effect on the luminance distribution. All lighting in the area—task, general, and supplementary—should be in normal use. Work areas used only in the daytime should be surveyed in the daytime; work areas used both day and night should be surveyed under both conditions, as the luminance distribution and the possibilities of comfort and discomfort can differ markedly between them. Nighttime surveys should be made at night or with shades drawn. Daytime surveys should be made with shades adjusted to positions actually set by the occupants. Measurement locations are usually those defined by luminance ratios or limits that have been specified. Refer to application chapters for recommended luminance ratios and limits.

9.15.2 Outdoor Measurements

For an accurate evaluation of roadway and many floodlight installations, illuminance measurements must be made with particular care, especially regarding the level of the illuminance meter or its alignment with the intended illuminance measurement plane. Typical preparation for an illuminance survey consists of the following.

- Inspect and record the condition of the luminaires (globes, reflectors, refractors, lamp positioning, etc.). In the case of roadway lighting, make sure the luminaires are level and their vertical and lateral placement is as designed. Unless the purpose of the test is to check depreciation or actual in-service performance, all units should be cleaned and new lamps installed. New lamps should be seasoned properly. While inoperative lamps are readily noticed in roadway installations, they can easily be overlooked in large floodlighting systems. If these lamps are not replaced for the field survey, proper consideration must be given when evaluating the results.

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- Measure and record the mounting heights of the luminaires.
- Measure and record the locations of the poles, the number of luminaires per pole, the wattage of the lamps, and other pertinent data. Check these data against the recommended layout; a small change in the location or adjustment of the luminaires can make a considerable difference in illuminance.
- Determine and record the burning hours of the installed lamps.
- Consider the impact of stray light on the measurements. The survey should be made only when the atmosphere is reasonably clear. Extraneous light produced by a store, a service station, or other lights in the vicinity requires careful attention in outdoor lighting tests.
- Luminaire voltage should be measured because it can affect illuminance. At night, during the hours when the luminaires are normally used, record the voltage at the lamp socket with all of the lamps operating. The voltage at the main switch can be used instead provided allowance is made for the voltage drop to the individual luminaires. If discharge lamps are used, record the input voltage to the ballast at the ballast terminals. Discharge lamps should be operated at least 60 min to reach normal operating conditions before measurements are made.

Measurements should be made with a recently calibrated illuminance meter with sufficiently accurate spectral and spatial response, capable of being leveled for horizontal measurements or positioned accurately for other measurement planes as required The photometer should be selected for its portability, repeatability, and measurement range.

- For roadway lighting systems, at least one traffic lane must be closed for substantial periods of time. Because of this difficulty and expense of making field measurements of pavement luminance, it is common to use a computerized design procedure using point calculations of horizontal illuminance level at each of the pavement luminance measurement points recommended As a check on the computer calculations, it is necessary only to measure the illuminance at a reduced number of points [62]
- For roadway signs, the minimum and maximum illuminance levels are determined by scanning the sign face. Additional illuminance measurements are taken at specific locations according to the sign size. Luminance measurements are also made for both externally and internally illuminated signs [63].
- For sports installations, the sports area (or the portion of the area under immediate consideration) should be divided into test areas of approximately 5% of the total area, and readings should be taken at the center of each area [66]. Some specific measurement grids have been developed for particular types of playing fields and are recommended for field measurements in these applications..
- So-called TV-illuminance requires the illuminance meter to be oriented so that its measurement normal points to the camera position(s).
- Readings should be made at each test station, with repeat measurements at the first station frequently enough to assure stability of the system and repeatability of results. Readings should be reproducible within 5%. Enough readings should be taken so that additional readings in similar locations will not change the average results significantly.

Many outdoor lighting applications have an appropriate standard governing the equipment, procedures, test conditions, instrumentation, and test report contents to be used for field tests. These include:

- Outdoor HID [61]
- Parking areas [62]
- Roadway [63]
- Roadway signs [64]
- Tunnel [65]
- Area and sports [66]

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9.16 References

[1] [ISO] International Standards Organizations. 2007. ISO Guide 99:2007

[2] [NIST] National Institute of Standards and Technology. 2008. NIST special publication 811, Guide for the use of the international system of Units (SI). 90 p.

[3] DiLaura D. 2006. A history of light and lighting. New York. IES. 402 p.

[4] Dilaura, D. 2005. Light's measure: A history of industrial photometry to 1909. Leukos. 1(3):75-140.

[5] Schanda J, editor. 2007. Colorimetry: Understanding the CIE system. New Jersey: Wiley. 373 p.

[6] Poikonen T, Karha P, Manninen P, Manoocheri F, Ikonen E. 2009. Uncertain analysis of photometer quality factor f_1'. Metrologia. 46(1):75-80.

[7] [IES] Illuminating Engineering Society. 1994. IESNA survey of illuminance and luminance meters. Light Des App. 24(6):31-42.

[8] Ohkubo K, Horiuchi M, Nakagawa Y, Tozawa H, Kobayashi K, Horie I, Chida N. 2000. Domestic comparison of relative spectral responsivity measurements for illuminance meters. J Light Vis Environ. 24(1):66-72.

[9] DeCusatis, C. 1997. Handbook of applied photometry. New York: AIPPress.

[10] Karas VI, Torpachev PA. 1991. Pulsed light flux measurement by a photodiode operational amplifier pair. Meas Tech. 34(5):13-15.

[11] Anonymous. 2003. Detector arrays. Laser focus World. 39(2).

[12] Choi H. 2004. Advantages of photodiode array. http://www.hwe.oita-u.ac.jp/kiki/ronnbunn/paper_choi.pdf

[13] [IES] Illuminating Engineering Society. 1994. LM-58 IESNA guide to spectroradiometric measurements. 9 p.

[14] ASTM International. 2006. ASTM E1341-06 Standard practice for obtaining spectroradiometric data from radiant sources for colorimetry. 12 p.

[15] ASTM International. 2008. ASTM G138-06 Standard test method for calibration of a spectroradiometer using a standard source of irradiance. 8 p.

[16] Brown SW, Eppeldauer GP, Lykke KR. 2000. NIST facility for spectral irradiance and radiance response calibrations with a uniform source. Metrologia, 37:579-582.

[17] [CIE} Commission Internationle de l'Eclairage. 2004. CIE 15-2004 Colorimetry. Vienna: CIE. 43 p.

[18] ASTM International. 2009. ASTM E1164-09a Standard practice for obtaining spectrometric data for object-color evaluation. 8 p.

[19] ASTM International. 2008. ASTM International standards on color and appearance measurement: 8th edition. 800 p.

[20] [CIE} Commission Internationle de l'Eclairage. 1987. CIE 53-1982 Methods of characterizing illuminance meters and luminance meters: Performance, characteristics and specifications. 43 p.

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[21] [IES] Illuminating Engineering Society. 2001. LM-75-01 Goniophotometer types and photometric coordinates. 6p.

[22] Rosa, E. B., and A. H. Taylor. 1922. Theory, construction, and use of the photometric integrating sphere: Paper No. 447. Sci. Pap. Bur. Stand. 18:281-325.

[23] [IES] Illuminating Engineering Society. 2007. IESNA approved method for total luminous flux measurement of lamps using an integrating sphere photometer. 15 p.

[24] Gibb DR, Duncan FJ, Lambe RP, Goodman TM. 1996. Ageing of materials under intense UV radiation. Metrologia. **32** (6):601-607.

[25] Ohno Y, Zong Y. 1999. Detector-Based Integrating Sphere Photometry. In: Proceedings, 24th Session of the CIE. (1)1:155-160.

[26] Rea, M. S., and I. G. Jeffrey. 1990. A new luminance and image analysis system for lighting and vision: I. Equipment and calibration. /. Ilium. Eng. Soc. 19(l):64-72.

[27] Lewin, I., R. Laird, andJ. Young. 1992. Video photometry for quality control. Light. Des. Appl. 22(1): 16-20.

[28] Fiorentin P, Iacomussi P, Rossi, G. 2005. Characterization and calibration of a CCD detector for light engineering. IEEE Transactions on Instrumentation and Measurement. 54(1):171-177.

[29] [IES] Illuminating Engineering Society. 1990. LM-44-90 IESNA approved method for total diffuse reflectometry. 6p.

[30] Levin R. 1982. The photometric connection. Parts 1-4. Light Des Appl. 12(9):28-35, 12(10):60-63, 12(11):42-47, 12(12):16-18.

[31] [IES] Illuminating Engineering Society. 1996. TM-6-96 IESNA understanding and controlling the effects of temperature on fluorescent lamp systems. 11p.

[32] [IES] Illuminating Engineering Society. 1996. LM-55-96 IESNA guide for the measurement of ultraviolet radiation from sources. 7p.

[33] [IES] Illuminating Engineering Society. 1999. LM-54-99 IESNA guide to lamp seasoning. 2p.

[34] [IES] Illuminating Engineering Society. 2000. LM-45-00 IESNA approved method for electrical and photometric measurements of general service incandescent lamps. 8 p.

[35] [IES] Illuminating Engineering Society. 1999. LM-9-99 IESNA approved method for electrical and photometric measurements of fluorescent lamps. 11 p.

[36] [IES] Illuminating Engineering Society. 2000. LM-66-00 IESNA approved method for electrical and photometric measurements of single-ended compact fluorescent lamps. 17 p.

[37] [IES] Illuminating Engineering Society. 2001. LM-51-00 IESNA approved method for electrical and photometric measurements of high intensity discharge lamps. 10 p.

[38] [IES] Illuminating Engineering Society. 2008. LM-79-08 IESNA approved method: electrical and photometric measurements of solid state lighting products. 16 p.

[39] [IES] Illuminating Engineering Society. 2002. LM-76-02 IESNA approved method for electrical and photometric measurements of fiber optics lighting systems. 20 p.

[40] [IES] Illuminating Engineering Society. 2007. LM-59-07 IESNA approved method for electrical and photometric measurements of low pressure sodium lamps. 10 p.

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[41] [IES] Illuminating Engineering Society. 2001. LM-49-01 IESNA approved method for life testing of incandescent filament lamps. 4 p.

[42] [IES] Illuminating Engineering Society. 2001. LM-40-01 IESNA approved method for life testing of fluorescent lamps. 4 p.

[43] [IES] Illuminating Engineering Society. 2001. LM-65-01 IESNA approved method for life testing of compact fluorescent lamps. 4 p.

[44] [IES] Illuminating Engineering Society. 2001. LM-47-01 IESNA approved method for life testing of high intensity discharge lamps. 5 p.

[45] [IES] Illuminating Engineering Society. 2001. LM-60-01 IESNA approved method for life testing of low pressure sodium lamps. 4 p.

[46] [IES] Illuminating Engineering Society. 2008. LM-80-08 IESNA approved method: measuring lumen maintenance of LED light sources. 4p.

[47] Whitehead L, Kan P, Lui K, Jacob S. 1999. Near field photometry of prism light guide luminaires using a CCD camera. J Illum Eng Soc. 28(2):3-9.

[48] [IES] Illuminating Engineering Society. 2005. LM-50-05 IESNA approved guide to near-field photometry. 6p.

[49] Levin RE. 1983. On fluorescent photometry. J Illum Eng Soc. 12(4):218-225.

[50] Zhang J, Ngai P. 2002. Photometry for T5 high-output lamps and luminaires. J Illum Eng Soc. 31(1):136-146.

[51] [IES] Illuminating Engineering Society. 1998. LM-41-98 IESNA approved method for photometric testing of indoor fluorescent luminaires. 18p

[52] [IES] Illuminating Engineering Society. 1996. LM-10-96 IESNA approved method for photometric testing of outdoor fluorescent luminaires. 23p

[53] [IES] Illuminating Engineering Society. 2004. LM-46-04 IESNA approved method for photometric testing of indoor luminaires using high intensity discharge or incandescent filament lamps. 15p.

[54] [IES] Illuminating Engineering Society. 1995. LM-31-95 Photometric testing of roadway luminaires using incandescent filament and high intensity discharge lamps. 15p.

[55] [IES] Illuminating Engineering Society. 2002. LM-35-02 IESNA approved method for photometric testing of floodlights using high intensity discharge or incandescent filament lamps. 17p.

[56] [IES] Illuminating Engineering Society. 1997. LM-11-97 IESNA guide for photometric testing of searchlights. 20p.

[57] Zhang J. 2008. Luminaire photometry for temperature-sensitive light source. Leukos. 4(4):225-241.

[58] [IES] Illuminating Engineering Society. 1997. LM-37-97 IESNA guide for determination of average luminance for indoor luminaires. 15p.

[59] [IES] Illuminating Engineering Society. 2007. TM-15-07 Luminaire classification system for outdoor luminaires. 11p.

[60] Joint Lighting Survey Committee. 1963. How to make a lighting survey. Ilium Eng. 57(2): 87-100.

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[61] [IES] Illuminating Engineering Society. 2006. LM-61-06 IESNA approved guide for identifying operating factors influencing measured vs. predicted performance for installed outdoor high intensity discharge (HID) luminaires. 15p.

[62] [IES] Illuminating Engineering Society. 2001. LM-64-01 IESNA guide for the photometric measurement of parking areas. 8p.

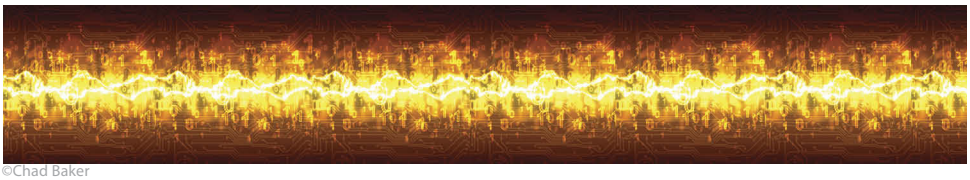
[63] [IES] Illuminating Engineering Society. 1999. LM-50-99 IESNA guide for the photometric measurement of roadway lighting installations. 3p.

[64] [IES] Illuminating Engineering Society. 2003. LM-52-03 IESNA guide for the photometric measurement of roadway sign installations. 9p.

[65] [IES] Illuminating Engineering Society. 2001. LM-71-01 IESNA approved guide for the photometric measurement of tunnel lighting installations. 4p.

[66] [IES] Illuminating Engineering Society. 2004. LM-5-04 IESNA guide for the photometric measurement of area and sports lighting installations. 26p.

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10 | CALCULATION OF LIGHT AND ITS EFFECTS

The purpose of computing is insight, not numbers. 1961
The purpose of computing numbers is not yet in sight. 1997
R. W. Hamming

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Predicting the performance of a proposed lighting design is an integral part of the design process, allowing the designer to examine and compare alternatives, refine a promising idea, see if applicable recommendations and codes will be met, evaluate energy conservation and lighting control opportunities, invoke standardized procedures to predict glare and visibility, and perhaps generate a rendering of how a space might appear. The ability to predict performance requires a computational infrastructure that consists of: standardized data that characterizes lighting equipment, a knowledge of the properties of surface and other components of the environment involved, theoretical models of how light behaves, software that makes use of those models, and computer hardware on which the software operates. However elaborate this infrastructure, its output still requires careful interpretation.

The purpose of this chapter is to provide the theoretical basis for lighting calculations, to describe how this theory is approximated and used, and how it is embodied in most lighting analysis software. This can provide, from a user's perspective, an understanding of the power and limitations of calculations – however performed – and thus make clear their use in the lighting design process. These purposes require the presentation of information in the following three general areas.

- The fundamental theories of light transport and interaction with architecture and what form—exact or approximate—the mathematical models of these theories take and how the models are, in turn, used in lighting software.
- The geometric, photometric, and physical information that is commonly available as input into a lighting calculation process and how the nature, limits, and uncertainties of this information affect the results.
- The various ways of predicting lighting system performance by assessing and interpreting calculation results and their comparison with anticipated or actual measured results.

In addition, this chapter explains IES standard calculation procedures including lumen method coefficients of utilization and glare assessment. The use of software for designing luminaires is described in 8 | Luminaires: Forms and Optics.

10.1 Role and Use of Lighting Calculations

Like most technical disciplines in engineering and design, lighting had a long history of support and direction provided by hand calculation, nomograms, and mechanical calculators [1]. By the middle of the 20th century these were, to some extent, augmented with large analog and then digital electronic computers. But the eventual widespread availability and use of inexpensive computers running standardized operating systems has made general purpose lighting analysis software (hereafter simply "software") a commercially viable enterprise, and hand calculations, however augmented, now have virtually no role in modern illuminating engineering or lighting design.

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Software is available from independent developers, lighting equipment manufacturers, equipment development consultants, and government agencies [2] and now has a part, however small, in the design and specification of most lighting systems. The development of general purpose software is a vast, highly technical undertaking that requires knowledge not only of illuminating engineering and lighting design but also mathematics and computer programming [3] [4] [5] [6]. In almost all cases, the complexities of the calculation process, including the fundamental basis and the assumptions that are always part of any practical calculation, are expressly and appropriately hidden from the user in the course of software usage. Nevertheless, some knowledge of these assumptions and approximations, coupled with an experience-based knowledge of the likely range of a quantitative result, helps prevent software misuse or misapplication and detects bad or inappropriate input data.

Reliability of software is usually established by comparison with simple geometric and photometric settings that can be calculated by hand from first principles or by comparison with photometric measurements. See 10.6.1 Accuracy and Assessment. The presumed and demonstrated reliability of software permits it to be used in several important aspects of illuminating engineering and lighting design.

10.1.1 Analysis of Proposed Lighting Systems

Software is used most frequently to demonstrate that a proposed lighting system produces illuminances that meet recommendations in their various forms and from various recommending or governing bodies. Luminance limits, luminance ratios, and proper luminaire placement can also be efficiently investigated with software.

In addition to performance testing, software can determine the effect of inevitable uncertainties in building or environmental parameters, such as surface reflectances and furniture placement.

10.1.2 Demonstration of Code Compliance

Code compliance involving illuminance minima in interiors, various maxima in exterior applications, and lighting power density limits are usually demonstrated with software.

10.1.3 Assessment of Some Aspect of Design Quality

The advent of sophisticated computer graphics rendering capabilities provides another use for software in the lighting design process. Renderings that are photometrically accurate and photographically realistic permit the communication and verification of lighting design ideas to clients and other design team members. Though limited by the capability of computer display technology, such renderings can help provide clearer conceptions of lighting system effects and performance.

10.1.4 Design of Lighting Equipment

Software has had a significant effect on the design of lighting equipment. The ability to accurately predict proposed luminaire performance is now used by equipment manufacturers to shorten the design-cycle time and reduce development costs for new product development and permit quicker and more extensive investigation of equipment design concepts. The repeated cycle of physical mockups and photometric testing has been significantly reduced, and is now used only near the end of the luminaire design process.

10.1.5 Education

Software permits students of lighting to learn and explore lighting concepts, test design ideas, and add to their store of experience with light, lighting, and lighting equipment. Though no substitute for real, hands-on work, software can significantly augment the

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range and depth of understanding of lighting system performance and provide an initial experience with a range of lighting equipment and lighting techniques that is otherwise very difficult to obtain.

10.2 Calculating Illuminance, Luminance, and Flux

All computational assessments of lighting systems are based on the determination of illuminance, luminance, or flux. This is the case for the simplest determination of average illuminance on a workplane, to the most elaborate computer rendering of a lighted space. All of these calculations involve:

- Photometric properties of light sources
- Surface and material properties including reflectance, transmittance, refraction, and color
- The geometry defining and relating sources and surfaces
- A final form of the computation, that can range in complexity from an array of illuminance values to a rendered image

Virtually all lighting calculations are performed with the assumption that the air through which light travels is clear and nonabsorbing. The atmospheric conditions that would seem to absorb light and affect daylighting calculations are taken into account when the sun and sky are defined as light sources.

Calculation of illuminance, luminance, and flux can be expressed in rigorously correct terms as equations derived from first principles. Though of theoretical interest, these equations must usually be approximated for practical implementation. Certain calculations can be simplified and less computer time used, if the sources involved are perfectly diffuse emitters or if the surfaces involved exhibit perfectly diffuse reflection.

10.2.1 Illuminance from Point Sources

The most fundamental and conceptually simplest calculation is the determination of the illuminance at a point produced by a point source. For purposes here, it is assumed that the intensity distribution of the source is defined by a function $I(\theta,\psi)$ with direction specified in spherical coordinates (θ,ψ) centered at the source. Assuming the geometric arrangement shown in Figure 10.1, the illuminated area dA_p located at point p is in direction (θ,ψ) from the source and distance D from it. The orientation of the illuminated surface is indicated by the surface perpendicular, n. Beginning with the definition of illuminance, and using the definition of luminous intensity, an equation for the illuminance at point p can be derived:

$$E_p = \frac{d\Phi}{dA_p} = \frac{I(\theta,\psi)\, d\omega_p}{dA_p} = \frac{I(\theta,\psi)\, dA_p \cos(\xi)}{dA_p\, D^2} = \frac{I(\theta,\psi)\cos(\xi)}{D^2} \qquad (10.1)$$

This is the so-called inverse-square cosine law. Since dA_p is differentially small, it is assumed that neither $I(\theta,\psi)$, nor the distance, nor any of the angles change for any point in the differential neighborhood of dA_p and so the illuminance is the same within dA_p.

10.2.2 Illuminance from area sources

When the source is a luminous area it is convenient to describe it photometrically in terms of luminance rather than intensity. The luminance distribution of the source is defined by a function $L(\theta,\psi;u,v)$ with direction specified in spherical coordinates (θ,ψ) centered at a point on the source located at (u,v). Figure 10.2 shows the arrangement.

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Beginning with the definitions of illuminance and luminance, an expression for the differential illuminance at point p due to the luminance of a differential element of source can be found. This is integrated (summed) over the entire source to give the illuminance at point p produced by the entire source.

$$\begin{aligned} E_p &= \int dE_p = \int d\frac{d\Phi}{dA_p} = \int \frac{dI_{dA_p}(\theta,\psi)\, d\omega_p}{dA_p} \\ &= \int \frac{L(\theta,\psi;u,v)\, dA_s \cos(\theta)\, dA_p \cos(\xi)}{dA_p\, D^2} \\ &= \int L(\theta,\psi;u,v) \cos(\xi)\, d\omega_s \end{aligned} \tag{10.2}$$

10.2.3 Luminance at a Point

The luminance at a point p on a surface is calculated from the illuminance at that point, integrated with the directional reflectance of the surface. The BRDF of the surface, $f_r(\theta_i,\psi_i;\theta_r,\psi_r)$ characterizes the directional reflectance. See 5.8.1 Reflectance. The luminance in direction (θ_r,ψ_r) is given by

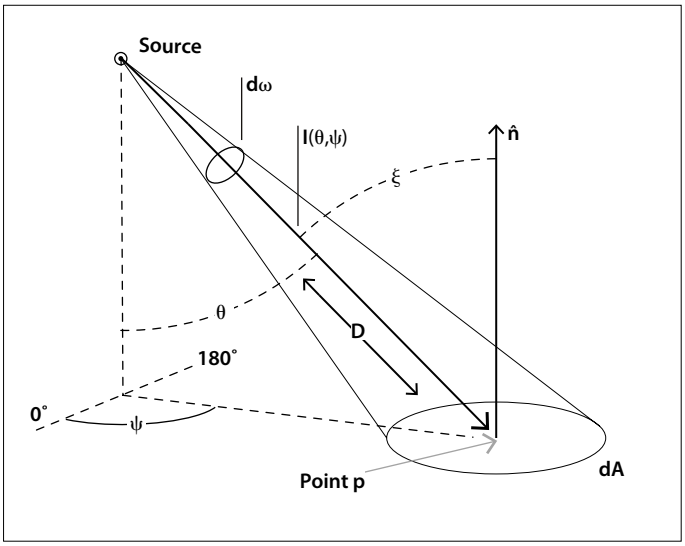


Figure 10.1 | Illuminance at a Point from a Point Source
Geometry of the calculation of illuminance at a point from a point source.

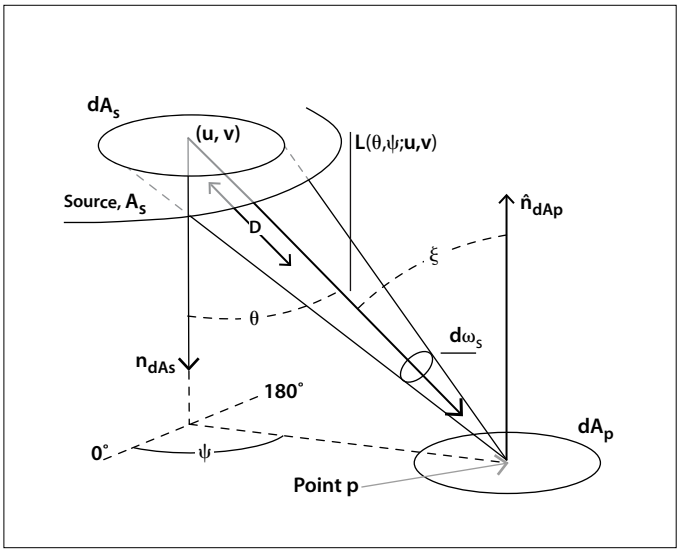


Figure 10.2 | Illuminance at a Point from an Area Source
Geometry of the calculation of illuminance at a point from an area source.

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$$L_p(\theta_r,\psi_r) = \int f_r(\theta_r,\psi_r;\theta_i,\psi_i)\, dE(\theta_i,\psi_i) \tag{10.3}$$

Where:

$dE(\theta_i,\psi_i)$ = differential amount of illuminance at the point from a direction (θ_i,ψ_i)

Using equation 10.2, L_p can be expressed explicitly as a function of the luminance distribution, $L_s(\theta,\psi)$, of the environment with respect to point p, substituted in equation 10.3. The luminance at point p becomes

$$L_p(\theta_r,\psi_r) = \int_{\Omega_s} f_r(\theta_r,\psi_r;\theta_i,\psi_i)\, L_s(\theta_i,\psi_i)\cos(\xi)\, d\omega_s \tag{10.4}$$

Note that equation 10.4 holds for the use of the BTDF of materials as well and thus the calculation of the transmitted luminance of a material.

10.2.4 Flux on an Area

Flux determination is a critical part of most calculations that involve interreflected light. The flux incident on a surface is obtained by multiplying the illuminance at a point by the differential area around that point, and integrating over the entire receiving area. If the source is a point, then the flux it produces on an area, A_r, is given by:

$$\Phi = \int_{A_r} \frac{I(\theta,\psi)\cos(\xi)}{D^2} dA_r \tag{10.5}$$

Where:

A_r = entire area of the receiver

If the source is an area, then the flux it produces on another area, A_r, is given by:

$$\Phi = \int_{A_s}\int_{\Omega_r} \frac{I(\theta,\psi)\cos(\xi)}{D^2} d\omega_s\, dA_r \tag{10.6}$$

Where:
Ω_s = entire solid angle of the source
A_r = entire area of the receiver

10.2.5 Approximations

As a practical matter, a continuous function of luminous intensity is never available to describe lighting equipment. Rather, an array of discrete values, $I'(\theta_i,\psi_j)$, i=1,...,N, j=1,...,M, that results from photometry must be used. In this common case it is necessary to use an interpolated value of luminous intensity $I'(\theta,\psi)$. An interpolation procedure must be used to generate the value $I'(\theta,\psi)$ from bracketing values available in the array of discrete values: $I'(\theta_i,\psi_j)$, $I'(\theta_{i+1},\psi_j)$, $I'(\theta_i,\psi_{j+1})$, $I'(\theta_{i+1},\psi_{j+1})$. The details of the procedure can have a large effect on the final value, especially if the intensity is changing rapidly in θ or ψ in the direction of point p. Similarly, a continuous function of luminaire luminances is almost never available and luminances must be inferred from values of luminous intensity and luminous area.

The integrals indicated in Equations 10.2 – 10.6 can rarely be performed analytically to obtain a closed-form expression. Rarely are all the functions and their integrands available in analytic form and the geometric settings required in practice usually involve relationships to the variables of integration that are overwhelmingly complex. Thus, in

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nearly all cases, numerical integration must be used rather than analytic integration. This can be accomplished by discretizing areas into small elements, evaluating integrands for each of these elements, and summing the resulting values. An alternative is to transform the area integrals into contour or edge integrals, discretize the edges, and numerically integrate around the edges of the source [7]. This approximation has been shown to be computationally faster than area discretization with no loss in accuracy.

The final result depends on the granularity of the discretization. In many cases, it is not possible to determine in advance how fine the discretization must be to provide useful accuracy. It is often necessary to iterate or pass through the discretization-calculation cycle more than once, increasing the discretization until the results do not change in a significant way. This general procedure is called adaptive computation. In some software this process is automatic, in other it is under user control.

10.2.6 Diffuse Surfaces

A surface that emits flux in a way such that it exhibits an intensity distribution that varies with the cosine of the exitant angle measured from the surface perpendicular is said to have a perfectly diffuse intensity distribution. Usually this is shortened to "diffuse distribution".

The intensity perpendicular to the surface, I_n, is the largest in the distribution and

$$I(\theta) = I_n \cos(\theta)$$

Where:

θ is the exitant angle measured from the perpendicular

Notice that the distribution is not dependent on the azimuthal angle. The simplicity of the function describing a diffuse distribution permits far reaching simplifications in the equations involving them as light sources or as elements in a system of interreflecting surfaces. This is particularly important since many real surfaces are approximately diffuse and calculations involving them can be radically simplified, leading to software that executes rapidly and so can have a significant place in the lighting design and analysis process.

A surface can be diffuse because it is a perfectly diffuse reflector, a perfectly diffuse transmitter, or generates light in a perfectly diffuse manner. As described in 5.8.1 Reflectance, many matte painted architectural surfaces are reasonable approximations to diffuse reflectors. Diffusing skylight domes are reasonable approximations to diffuse transmitters. Many OLED sources have a distribution that is close to diffuse.

The following basic properties of the photometric characteristics of a diffuse surface are a direct result of its simple distribution [8]. See 10.2.6 Diffuse Surfaces.

$$\begin{aligned} I(\theta) &= I_n \cos(\theta) \\ I_n &= \frac{\Phi_{off}}{\pi} = \Phi_{on}\frac{\rho_{pdr}}{\pi} = E\,A\frac{\rho_{pdr}}{\pi} = \frac{M\,A}{\pi} \\ L(\theta,\psi) &= \frac{I(\theta)}{A\cos(\theta)} = \frac{I_n\cos(\theta)}{A\cos(\theta)} = \frac{I_n}{A} \\ L &= \frac{I_n}{A} = \frac{M\,A}{\pi\,A} = \frac{M}{\pi} \end{aligned} \tag{10.7}$$

Using these properties and the definition of solid angle, equation 10.2 can be simplified to give the illuminance at a point from a uniform, diffuse area source:

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$$E_p = \frac{M}{\pi}\int_{\Omega_s}\frac{\cos(\xi)}{D^2}d\omega_s = M\frac{1}{\pi}\int_{A_s}\frac{\cos(\theta)\cos(\xi)}{D^2}dA_s \tag{10.8}$$

The diffuse assumption permits the photometric properties of the surface to be expressed as a single value of exitance, M, and to be completely separated from the surface's geometric properties. That is, the integral is a purely geometric quantity. It is called the configuration factor, c, [9] and so if

$$c = \frac{1}{\pi}\int_{A_s}\frac{\cos(\theta)\cos(\xi)}{D^2}dA_s \tag{10.9}$$

then the illuminance at a point from a uniform diffuse surface with exitance M_s is simply

$$E_p = M_s\, c \tag{10.10}$$

If the direction of the flux flow assumed in Figure 10.2 is reversed and the area at point p is assumed to be the diffuse source, then an expression for the fraction of the total flux it emits that directly reaches the large area is also given by equation 10.9. So a configuration factor can also be defined as that fraction of the total flux emitted by a differential diffuse emitter that is received directly by an area. This shows that the configuration factor has the limiting values $0 \le c \le 1$.

Equation 10.9 can be analytically evaluated for a large number of geometric conditions to produce closed-form expressions for the configuration factor [10]. A selection of these expressions is in the Formulary. The purely geometric nature of the configuration factor permits the development of what is called configuration factor algebra and also a geometric analogy of its value. Figure 10.3 shows this analogy.

The analogy also shows another remarkable property of uniform diffuse sources: the illuminance they produce at a point depends only on their outline or silhouette as seen from the point. This property can also be demonstrated mathematically [11].

If a diffuse area source is considered to illuminate an area receiver, then equation 10.6 simplifies and the flux $\Phi_{s\to r}$ from a uniform diffuse area source A_s with uniform exitance

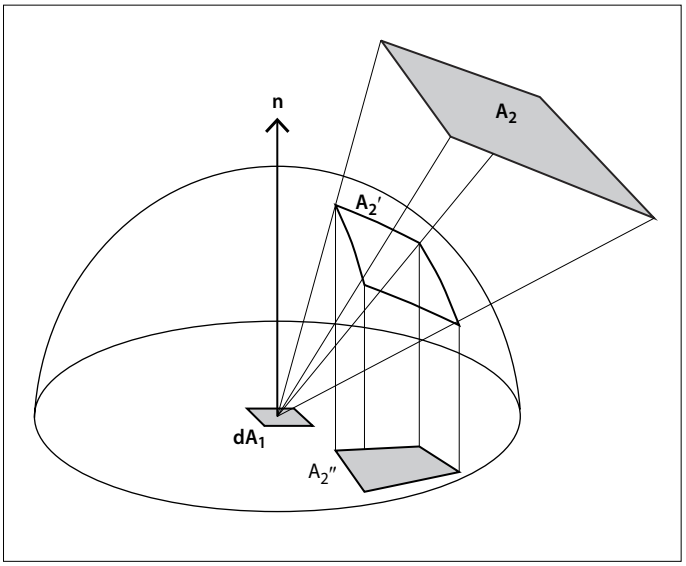


Figure 10.3 | Nusselt Analogy for Configuration Factors
The Nusselt analogy for the computation of a configuration factor for surface A_2 and point at dA_1. Surface A_2 is radially projected onto a hemisphere with base centered at dA_1, giving projection $A_{2'}$. This is, in turn, projected downward to the base of the hemisphere, giving projection $A_{2''}$. The configuration factor is numerically equal to the area of $A_{2''}$ divided by the area of the circular base of the hemisphere.

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M_s, that directly reaches a receiving area A_r is

$$\Phi_{s\to r} = \frac{M_s}{\pi}\int_{A_r}\int_{A_s}\frac{\cos(\theta)\cos(\xi)}{D^2}dA_s dA_r \tag{10.11}$$

This assumes that all points on A_s have an unobstructed view of A_r. As with the configuration factor, the integral is a purely geometric quantity. It is customary to scale the geometric quantity by the source area and so

$$\begin{aligned}\Phi_{s\to r} &= \frac{A_s M_s}{\pi}\frac{1}{A_s}\int_{A_r}\int_{A_s}\frac{\cos(\theta)\cos(\xi)}{D^2}dA_s dA_r \\ &= \Phi_s\frac{1}{\pi A_s}\int_{A_r}\int_{A_s}\frac{\cos(\theta)\cos(\xi)}{D^2}dA_s dA_r\end{aligned} \tag{10.12}$$

Analogous to the configuration factor, a form factor $f_{s\to r}$ can be defined as the purely geometric part of equation 10.12.

$$f_{s\to r} = \frac{1}{\pi A_s}\int_{A_r}\int_{A_s}\frac{\cos(\theta)\cos(\xi)}{D^2}dA_s dA_r \tag{10.13}$$

The form factor $f_{s\to r}$ gives the fraction of flux leaving A_s that gets directly to A_r. Thus

$$\Phi_{s\to r} = \Phi_s f_{s\to r} \tag{10.14}$$

Equation 10.13 can be analytically evaluated for a large number of geometric conditions to produce closed-form expressions for the form factor [10]. A selection of these expressions is in the Formulary. Like configuration factors, form factors can be shown to obey an algebra, and among the relationships that can be established are the following.

$$\begin{aligned}&0 \le f_{s\to r} \le 1 \\ &\sum_{r=1}^{N} f_{s\to r} = 1\,(\text{for a completely enclosed environment}) \\ &A_s f_{s\to r} = A_r f_{r\to s} \\ &f_{r\to s} = \frac{A_s}{A_r} f_{s\to r}\end{aligned} \tag{10.15}$$

Thus, for example, the average illuminance at A_r produced by uniform diffuse source A_s is:

$$\bar{E}_r = \frac{\Phi_{s\to r}}{A_r} = \frac{\Phi_s}{A_r}f_{s\to r} = \frac{\Phi_s}{A_r}\frac{A_r}{A_s} f_{r\to s} = \frac{\Phi_s}{A_r} f_{r\to s} = \bar{M}_s f_{r\to s} = \bar{E}_s \rho_s f_{r\to s} \tag{10.16}$$

Configuration and form factors form the basis for the diffuse radiative transfer analysis that is incorporated in most software used in lighting design and analysis.

10.3 Photometric Data for Calculations

Lighting calculations involve the photometric characteristics of luminaires and architectural materials, quantified and supplied in a form that can be used in commonly available lighting software. Measurement procedures for acquiring data describing luminaire photometry and surface reflectance and transmittance have been standardized to permit such use.

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Table 10.1 | Tabulation of Fundamental Equations

Quantity	Condition	Formula	
Illuminance at a Point	Point Source	$E_p = \frac{I(\theta,\psi)\cos(\xi)}{D^2}$	
Illuminance at a Point	Point Source, using an Intensity Array	$E_p = \frac{I'(\theta,\psi)\cos(\xi)}{D^2}$	$I'(\theta,\psi)$ interpolated from: $I'(\theta_i,\psi_j), I'(\theta_{i+1},\psi_j), I'(\theta_i,\psi_{j+1}), I'(\theta_{i+1},\psi_{j+1})$ $\theta_i \le \theta \le \theta_{i+1}$ and $\psi_j \le \psi \le \psi_{j+1}$
Flux on an Area	Point Source	$\Phi = \int_{A_r} \frac{I(\theta,\psi)\cos(\xi)}{D^2} dA_r$	
Flux on an Area	Point Source, using an Approximate Area Integral	$\Phi = \sum_{i=1}^{N} \frac{I'(\theta_i,\psi_i)\cos(\xi_i)}{D^2}\Delta A_i$	N = number of pieces of area ΔA_r = area of i^{th} piece $I'(\theta_i,\psi_i)$ = interpolated intensity for i^{th} piece
Illuminance at a Point	Area Source, Arbitrary Luminance	$E_p = \int L(\theta,\psi;u,v)\cos(\xi)\, d\omega_s$	
Illuminance at a Point	Area Source, Homogeneous Luminance	$E_p = \int L(\theta,\psi)\cos(\xi)\, d\omega_s$	
Illuminance at a Point	Area Source, Homogeneous Luminance, using an Approximated Area Integral	$E_p = \sum_{i=1}^{N} \frac{L'(\theta_i,\psi_i)\cos(\theta_i)\cos(\xi_i)}{D_i^2}\Delta A_i$	N = number of pieces of area ΔA_r = area of i^{th} piece $L'(\theta_i,\psi_i)$ = interpolated for i^{th} piece
Illuminance at a Point	Area Source, using Far-Field Luminous Intensity and an Approximated Area Integral	$E_p = \frac{1}{A}\sum_{i=1}^{N} \frac{I'(\theta_i,\psi_i)\cos(\xi_i)}{D_i^2}\Delta A_i$	N = number of pieces of luminaire ΔA_i = area of i^{th} piece of luminaire $I'(\theta_i,\psi_i)$ = interpolated for i^{th} piece
Illuminance at a Point	Area Source, Homogeneous Diffuse Exitance	$E_p = M\frac{1}{\pi}\int_{A_s} \frac{\cos(\theta)\cos(\xi)}{D^2} dA_s$	M = diffuse exitance of area source A_s = entire area of the source
Flux on an Area	Area Source, Arbitrary Luminance	$\Phi = \int_{A_r}\int_{\Omega_s} L(\theta,\psi;u,v)\cos(\xi)\, d\omega_s\, dA_r$	Ω_s = entire solid angle of the source A_r = entire area of the receiver
Flux on an Area	Area Source, Homogeneous Luminance, using an Approximated Area Integral	$\Phi = \sum_{j=1}^{K}\sum_{i=1}^{N} \frac{L'(\theta_{ij},\psi_{ij})\cos(\theta_{ij})\cos(\xi_{ij})\Delta A_i \Delta A_j}{D_{ij}^2}$	N = number of source pieces K = number of receiver pieces ΔA_i = i^{th} piece of source ΔA_j = j^{th} piece of receiver $L'(\theta_{ij},\psi_{ij})$, $I'(\theta_{ij},\psi_{ij})$ are interpolated for each (i, j) A_s = entire are of the source
Flux on an Area	Area Source, using Far-Field Luminous Intensity and an Approximated Area Integral	$\Phi = \sum_{j=1}^{K}\frac{1}{A_s}\sum_{i=1}^{N} \frac{I'(\theta_{ij},\psi_{ij})\cos(\xi_{ij})\Delta A_i}{D_{ij}^2}\Delta A_j$	

Table 10.1 | Tabulation of Fundamental Equations continued next page

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Table 10.1 | Tabulation of Fundamental Equations continued from preceding page

Quantity	Condition	Formula
Flux on an Area	Area Source, Homogeneous Diffuse Exitance	$\Phi_{s\to r} = \frac{M_s}{\pi}\int_{A_r}\int_{\Omega_s}\cos(\xi)\,d\omega_s\,dA_r = \frac{M_s}{\pi}\int_{A_r}\int_{A_s}\frac{\cos(\theta)\cos(\xi)}{D^2}\,dA_s\,dA_r$
Configuration Factor	No Occlusion	$c = \frac{1}{\pi}\int_{A_s}\frac{\cos(\theta)\cos(\xi)}{D^2}\,dA_s$
Form Factor	No Occlusion	$f_{s\to r} = \frac{1}{\pi A_s}\int_{A_r}\int_{A_s}\frac{\cos(\theta)\cos(\xi)}{D^2}\,dA_s\,dA_r$
Illuminance at a Point	Uniform Diffuse Source	$E_p = M_s\,c$
Average Illuminance on a Surface	Uniform Diffuse Source	$\bar{E}_r = \bar{M}_s\,f_{r\to s}$

10.3.1 Luminaire Photometry for Calculations

Equivalent luminous intensity distributions are used to specify the spatial flux distribution characteristics of luminaires. See 5.7.2 Luminous Intensity and 9.9.2 Distribution Photometry. Luminaire photometry gives the equivalent luminous intensity in a set of directions, with the angular spacing of measurements sufficiently small to provide an accurate and useful description of the distribution.

10.3.2 Far-Field Luminaire Photometry

Photometry determines intensity by calculation, using an illuminance measurement and a test distance. For most photometry, the test distance is constant for all measurement points. Thus, illuminance measurements are made at positions on an imaginary sphere with a radius equal to the test distance. The sphere center coincides with a fiducial point inside the luminaire. This so-called photometric center is often the origin of the coordinate system used for calculations. If illuminances are calculated from this data, correct values result only if the calculation distance is the same as the photometric test distance and the illuminated surface's perpendicular is oriented toward the photometric center of the luminaire; setting aside all other factors that might affect the result. However, regardless of the luminaire size, it is always possible to choose a photometric distance, D_t, sufficiently large so that illuminances produced at distances greater than D_t do vary (nearly) as the inverse square of the distance to the photometric center. This was first shown for diffuse emitters [12] [13]. For them, if D_t was five times the maximum dimension of the emitter a computational accuracy of at worst 2% resulted. This "five times rule" has been adopted as standard photometric practice [14]. This is far-field photometry, and a distance of at least D_t is used to make the illuminance measurements from which the equivalent luminous intensities are calculated. These intensities can then be used to calculate illuminances at distances greater than D_t, treating the luminaire as a point source. Virtually all commercial photometry is far-field photometry.

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Illuminance calculations at distances less than D_t and which assume the luminaire to be a point source are likely to be inaccurate [15] [16]. It should be noted that distributions other than diffuse have different values of D_t, however, it is customary to apply the five times rule to most indoor luminaire photometry.

10.3.3 Near-Field Luminaire Photometry

Near-field photometry describes the spatial flux distribution of a luminaire in a manner permitting accurate illuminance calculations at distances less than D_t. Near-field photometry is particularly important for analyzing indirect lighting systems. Two types of near-field photometry have been developed expressly for improving computational accuracy.

Application-distance photometry uses test distances that are equal to the distances at which illuminance calculations will be made [17] [18] [19]. No assumptions about distance invariance are made. In this case the luminaire must be treated as a point source for calculations. Since illuminance calculations are likely to be made at many distances, application-distance photometry provides intensity distributions for several test distances. Luminance-field photometry [20] [21] measures and reports the luminance distribution of the luminaire as viewed from a set of points completely surrounding the luminaire. All points are the same distance from the luminaire photometric center. Precisely stated, the data describe a four-dimensional scalar field of luminance. From these luminance data, illuminance can be calculated at any distance and orientation from the luminaire. Luminance-field photometric measurements can be made using a CCD video camera [20]; however, the quantity of data can be difficult to manage [5].

10.3.4 Properties of Surfaces and Materials

In many cases, the reflectance or transmittance of surfaces is not known at design time and it is often assumed that this limits, if not eliminates, the utility of calculations. But in this case, if calculations are performed with the lowest and highest values of reflectance or transmittance that be reasonably expected, the resulting set of calculations reveals the sensitivity of lighting system performance to surface finishes.

10.3.4.1 Reflection

Many surfaces and finishes used in architecture exhibit a reflectance that is sufficiently diffuse to be considered perfectly diffuse. This is important for computational purposes, since they can be considered diffuse emitters regardless of the incident direction of the light. Unless otherwise expressly stated, most software assumes that the reflectances specified by the user are perfectly diffuse reflectances.

In some cases, assumptions about diffuseness will lead to very inaccurate results. An example of this is the calculation of the luminance of visual tasks, such as pencil marks on paper, etched marks on a rule, and roadway surfaces. The BRDF of a surface must be used in these cases. Modeling of luminaire performance and generating photorealistic renderings of lighted environments require bidirectional reflectance information about surfaces [22] [23] [24].

In addition to simplifying the spatial distribution characteristics of reflectance, it is often permissible and necessary to simplify its spectral characteristics. It is a useful approximation to assume that reflectance is spectrally flat and is assigned a “gray reflectance” equal to the integrated value of the surface’s spectral reflectance illuminated by an equal energy source. Thus, it is assumed that the surface exhibits the same reflectance regardless of the spectral power distribution of incident light used in calculations. This is referred to as the “gray assumption”.

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Although this simplifies calculations and usually introduces only small errors, difficulties can arise. The reflectance of a surface with a deeply saturated color usually has a significant reflectance only in a narrow band of wavelengths. Use of a light source spectrally different from that used in making a reflectance measurement can then lead to large quantitative errors and significantly shifted rendered color. Errors can also arise when calculating with a broadband 'white' light and saturated colored surfaces.

10.3.4.2 Transmittance

Many transmissive surfaces used in architecture are either image-preserving or diffuse. See 1.5.1.2 Transmission. These two cases can usually be treated with sufficient accuracy, if the gray assumption is made, with the transmittance represented by a single value. Some software treats transmittances this way, while other does not make the gray assumption and uses either full spectral transmittance data or an approximation using wide-band red, green, and blue transmittances.

In some cases, assumptions about single-value transmittance will lead to very inaccurate results. Examples are the large change in transmittance of ordinary window glass at high incident angles and the transmittance of daylight delivery fenestration systems designed to redirect and disperse sunlight. In the first case, an angular transmittance function of one angle suffices, in the second, the bidirectional transmittance distribution function (BTDF) of the material must be used [25] [26]. See 1.5.1.2 Transmission and Formulary for equations and useful approximations.

10.4 Models of Light Transport

Most of the quantitative characteristics of a proposed lighting design can be determined from the calculation of illuminance, sometimes augmented with information about incident directions. All of the most basic assessments of lighting systems use illuminance. These include:

- illuminance at an array of points
- illuminance averages,
- illuminance ratios involving averages, minima, or maxima

Surface luminances can be determined from detailed illuminance information and the reflection or transmission properties of the surface. These cases include:

- luminances to determine visual target contrast
- luminances in glare assessments
- luminances of roadways
- luminances to build a rendering of a lighted space

In virtually all lighting calculations it is conceptually and computationally convenient to separate the calculation of illuminance into direct and interreflected components. The direct component is the flux incident directly from a source: a luminaire or a component of a daylight delivery system. The interreflected component is the flux incident from surfaces made luminous by the multiple reflections of light within a space.
The total illuminance is the sum of the two components:

$$E = E_{direct} + E_{interreflected} \tag{10.17}$$

Some assessments have only a direct component, such as the calculations of either illuminance or luminance performed in many outdoor, roadway, and sports applications where the interreflected component is presumed negligible or is required to be

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ignored. Some assessments have only an interreflected component, such as the work plane illuminance calculations in a space with only an indirect lighting system. Most assessments of interior lighting applications, and some outdoor applications, have both direct and interreflected components.

For computation of maintained values, light loss factors are used in the calculation of both the direct and interreflected components of equation 10.17.

10.4.1 Direct Component Calculations

Direct illuminance component calculations from luminaires are driven by the available photometric and geometric information. In virtually all cases, only far-field photometric information is available and it is reported in one of the standard electronic formats [27]. This very basic photometric information requires additional assumptions if it is used to predict the effects of real luminaires. See 10.2 Calculating Illuminance, Luminance, and Flux, and 10.3.1 Luminaire Photometry for Calculations.

Direct component calculations from daylight delivery systems are driven by models of the sun and sky as light sources, and available photometric and geometric information about glazing, louvers, shades, lightshelves, and other devices used in daylighting. See 7.1 Daylight for a description of sun and sky models, and 14.2.3.1 Initial Daylighting Analysis.

10.4.2 Interreflected Component Calculations

The determination of the interreflected illuminance component requires the luminance of surfaces that comprise the lighted environment. Generally, there are two methods used to determine these: radiative transfer and ray tracing. In the computer graphics literature the interreflected component is described as the “global illumination”.

10.4.2.1 Radiative Transfer

Radiative transfer uses the bulk flux model of light transport to perform lighting calculations. Light transport is modeled as a divergent flux beam that radiates outward from a surface. Radiant or luminous flux is introduced into a radiative transfer model of an architectural environment by luminaires or daylight sources. This flux reaches various surfaces where it is reflected and scattered as additional divergent flux beams, or is absorbed. These reflected divergent flux beams then radiate to other surfaces. The process can be continued multiple times, accounting for as many multiple reflections as need requires or resources permit. At the end of this process the total number of lumens arriving at a surface, combined with its reflectance, can be used to determine luminance.

Radiative transfer computation is radically simplified if all surfaces involved are assumed to exhibit perfectly diffuse reflectance. That is, reflected flux has a diffuse distribution, independent of incident direction, and so the transfer between surfaces is simple to express. Most radiative calculations in architectural lighting make this assumption. In the computer graphics literature the diffuse radiative transfer method is referred to as “radiosity”.

Inherent in this model is the treatment of radiatively interacting surfaces as discrete elements that exhibit constant reflective, transmissive and photometric properties across their extent. A flux balance equation is written for each element, equating the total flux leaving an element to the total incident flux multiplied by the element’s reflectance. The total incident flux has a direct component due to electric and daylight sources, and an interreflected component due to the flux from all the other elements. The equality expressing the flux balance exists when all interreflections are taken into account. For the i^{th} element of a radiative transfer system the equation is

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$$\Phi_i = \Phi_{oi} + (f_{1\to i}\Phi_1\rho_1 + f_{2\to i}\Phi_2\rho_2 + \ldots + f_{m\to i}\Phi_m\rho_m) \tag{10.18}$$

This can be written for each surface element in the system, i=1,…,m and a set of linear, independent, simultaneous equations results. Expressed in matrix form, this gives

$$\begin{bmatrix}\Phi_1\\ \Phi_2\\ \vdots\\ \Phi_m\end{bmatrix} = \begin{bmatrix}\Phi_{01}\\ \Phi_{02}\\ \vdots\\ \Phi_{0m}\end{bmatrix} + \begin{bmatrix}\rho_1 f_{1\to 1} & \rho_2 f_{2\to 1} & \cdots & \rho_m f_{m\to 1}\\ \rho_1 f_{1\to 2} & \rho_2 f_{2\to 2} & \cdots & \rho_m f_{m\to 2}\\ \vdots & \vdots & \vdots & \vdots\\ \rho_1 f_{1\to m} & \rho_2 f_{2\to m} & \cdots & \rho_m f_{m\to m}\end{bmatrix} \times \begin{bmatrix}\Phi_1\\ \Phi_2\\ \vdots\\ \Phi_m\end{bmatrix} \tag{10.19}$$

Where:

m = number of elements in the system
Φ_i = flux onto the i^{th} element, due to direct and interreflected flux
ρ_i = diffuse reflectance of the i^{th} element
Φ_{0i} = direct flux onto the i^{th} element (due to luminaires and daylight sources),
$f_{i\to j}$ = form factor from element i to element j, accounting for occluding surfaces

The above matrix equation can also be rewritten in terms of the illuminance on each surface. This form is particularly valuable when one or more of the reflectances is assigned a value of zero, since then the illuminance striking each element is independent of the element's reflectance. Note that this transformation changes the order of the subscripts of the form factors.

$$\begin{bmatrix}E_1\\ E_2\\ \vdots\\ Em\end{bmatrix} = \begin{bmatrix}E_{01}\\ E_{02}\\ \vdots\\ E0m\end{bmatrix} + \begin{bmatrix}\rho_1 f_{1\to 1} & \rho_2 f_{2\to 1} & \cdots & \rho_m f_{m\to 1}\\ \rho_1 f_{1\to 2} & \rho_2 f_{2\to 2} & \cdots & \rho_m f_{m\to 2}\\ \vdots & \vdots & \vdots & \vdots\\ \rho_1 f_{1\to m} & \rho_2 f_{2\to m} & \cdots & \rho_m f_{m\to m}\end{bmatrix} \times \begin{bmatrix}E_1\\ E_2\\ \vdots\\ Em\end{bmatrix} \tag{10.20}$$

Equation 10.20 can be written more compactly as

$$\vec{E} = \vec{E}_0 + \vec{\vec{F}}\,\vec{\vec{\rho}}\,\vec{E} \tag{10.21}$$

Where:

$\vec{E}$ = vector of final illuminances
$\vec{E}_0$ = vector of initial illuminances
$\vec{\vec{F}}$ = matrix of form factors
$\vec{\vec{\rho}}$ = diagonal matrix of diffuse reflecances

The simplest way to solve large matrix systems is to use the method of iteration [28] [5]. The iteration begins by setting the vector $\bar{E}$ equal to the direct illuminance vector $\bar{E}_0$ and using it as an initial estimate of vector $\bar{E}$ after interreflections. This initial estimate is then used on the right-hand side of Equation 10.21 to generate another estimate of the solution vector on the left. It can be shown the process converges. Various other iteration methods are used that speed up convergence and use less computer memory. Some geometrically simple systems permit closed-form solutions. See Table 10.1.

Finally, the interreflected component of illuminance at a point is obtained by applying equation 10.10 to each interreflecting surface in the system, using the illuminance at those surfaces found by solving equation 10.21, and adding the individual contributions.

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$$E_{inter} = \sum_{i=1}^{N} M_i c_i = \sum_{i=1}^{N} E_i \rho_i c_i \qquad (10.22)$$

Where:

c_i = configuration factor from p to surface element i, accounting for occlusion
ρ_i = diffuse reflectance of surface element i
E_i = illuminance of surface element i, accounting for all interreflections

Generally, discrete radiative transfer models use the gray assumption for reflectances and the total lumen output of luminaires to solve for spectrally flat illuminances at each element. If surface reflectances represent fairly saturated colors or if sources are strongly colored, then spectral power distributions of luminaires and spectral reflectances of surfaces can be discretized into wavelength bands, and the general problem solved for each wavelength band. These multiple solutions provide a spectral distribution of illuminances at each surface element. Alternatively and less accurately, the radiative transfer problem can be solved using three very broad bands in the spectrum, corresponding to the SPDs of three primaries in the RGB color system.

Discrete radiative transfer models can assign each surface only one reflectance, one transmittance, and a single value of incident flux. If it is known that a surface exhibits changing reflectance across its extent, accurate modeling requires that the surface be broken into smaller pieces (discretized) according to its distribution of reflectances. These smaller pieces are usually three or four-sided polygons. The network of vertices and borders of this collection of polygons is called a mesh.

Further, if it is anticipated that a surface will exhibit changing luminance or color across its extent, then it must be meshed according to these changes in order for the final calculation to be sufficiently accurate. That is, small elements are needed where the changes are large and large elements suffice where the changes are small. In this sense, the fidelity of the final result depends on the nature and granularity of surface meshing. Figure 10.4 shows meshing for a simple rectangular room containing shadowing objects.

10.4.2.2 Ray Tracing

Ray tracing uses the geometric optics model of light transport to perform calculations. Light is modeled as rays, or bundles of rays, moving through an environment, reflecting and scattering off opaque surfaces, refracting and dispersing through transparent or translucent ones [29]. The resolution of this method of light transport depends on the number of rays traced. The fidelity of the final result depends on how accurately the spatial variance of radiant sources are modeled, and how well radiant or luminous

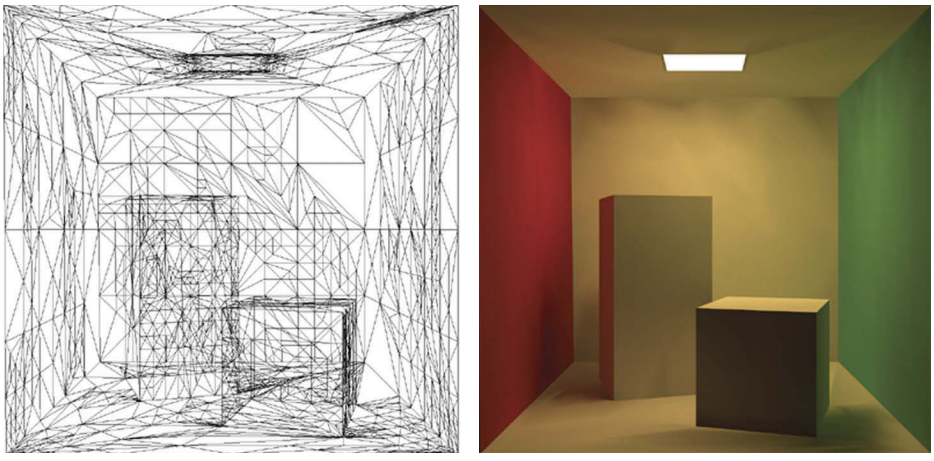


Figure 10.4 | Meshing for Radiative Transfer
Surface meshing (left) in preparation for radiative transfer calculations used to produce a rendering (right).

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variation across surfaces are modeled. Both depend on the density and therefore number of rays. In most software that uses ray tracing, rays are radiant rather than luminous entities. See 5.1.3 Radiant and Luminous Concepts.

Forward ray tracing initiates rays outward from light sources. A ray or a bundle of rays are traced until they encounter a surface which is reflective or transmissive or both. Depending on the optical properties of the surface, second order rays are launched from the point of this ray-surface intersection into appropriate directions, and these are each subsequently followed through the environment, producing third order rays. The number, luminous or radiant power, and direction of high-order rays depends on the direction and power of the incident ray, and the reflective, transmissive, refractive, or scattering character of the surface it encounters. This process of high-order ray tracing and generation is repeated until the number of high-order rays involved is small or their luminous or radiant power has been reduced to insignificance. Figure 10.5 shows forward ray tracing. At the end of the ray tracing process the luminance at a point on a surface in the environment is proportional to the total number and power of rays that are known to leave it. Forward ray tracing is seldom used in software for simple quantitative analyses of general lighting systems, but is sometimes used in daylighting analyses to model geometrically or photometrically complex daylight delivery systems. Forward ray tracing is used as a hybrid with radiative transfer to determine interreflected surface luminances in the space. It is also used extensively in software for designing and analyzing lighting equipment [30] [31].

Backward ray tracing is generally used for generating computer graphic rendered images of lighted environments. In this case, a ray is launched in a particular direction from a fixed point of view, backward toward the environment and through an imaginary image plane. This is designated the 0^{th} order ray. The intersection of this ray and the image plane defines an image point. The ray is traced into the environment until it encounters a surface. The luminance of the image point is the luminance of this surface at the ray-surface intersection point. Higher order rays from this point are, in turn, launched backward into the environment and traced through possibly higher orders of ray-surface interaction until light sources are encountered. The luminance of the image point is determined from the trace of all these backward rays. Figure 10.6 shows backward ray tracing. In some implementations of backward ray-tracing, when the 0^{th} order ray encounters a surface, the direct luminance at the intersection point is determined only that one time from each light source.

Sophisticated procedures have been developed to guide and optimize the number and tracing direction of rays. Photon mapping [32] involves both forward and backward tracing and is used to generate rendered images of spaces. A forward trace is performed first, tracing rays (photons) from sources through the environment. Individual rays are reflected, transmitted, refracted, or absorbed. A ray that encounters a surface or object is absorbed or redirected; statistics and the reflectance or transmittance of the surface or object determines which. When absorbed, a ray's position and incident direction is recorded; that is, mapped. The mapping is stored and does not depend on rendering viewing point. In a second pass, single-step backward ray tracing is used. A ray is traced from a viewing point through the image plane and into the scene, but only until it intersects a surface. Any first-pass rays that mapped (were absorbed) near this intersection point are used to determine the luminance of the point on the image plane. This procedure do not require first pass remapping when the point of view for the rendering changes; unlike pure backward ray tracing procedures.

10.5 Renderings Based on Calculations

Surface luminances, calculated at dense arrays of points, displayed with the appropriate geometric projection on a high-resolution computer display, can produce realistic images of lighted environments that are useful in lighting system design and analysis. In the limit

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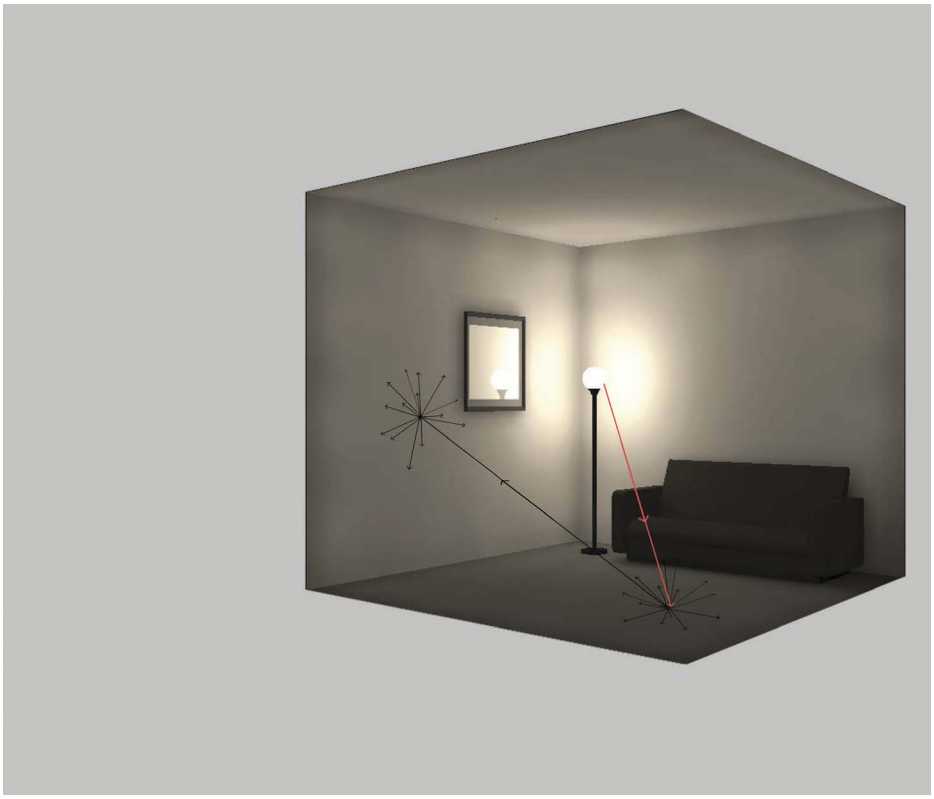


Figure 10.5 | Forward Raytracing
Forward raytracing showing an initial (0th order) ray in red leaving the luminaire and intersecting the floor. Subsequent 1st order rays are cast from this intersection point. One of these 1st order rays is traced until it strikes another surface (in this case, the side wall). From this intersection point 2nd order rays are cast. The number and power of high order rays depends on the incident ray and the reflective or transmissive properties of the surfaces involved.

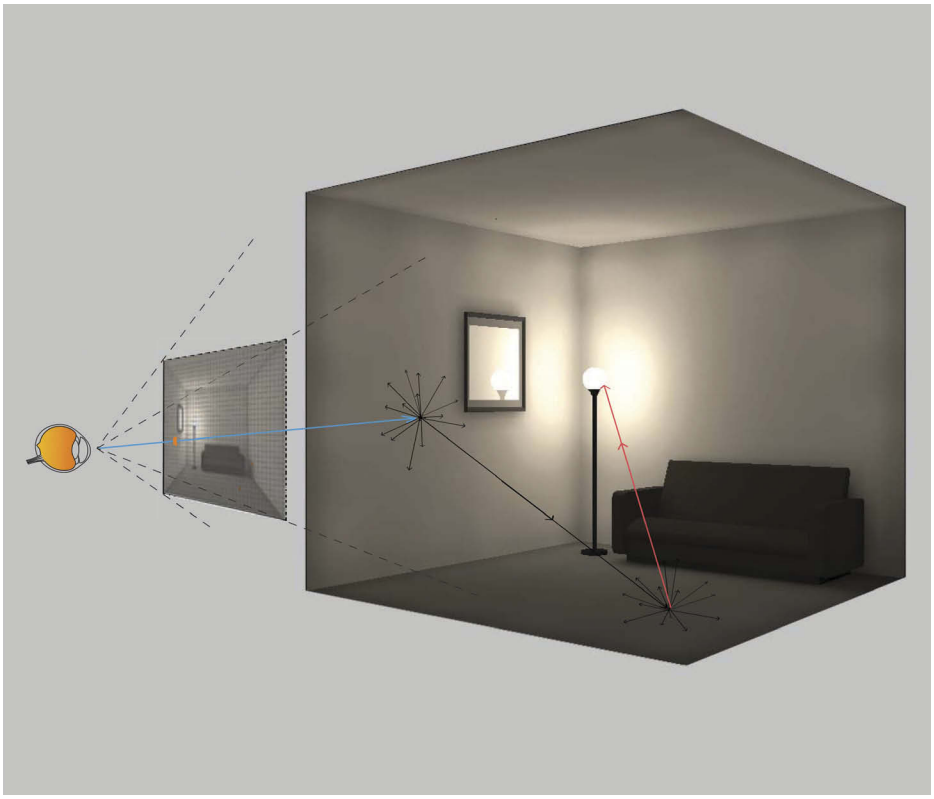


Figure 10.6 | Backward Raytracing
Backward raytracing is used to generate an image of a lighted space. The 0th order ray (shown blue in the figure) leaves the viewing position and passes through a point (shown orange) on the viewing plane that is positioned between the viewing point and the scene to be rendered. This ray is traced until it strikes a surface (in this case, the side wall). It then generates 1st order rays, each of which is traced until it strikes a surface. In the figure on of these 1st order rays is shown intersecting the floor. At this intersection point the 1st order ray generates 2nd order rays. Each of these are traced as before. This process continues until a ray strikes a light source. In the figure, one of the 2nd order rays (shown in red) strikes the luminaire. From this ray, a backward accounting of the rays intersections and surface properties encountered during tracing is made, and the luminance of the image plane at the point defined by the 0th order ray is incremented appropriately. An accounting of all the high order rays generated by the 0th order ray that eventually intersect light sources, determine the luminance assigned to point on the viewing plane.

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of geometric, computational, and display detail, these images can assume the appearance of photographs and are sometimes described as photorealistic renderings.
These images involve the following types of information and computational work, acquired or performed in the order listed [33] [34].

- Geometric description of the environment
- Definition of surface properties
- Definition of light source properties
- Calculation of surface luminances or spectral radiance
- Transformation of surface photometric or radiometric properties for display
- Image display

10.5.1 Overview of Rendering Generation

Renderings of lighted environments are perspective projections of surfaces onto an imagined viewing plane. What surfaces, or portions of surfaces, are visible depends on the viewing point, the order in which surfaces present themselves to the viewpoint, and the transparency of intervening surfaces. Every visible point on a surface projects to a point on the viewing plane. Figure 10.7 shows this typical arrangement.

The photometric or radiometric properties of each point on a visible surface is determined by calculation and become, by projection, the properties of each point on the viewing plane. For most computer systems, these photometric or radiometric properties are converted to three values, each ranging from 0 to 255 that determine the luminance of the red, green, and blue (RGB) elements that comprise a single pixel on the computer display. All or part of the viewing plane is displayed on the computer display, each pixel being set to its calculated RGB value. See 10.5.4 Display Properties and Limitations.

10.5.2 Computational Basis

The computational basis for renderings has two principal aspects: whether the calculation is photometric or radiometric, and whether the calculation is based on radiative transfer, ray tracing, or a mix of both.

10.5.2.1 Photometric Calculations

Some rendering software based only on photometric calculations produce gray-scale renderings. Light sources are described with flux or intensity, single values that subsume the spectral properties of the source. Material properties are described with integrated reflectance or transmittance, values that subsume the spectral reflectance or transmittance into a single quantity. Calculations using just these quantities usually make the so-called gray assumption; that is, the spectral properties of sources and surfaces are flat or uniform.

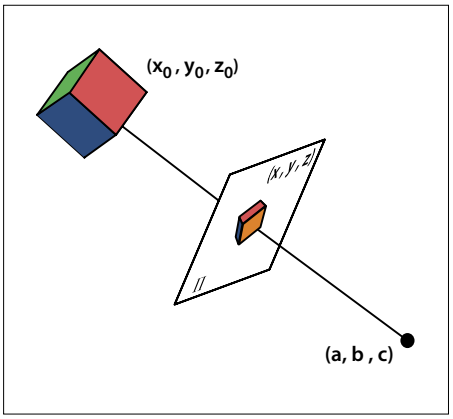


Figure 10.7 | Rendering Projections
Typical perspective rendering projection. The object is projected onto a picture plane, P, located with respect to a viewing position (a,b,c) and perpendicular to the direction of view. All points (xo,yo,zo) in the environment project to points (x,y,z) on the viewing plane. The projection points are along lines that converge to the viewing point. If only the corners and edges of the surfaces are displayed, a so-called wire-frame view of the space is generated.

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The luminances calculated on this basis can only be mapped to a single perceptual scale: lightness. Photometric calculations have the benefit of requiring only commonly available information about lighting equipment and materials.

10.5.2.2 Radiometric Calculations

Rendering software based on radiometric calculations can produce color renderings. Sources are characterized not only by a spatial distribution of flux but also a spectral power distribution. Surfaces are described with spectral reflectances and transmittances. The resulting calculations are spectral radiances at points on surfaces. As with any spectral data, these can be transformed into colorimetric quantities and, to the extent permitted by computer displays, can be used to show surface colors. See 6.5 Digital Color Specification.

In some software, radiant calculations are done using three broad, overlapping bands in the radiometric spectrum, concentrated in the long, medium, and short wavelengths. These are usually referred to as red, green, and blue, or RGB. Surfaces have reflective and transmissive properties specified by three value in these wavelength regions. Unless specific information is available, sources are assumed to have a spectral power distribution of a 6500 K blackbody. This radiant power is apportioned into the three radiometric bands.

10.5.2.3 Radiative Transfer Calculations

Surface luminances or radiances can be calculated using the solution of equation 10.21 and surface reflectances. See 10.4.2.1 Radiative Transfer. The luminance or radiance of a discretized element is assigned to a point on the element. These points are treated as vertices of triangles that are projected onto the viewing plane and displayed. Points between these vertices have luminances or radiances determined by interpolation. This final interpolation is usually bilinear and is often done by the computer graphics hardware. In this case, spatial accuracy or resolution depends on the discretization used in the radiative transfer calculation, since that determines the point spacing and position. A mesh with large elements can produce incorrect luminance patterns, especially with luminaires that are close to a surface as in the case of a wall sconce, wall slot, or an indirect luminaire.

Rendering systems of this type may exhibit artifacts caused by the failure of triangle edges or vertices to align with geometric edges and intersections, as when surfaces are covered by touching or intersecting surfaces. This can result it inappropriate areas of high or low luminance, called light-leaks or shadow-leaks. This problem can be solved by additional geometric constraints on the radiative transfer discretization process, or minimized by calculating the direct component of luminances at a more closely or more carefully placed set of points.

An alternative procedure is to calculate surface luminances at points not necessarily related to the underlying surface discretization, but spaced and located based only on anticipated luminance gradients and surface contact or intersections. The luminance at these points is determined not from the underlying surface, but by use of equations 10.22 and approximations of 10.2 to calculate the illuminance at the point and then use the diffuse reflectance of the surface to obtain the luminance. This procedure has the advantage of uncoupling the discretization and subsequent radiative transfer analysis from the calculation desired for displaying surface luminances in renderings. That is, the two can have different spatial resolutions. This procedure has the disadvantage of involving an additional computational step.

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Virtually all rendering systems that use radiative transfer are based on diffuse radiative transfer in that reflecting surfaces are assumed to be diffuse. However, even in the case of a diffuse radiative transfer model, some special types of transfer, such as flux passing through windows, do not have to be assumed to be diffuse.

10.5.2.4 Ray tracing Calculations

Ray tracing calculations are described in 10.4.2.2 Ray tracing. In most cases, backward ray tracing, coupled with the cached results from a forward ray trace, is used to determine the photometric or radiometric properties of points on the viewing plane. In these cases, the position of these points is not determined by forward projection from the environment, but backward projection: from the viewing point, through a position exactly corresponding to the position of a pixel on the computer display, and back into the environment. This produces the greatest spatial resolution.

Ray tracing easily accounts for the directional reflectance and transmittance properties of materials. Since individual rays are traced, no assumptions need to be made about their reflected or transmitted distribution. Rather, the bidirectional reflectance and transmittance data describing materials, when available, is used to determine reflected, transmitted, or refracted ray directions.

10.5.2.5 Mixed Calculations

Some software systems combine radiative transfer and ray tracing. It is possible to approximately account for the visual appearance of specular and semispecular reflection in an environment by separating the calculation of the direct and interreflected luminance of a surface used in a rendering. One implementation of this procedure calculates the interreflected luminance using the integrated reflectance of the surface, and the direct luminance using the appropriate BRDF. The interreflected component at each point on the surface is calculated using equation 10.22, the direct component by use of equation 10.4 or its approximation.

Mixed calculations are approximations to what is rigorously a non-diffuse radiative transfer problem. They are reliable when the amount of non-diffuse transfer in the environment is small. That is, when the number of lumens transported in the environment by non-diffuse reflection is small. This is the case when the specular component of mixed reflectance is small compared to the total reflectance, or when the surface area with non-diffuse reflectances is small compared to the total.

10.5.3 Adding Realism to Renderings

Texture mapping is a rendering procedure that modifies a surface by the computational equivalent of applying a pattern after all other calculations have been complete [35]. The pattern can have various amounts of transparency and color, and is often used to simulate wood grain, marble and tile textures, and other surface finishes. Texture mapping can add considerable realism to a rendering.

Bump mapping is a rendering procedure that alters the luminance calculation (often just the direct component) at points on a surface. At each point, a texture height map is consulted and the normal of the surface at that point is altered accordingly. This perturbed normal is used in the calculation of the luminance at the point. Depending on the texture height map, this can give the surface a textured appearance, such as brushed metal, or the skin of an orange. Other procedures to process surfaces to make them appear more realistic are parallax mapping [36], displacement mapping, normal mapping, and relief mapping [35].

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10.5.4 Display Properties and Limitations

Rendering involves the conversion of photometric or radiometric properties of points on a viewing plane to appropriate signals for pixels on a computer display or dots of a color printer. In almost all cases, the gamut of colors and the range of luminances of the array of points on the viewing plane far exceed what can be directly produced by a computer display or, less so, by printer. Color gamuts of common computer displays do not include very saturated colors. See 6.5 Digital Color Specification. Commonly used computer displays have maximum luminance ratios of approximately 150:1, while real environments often present ratios as high as 75,000:1. Thus, the color gamut and luminance range of the original computation must be compressed. This compression process is called tone mapping.

Tone mapping can also account for a failure to produce deep black, the effect of object size in an image, and the local range of luminance in the field of view. The fundamental task is to produce a stimulus on the computer display or printed page that produces a perception similar to that produced by viewing the actual environment. That is, produce a perceptual metamer for the environment.

Tone mapping procedures, and the images they produce on commonly available computer displays, have not been extensively evaluated against actual environments, but existing data indicate that rendered images can be useful perceptual metamers [37]. Tone mapping procedures have been evaluated psychophysically by comparing the images they produce on commonly available displays to images displayed directly on custom display devices with very large color gamuts and luminance ratios [38] that can accurately reproduce luminance and colors [39]. Some of these procedures [40] [41] are particularly effective and necessary when compressing images with very high luminance ratios, as often occurs when rendering daylighted environments.

Automatic tone mapping does not always work without user or observer intervention and so some software systems permit modifications to the parameters that govern tone mapping to adjust the rendered image. Though useful, and sometimes essential, abuse or incorrect use of these adjustments can produce a realistic or pleasing image, but one that fails to accurately represent the luminous environment.

10.6 Evaluating Lighting Analysis Software

Most lighting calculations required in the course of lighting design are performed with computer software specifically written for this purpose. The reliability of the output of lighting software can be determined by sufficiently detailed testing. Even with successful testing, at least an approximate idea of how the software operates, including what approximations it makes and what assumptions it makes, is necessary in order to know the range of problems or situations for which it can be reliably used.

10.6.1 Accuracy and Assessment

Two ways for testing software used for lighting analysis have been developed: comparison with analytic results and comparison with photometric measurements.

10.6.1.1 Analytic Tests

The CIE has established test conditions involving light sources with analytically-characterized distributions, surfaces with perfectly diffuse reflectances, and geometry simple enough to permit the analytic determination of, say, illuminances at points. The specification of such conditions can be very precise and quantities such as illuminances

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Table 10.2 | Examples of Rendering Using Different Procedures

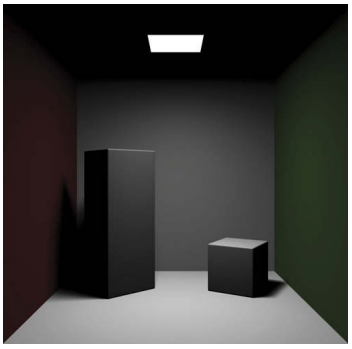
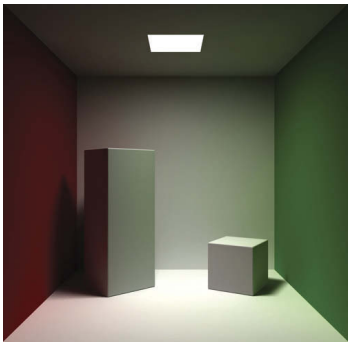
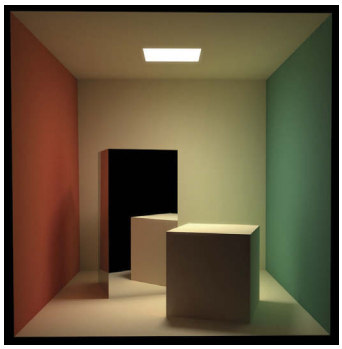
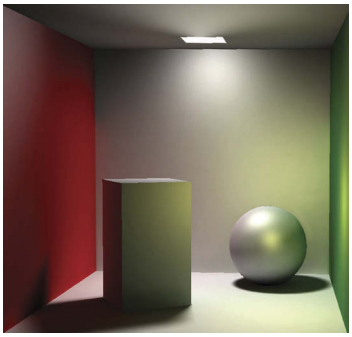
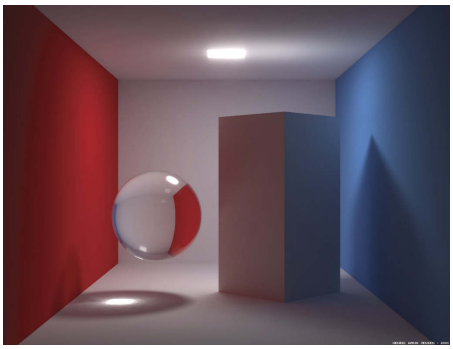
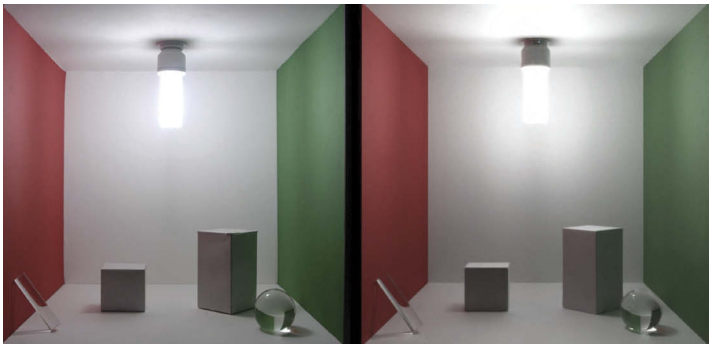
Rendering Method	Condition	Rendering
Radiative Transfer with Simple Photomettic Meshing	The surfaces were meshed photometrically; that is, discretized into smaller elements where large changes in luminance were anticipated. The radiative transfer solution gave a final exitance to each discretized element. The rendering used the centers of these discretized elements to locate the calculated exitances, and then interpolated smoothly between them. A more elaborate method is to account for the boundaries between discrete elements. In either case, this type of discretization only can produce artifacts. Since the surfaces are not necessarily discretized at points or lines of contact, shading can produce so-called light leaks or shadow leaks. Thus, the lower left corner of the box in the foreground appears to float.	
Radiative Transfer with Geometric and Photometric Meshing	In this case, the surfaces are discretized not only photometrically but also geometrically; being divided along lines defined by any edge of another surface that is in contact. This helps eliminate light and shadow leaks. There are almost always more discretized elements.	
Radiative Transfer Color Rendering Direct Light Only	This rendering was made with direct illumination only, the interreflected component was supressed. In this case, the spectral reflectivity of the surfaces is taken into account. That is, the grey assumption is not made. The left and right walls demonstrate the color (red and green) determined by their spectral reflectance and the SPD of the light source. No interreflected light means that the shadows are mostly umbral and the ceiling is completely unilluminated.	
Ray Tracing Color Rendering Direct and Interreflected light	In this case the iterreflected component is accounted for. The deeply saturated colored walls reflect radiation of relatively narrow spectral composition and so the interreflected light on the floor near the left and right walls is faintly red and green. This so-called color bleeding can only be modeled if the radiative transfer is conducted in multiple wavelength bands with the appropriate radiative power from the luminaire assigned to each band, and the appropriate surface reflectances used for each band. The result is a surface exitance for each element in each wavelength band. Alternatively, it has been shown that it is almost always a sufficiently accurate approximation to use three broadband analyses: corresponding to the red, green, and blue of the standard RGB.	

Table 10.2 | Examples of Rendering Using Different Procedures continued next page

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Table 10.2 | Examples of Rendering Using Different Procedures continued from preceding page

Rendering Method	Condition	Rendering
Ray Tracing with Diffuse and Perfectly Specular Surfaces	Ray tracing permits the surfaces in the space being modeled to have reflectance characteristics other than perfectly diffuse. In this case, ray tracing accounts for the perfect specularity of the mirror surfaces of the box in the background. In this analysis, the surfaces are either perfectly diffuse or perfectly specular. Though somewhat more elaborate than just a diffuse analysis, the information needed about the mirrors is relatively simple: its specular reflectance. Transfer off the mirror takes place only at pairs of angles obeying Snell's Law.	
Ray Tracing with BRDF Modeling of Surfaces	Ray tracing permits the realistic accounting for surfaces with arbitrary directional reflectances. These are almost always characterized by BRDF data. In this case, the sphere in the background has a satin-like finish, with a relatively strong specular component. Note the bright spot produced on the right green wall by flux from the luminaire reflecting off the sphere. The spectral analyses were done with broadand RGB.	
Photon Mapping and Ray Tracing with Transparency and Refraction	Photon mapping, a kind of view-independent pre-computing, permits quicker raytracing and, for a given computation time, more accurate rendering. Focusing effects, such as produced by the transparent sphere and the luminaire can be modeled.	
Ray Tracing Comparision with Photograph	The image on the left is a color photograph of a box that has been proportioned, papered, and furnitured to be like one of the most common, simple tests for computer renderings, the so-called "Cornell Box." On the right is a rendering produced with the reflectances and objects in the real box. The rendering is satisfactorily close to the photograph.	

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can be calculated directly from well-known theory [42]. Software can be tested by modeling these analytic conditions and comparing results. Situations have been defined to test various aspects of software. Figure 10.8 shows an analytic case to test direct illuminance calculations. The luminaire is analytically described and the illuminance at various points can be determined and compared to software predictions. Figure 10.9 shows a similar case for testing the direct component of daylighting. More complicated analytic test cases have been developed for testing interreflected components and the effect of obstructions, as shown in Figure 10.10

10.6.1.2 Measurement Tests

The CIE has also developed a set of photometric measurements of illuminance in a room containing various types of luminaires and surface reflectances. The photometric properties of the luminaires, surfaces, measurement equipment, and measurement process were accurately characterized [42]. Figure 10.11 shows a plan view of the room.

10.6.1.3 Testing software

The CIE data, and other sets of photometric measurements, have been used to test commercially available software, with generally good results [43] [44] [45] [46] [47].

10.7 Factors Affecting Lighting Calculations

10.7.1 Light Loss Factors

Light loss factors (LLF) adjust lighting calculations from laboratory to field conditions. They represent differences in lamp lumen output, luminaire output and surface reflectances between the two conditions. Calculations based on laboratory data alone are likely to provide unrealistic values if not modified by light loss factors. LLFs are assumed to represent independent effects and are therefore multiplicatively cumulative: the total light loss factor is the product of all the applicable factors. No factor should be ignored (set equal to 1) until investigations justify doing so.

LLFs are divided into recoverable and nonrecoverable. Recoverable factors are those that can be changed by regular maintenance, such as cleaning and relamping luminaires. Nonrecoverable factors are those attributed to equipment and site conditions and cannot be changed with normal maintenance.

10.7.1.1 Nonrecoverable Light Loss Factors

The nonrecoverable factors usually are not controlled by lighting maintenance procedures. Some will exist initially and continue through the life of the installation, either being of such little effect as to make correction needless, or being too costly to correct. Some, such as ballast factor, are inherent in the lighting equipment.

Luminaire Ambient Temperature Factor

The effect of ambient temperature on the output of some luminaires is considerable. Variations in temperature, within the range of those normally encountered in interiors, have little effect on the light output of incandescent and high-intensity discharge lamp luminaires, but appreciably affect the light output of fluorescent and LED luminaires. The luminaire ambient temperature factor accounts for the fractional lumen loss or gain of a fluorescent luminaire due to internal luminaire temperatures differing from the temperatures at which photometry was performed. This factor should take into consideration any variation in the temperature around the luminaire, the means and conditions of mounting the luminaire, and the use of any insulation in conjunction with the application of the luminaire.

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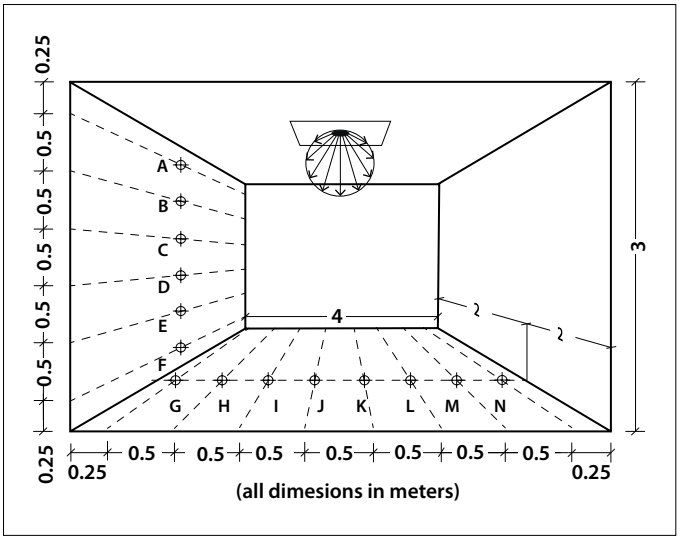


Figure 10.8 | CIE Computer Testing for Electric Lighting
CIE analytic test case for direct illuminance calculations. Point A through N are arranged in a zero reflectance room beneath a luminaire in the ceiling with an analytic intensity distribution.

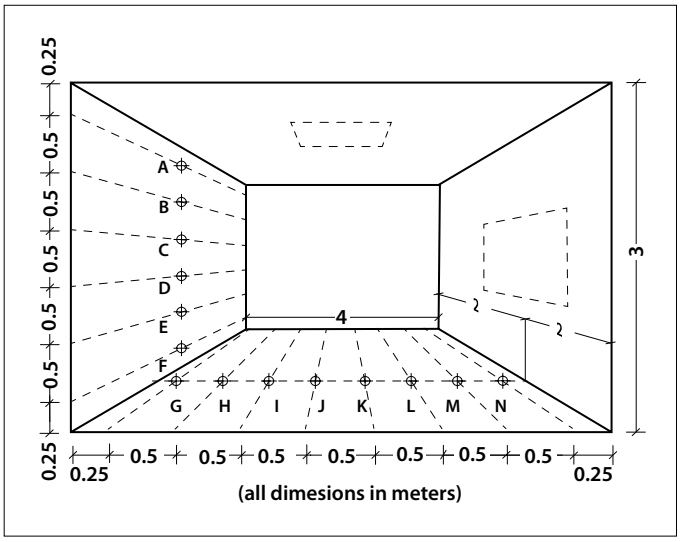


Figure 10.9 | CIE Computer Testing for Daylighting
CIE analytic test case for direct illuminance calculations for daylighting. Point A through N are arranged in a zero reflectance room with either a skylight or window located as shown by the dashed rectangles.

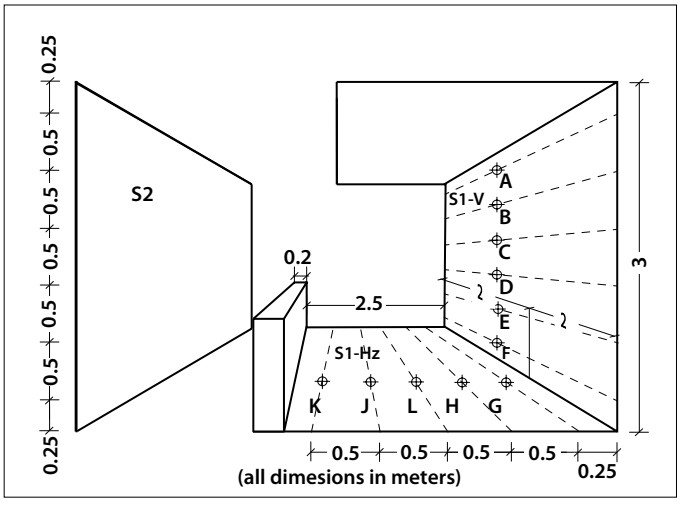
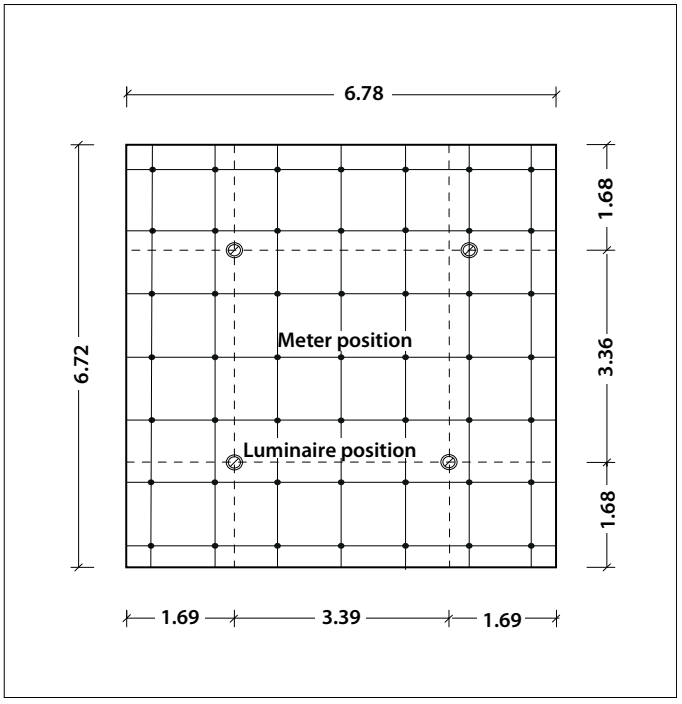


Figure 10.10 | CIE Computer Testing for Obstructions
CIE analytic test case for direct illuminance calculations for testing diffuse area source illuminance and the effect of occlusion.

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Figure 10.11 | CIE Computer Testing with Measurements
CIE photometric test room, with four luminaires and horizontal illuminance measurement points indicated. Different luminaire distributions and surface reflectances were used.



Heat Extraction Thermal Factor

Air-handling fluorescent luminaires are integrated with the HVAC system as a means of introducing or removing air. This will affect lamp temperature and consequently lamp lumens. The heat extraction thermal factor is the fractional lumen loss or gain due to the air flow. Generally, manufacturers provide specific luminaire test data for this factor at various air flows. Typically, the factor approaches a constant value for air flows in excess of 10-20 ft^3/min through the lamp compartment of an air-handling luminaire.

Voltage-to-Luminaire Factor

In-service voltage is difficult to predict, but high or low voltage at the luminaire affects the luminous output of many luminaires. For incandescent units, small deviations from rated lamp voltage cause approximately a 3% change in lumen output for each 1% of voltage deviation. The luminous output of fluorescent luminaires using conventional magnetic ballasts changes approximately 1% for each 2.5% change in primary voltage. Electronic ballasts for fluorescent and HID lamps, and drivers for LEDs, are usually capable of compensating for considerable change in input voltage and so lamp output is not affected.

Ballast Factor

The lumen output of fluorescent lamps depends on the ballast used to drive the lamps. The lumen output from lamps on commercial ballasts generally differs from that of lamps on the standard reference ballast used for determining rated lumens. For this reason, a multiplicative ballast factor is required to correct nominal rated lamp lumens to actual luminaire performance. The ballast factor is the fractional flux of a fluorescent lamp or lamps operated on the actual ballast divided by the flux when operated on the standard (reference) ballasting specified for rating lamp lumens. Ballast factors are determined in accordance with American National Standards Institute (ANSI) methods [48]. Manufacturers should be consulted for necessary factors. Data on ballast factors for electronic ballasts are available [49] [50].

The ballast factor depends on the lamp as well as on the ballast, so that a ballast factor developed for a standard lamp does not apply when, say, an energy-conserving lamp is used, even though the ballast is the same. The ANSI test method for the ballast factor specifies that the test be performed on a cold ballast (for convenience in testing).

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Significant temperature rise occurs for operating ballasts in luminaires. This causes additional lumen loss, usually on the order of 1.5%, but values as high as 2.5 to 3.5% have been reported.

Ballast-Lamp Photometric Factor
Fluorescent luminaire photometry is performed at a standard ambient temperature of 25°C (77°F). The lamp temperature will differ from this value when rated lamp lumens are determined. The consequent lamp lumen change from rated lumens is incorporated in the photometric data. The lamp temperature within the luminaire depends on the particular combination of ballasting and lamps. For this reason the photometric data apply only to the specific lamp and ballast types used in the tests. This also applies to the derived data such as coefficients of utilization.

Lamp lumen variations cause a change in the magnitude but not in the spatial distribution of fluorescent luminaire intensity. Consequently, all photometric data can be corrected by a multiplicative factor for ballast and lamp types that differ from those used in the photometric tests. This factor is the ballast-lamp photometric factor, and it is measured for a specific ballast-lamp combination in relation to those used in the luminaire photometry. Values for it are available as part of the luminaire photometric report or from the lamp manufacturer. Note that this factor includes adjustment for lamp and ballast changes at the photometric test temperature of 25°C (77°F). The luminaire ambient temperature factor is a separate correction for differences between the laboratory and the expected luminaire installation temperature.

Equipment Operating Factor
The lumen output of high-intensity discharge (HID) lamps depends on the ballast, the lamp operating position and the effect of power reflected from the luminaire back onto the lamp. These effects are collectively incorporated in the equipment operating factor (EOF), which is defined as the ratio of the flux of an HID lamp-ballast-luminaire combination, in a given operating position, to the flux of the lamp-luminaire combination operating in the position for rating the lamp lumens and using the standard (reference) ballasting specified for rating lamp lumens. Equipment operating factors are determined in accordance with the IES Approved Methods [51].

Lamp Position or Tilt Factor (Part of EOF)
For HID lamps, the lamp position factor (sometimes known as the tilt factor) is the ratio of the flux of a metal halide lamp in a given operating position to the flux when the lamp is operated in the position at which the lamp lumens are rated. This factor is determined at constant lamp wattage and constitutes part of the equipment-operating factor. The lamp position factor is reasonably consistent for mercury and HPS lamp types. Manufacturers should be consulted regarding specific lamp types. Tilt factors can be important in sports lighting applications where luminaires are aimed into orientations that position the lamp in something other than its position for rated lumens.

10.7.1.2 Recoverable Light Loss Factors
Recoverable factors always need to be considered in determining the total light loss factor. The magnitude of each will depend on the maintenance procedures to be used in addition to the physical environment and the lamps and luminaires to be installed.

Lamp Lumen Depreciation Factor
The lumen output of lamps changes gradually and continuously over their operating lives, even with constant operating conditions. In almost all cases, the lumens will decrease. The lamp lumen depreciation (LLD) factor is the fraction of the initial lumens produced at a specific time during the life of the lamp. Information about LLD as a function of the hours of lamp operation is available from manufacturers. The rated average life should

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be determined for the expected number of hours per start; it should be known when burnouts will begin in the lamp life cycle. From these facts, a practical group relamping cycle can be established, and then, based on the hours elapsed to lamp removal, the LLD factor can be determined. 70% of average rated life is the suggested criterion for lamp replacement for group relamping programs. It should be noted that some electronic ballasting systems compensate to varying degrees for change in lamp lumen output through life, either by an average correction or by feedback control. See 7.3.6.2 Lumen Maintenance and 7.4.5 Lamp Life and Lumen Maintenance for information on lumen depreciation of fluorescent and HID lamps.

Luminaire Dirt Depreciation Factor (non-industrial spaces)
The accumulation of dirt on luminaires and lamps results in a loss of light output. This loss is known as the luminaire dirt depreciation (LDD) factor and is determined for non-industrial spaces by the following steps [52].

1. Characterize the operating environment according to the degree of dirt judged to be present:
   - Clean: Institutional, retail, office areas, and similar environments using filtered air circulation generally associated with heating, cooling, and ventilation systems.
   - Moderate: Spaces not expected to reach the level of Clean, such as light industry or manufacturing, areas with significant air introduced through windows, or areas without air filtering.
   - Dirty: Spaces where normal activities introduce significant airborne dirt.

2. Place the luminaire into groups, according to its structural characteristics
   - Open/unventilated: Open at the bottom or with louvers or baffles, with a top enclosure which has no ventilating apertures to provide a free and steady path for the movement of air through the luminaire.
   - Other: All other luminaire structures including enclosed, bare lamps, strip luminaires, luminaires with significant opening at the top.

Table 10.3 | CIE Luminaire Classifications Based on Flux Distribution

Classification	Percent Up Light	Percent Down Light
Direct	0-10	90-100
Semi-Direct	10-40	60-90
General Diffuse	40-60	40-60
Semi-Indirect	60-90	10-40
Indirect	90-100	0-10

Table 10.4 | Combinations of CIE classifications and environments

Environment	Luminaire Ventilation	CIE Classification				
		Direct	Semi-Direct	General Diffuse	Semi-Indirect	Indirect
Clean	Open/Unventilated	W	W	W	X	X
	All Other	W	W	W	X	X
Moderate	Open/Unventilated	XY	XY	XY	Y	Y
	All Other	X	X	X	Y	Y
Dirty	Open/Unventilated	Z	Z	Z	Z	Z
	All Other	Y	Y	Y	Y	Y

Table 10.5 | Constants for LDD Equation

Constant	Letter Classification						
	W	WX	X	XY	Y	YZ	Z
A	0.024	0.020	0.018	0.037	0.059	0.050	0.044
B	0.440	0.596	0.700	0.586	0.535	0.670	0.785

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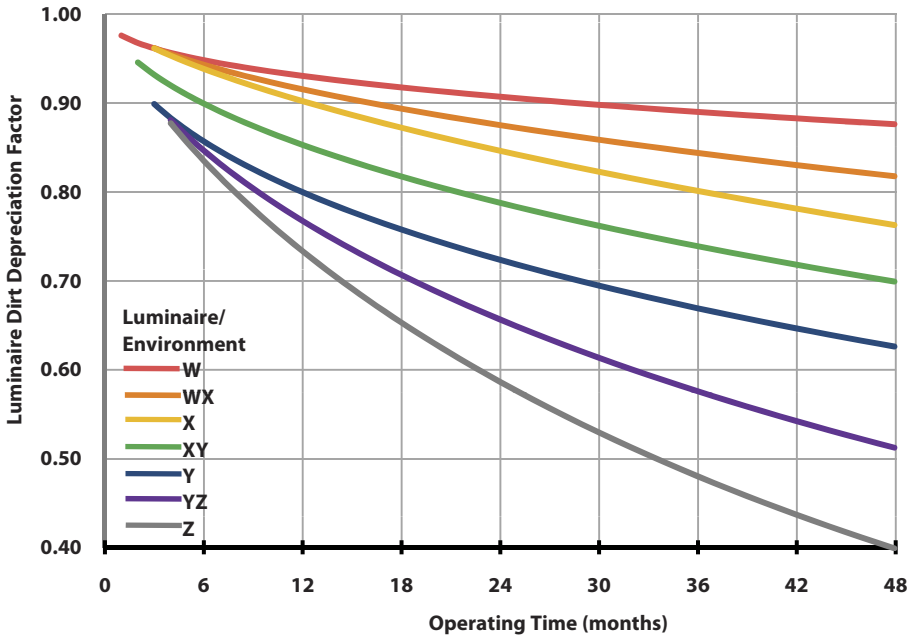


Figure 10.12 | Luminaire Dirt Depreciation Factors
Luminaire dirt depreciation factors as a function of luminaire/environment combinations and operating time, along with the constants for the governing equation.

3. Determine the luminaire's CIE classification. Laboratory photometric reports normally identify this classification for indoor luminaires. Otherwise, it can be found from the percentage of the luminaire's output directed in the upward and in the downward directions. Table 10.3 shows the classifications.

4. Determine a letter assignment (W, X, XY, Y, or Z) according to the appropriate environment and luminaire classification combination. See Table10.4.

5. Determine the LDD using the curve in Figure 10.12**,** which corresponds to the letter assignment made in step 4. The values plotted in the figure can also be calculated from:

$$LDD = e^{-A\,t^{B}} \qquad (10.23)$$

Where:

A and B are listed in Table 10.5 for different luminaire/environment combinations
t is in operating months.

Table 10.6 | Industrial Luminaire Maintenance Categories

Maintenance Category	Top Enclosure	Bottom Enclosure
I	No enclosure	No enclosure
II	No enclosure or enclosure with apertures allowing at least 15% uplight	No enclosure, perhaps louvers or baffles
III	Enclosure with apertures allowing at least 15% uplight	No enclosure, perhaps louvers or baffles
IV	Enclosure with no apertures	No enclosure, perhaps louvers
V	Enclosure with no apertures	enclosure with no apertures
VI	No enclosure or Enclosure with no apertures	enclosure with no apertures

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Table 10.7 | Industrial Luminaire Maintenance Environments

Environment	Types of Dirt and Process				
	Generated Dirt	Ambient Dirt	Removal or Filtration	Adhesion	Examples
Medium	Noticeable but not heavy	Some enters area	Poorer than average	Enough to be visible	Mill offices, paper processing
Dirty	Accumulates rapidly	Large amount enters area	Only fans or blowers, if any	High: due to oil, humidity, or static	Heat treating, high-seed printing
Very Dirty	Constant accumulation	Almost none excluded	None	High	Luminaire near area of contamination

Table 10.8 | Constants for Industrial Luminaire LDD Equation

Constant	Environment	Luminaire Maintenance Category					
		I	II	III	IV	V	VI
A	Medium	0.111	0.102	0.143	0.216	0.190	0.218
	Dirty	0.162	0.147	0.184	0.314	0.249	0.284
	Very Dirty	0.301	0.188	0.236	0.452	0.321	0.396
B		0.690	0.620	0.700	0.720	0.530	0.880

Luminaire Dirt Depreciation Factor (industrial spaces)
LDD factor for industrial spaces is determined by the following steps.

1. The luminaire maintenance category is selected from Table 10.6.

2. The atmosphere (one of three degrees of dirt conditions) in which the luminaire will operate is found from Table 10.7.

3. Using the applicable dirt condition and luminaire maintenance category, the appropriate constants are found for the equation giving the LDD:

$$LDD = e^{-A\,t^{B}} \qquad (10.24)$$

Where:

A and B are given in Table 10.8 for different luminaire/environment combinations
t is the elapsed time in years of the planned cleaning cycle

Lamp Burnout Factor
Lamp burnouts contribute to light loss. If lamps are not replaced promptly after burnout, the average illuminance will be decreased proportionally. In some instances, more than just the faulty lamp may be lost. For example, when series sequence fluorescent ballasts are used and one lamp fails, both lamps go out. The lamp burnout (LBO) factor is the ratio of the number of lamps remaining lighted to the total, for the maximum number of burnouts permitted.

Manufacturers' mortality statistics should be consulted for the performance of each lamp type to determine the number expected to burn out before the time of planned group replacement is reached. In practice, the number of lamp burnouts will be a reflection of the quality of the lighting maintenance services program.

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A large group of lamps of the same lamp type will fail in a predictable manner. For all but LEDs, a lamp's rated life is defined as that point in time where half of the large group can be expected to have failed. Published fluorescent lamp life data is based on three hours of operation per start [53]. High intensity discharge (HID) lamp life data is based on 11 hours per start [54]. Deviation from these hours of operation between lamp starts significantly affects average life. The life of fluorescent lamps on conventional magnetic ballasts typically increases relative to the rated life at three hours per start, as the number of operating hours per start increases. The improvement is about 30 percent for 10 hours per start, about 50 percent for 12 hours per start, and about 60 percent when the lamps operate continuously. These improvement percentages do not necessarily apply when electronic ballast technologies are used. In many cases the change in life with hours per start depends on the specific ballast and lamp types. Fluorescent lamp operating life may be relatively independent of operating hours per start on program-start operation.

10.8 Assessing Computed Results

When lighting calculations are used to assess lighting system performance, it is important that an appropriate method be used. Software is capable of producing a large amount of data, and measures constructed from these data must be chosen and used carefully if they are to support judgments about lighting system performance.

10.8.1 Averages

Average usually refers to the mean of several calculated or measured values. The greater the number of values, the more accurate the mean across a given area. Grids of calculation points are usually used, often formed by a rectangular array of rows and columns. Point spacing is determined by the accuracy requirements for the average.

An average can be accurate but it would never be indicative of the variation in values. For this reason, the average illuminance (or an average of any other quantity) should be used only when the distribution is expected to be relatively uniform across an area. When a localized lighting system is desired, such as task lighting or non-uniform lighting, average illuminance reveals little about the success of the design unless the analysis is limited to the local area. Similarly, an average ceiling luminance produced by an indirect lighting system is not a good measure of performance.

In general, an average value alone is not sufficient to fully describe or evaluate lighting system performance. Information on the uniformity and range of values is also important.

10.8.2 Minima and Maxima

If a large number of analysis points are used for calculation, then the variability of the lighting can be evaluated and the minimum and maximum values can be determined and located. The minima and maxima can be important indicators of the quality of the design, particularly if they deviate significantly from the desired average. In some design situations, maximum and/or minimum design values may be required criteria.

Uniformity is often expressed in terms of a ratio of two quantities. Examples are maximum to minimum, maximum to average, and average to minimum. Different design situations warrant different use of these metrics.

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10.8.3 Coefficient of Variation

Coefficient of variation (CV) is the unitless ratio of the standard deviation to the mean.

$$CV = \frac{\text{Standard Deviation}}{\text{Mean}} = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2}}{\bar{x}} \tag{10.25}$$

Where:

$\bar{x}$ = mean of the data values
N = number of data values

Roughly, CV is the average difference from the average, divided or scaled by the average. It expresses how far most of the values are from the average. CV is often presented as the given ratio multiplied by 100. The CV describes the dispersion of the data: the higher the CV, the greater the dispersion and the more different (higher or lower) the values are from the mean.

10.8.4 Criterion Ratings

The maximum and minimum values provide little information about the overall distribution of a particular photometric or derived quantity across a space. The criterion rating is a convenient way to obtain greater detail regarding the distribution of a quantity across a space. The criterion rating is the probability that a specific criterion will be met or exceeded anywhere within a defined area. It can be used in addition to (or instead of) concepts such as averages or minimum and maximum levels. Lighting criteria to which this technique may be applied include luminance, illuminance, contrast, visibility metrics and visual performance metrics.

The criterion rating assumes the name of the criterion being rated. For example, the criterion rating for illuminance is called the illuminance rating Assume, for example, that an illuminance of 300 lx has been established as the design criterion for a space. The illuminance rating defines the likelihood that at any point on the workplane the illuminance will be equal to or greater than 300 lx. This criterion rating is determined by evaluating the appropriate quantity at a grid of points covering the area in question. The distance between evaluation points must not exceed one-fifth the distance from any luminaire to the evaluation plane. The percentage of points that comply with the criterion is the criterion rating:

$$\text{Criterion Rating} = \frac{\text{number of points satisfying criterion}}{\text{number of points computed or measured}} 100 \tag{10.26}$$

Criterion ratings may be expressed using a notation which lists the rating, in percent, followed by the criterion, separated by the symbol @, which stands for “at.” For example, a lighting system producing a luminance of 20 cd/m^2 over 60% of the specified area may have its luminance rating expressed as 60%@20 cd/m^2.

10.9 Standardized Calculation Procedures

Some quantities are calculated frequently enough to warrant a standardized calculation procedure to help provide uniform processes, consistent bases for comparisons, and reliable and uniform data. Standardized procedures have been developed for calculating average illuminance and the potential for discomfort glare.

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10.9.1 Calculating Average Illuminance

The lumen method is used in calculating the average illuminance, $\bar{E}$, on a workplane in an interior, which is defined as

$$\bar{E} = \frac{\text{total flux onto workplane}}{\text{workplane area}} \tag{10.27}$$

A coefficient of utilization gives the fraction of lamp lumens that reach the workplane, directly from sources and from interreflections. The Coefficient of Utilization (CU) takes into account the efficiency of the luminaire and the impact of the luminaire distribution and the room surfaces in its derivation. The algorithm for calculating a CU is given in the Formulary. Thus the number of lumens produced by the lamps, multiplied by this CU, determines the number that reaches the workplane. Thus:

$$\bar{E}_{\text{maintained}} = \frac{(\text{total lamp lumens}) \times \text{CU} \times \text{LLF}}{\text{workplane area}} \tag{10.28}$$

Since the design objective is usually maintained illuminance, a light loss factor must be applied to allow for the estimated depreciation in lamp lumens over time, the estimated losses from dirt collection on the luminaire surfaces (including lamps) and other factors which affect luminaire lumen output over time. The formula thus becomes

$$\bar{E}_{\text{initial}} = \frac{(\text{total lamp lumens}) \times \text{CU}}{\text{workplane area}} \tag{10.29}$$

Where:

CU = coefficient of utilization
LLF = light loss factor

Although design calculations are based on the LLF using both non-recoverable and recoverable factors, it is sometimes necessary to calculate illuminance in a new lighting installation. In such cases, perform the calculation using the non-recoverable losses, since the recoverable losses will not have occurred at 100 hours, the time at which lamps are nominally at rated lumens.

The lamp lumens in the formula are most conveniently taken as the total rated lamp lumens in the luminaires:

$$\bar{E}_{\text{maintained}} = \frac{(\text{number of luminaires})(\text{lamps/luminaire}) \times (\text{total lamp lumens}) \times \text{CU} \times \text{LLF}}{\text{workplane area}} \tag{10.30}$$

If the desired maintained illuminance is known, this equation can be solved for the total number of luminaires needed:

$$\text{number of luminaires} = \frac{\bar{E}_{\text{maintained}} \times \text{workplane area}}{(\text{lamps/luminaire})(\text{total lamp lumens}) \times \text{CU} \times \text{LLF}} \tag{10.31}$$

10.9.1.1 Limitations

The illuminance computed by the lumen method is an average value that will be representative only if the luminaires are spaced to obtain reasonably uniform illuminance. The calculation of the coefficients of utilization is based on empty interiors having surfaces that exhibit perfectly diffuse reflectance. The average illuminance determined by the lumen method is defined to be the total lumens reaching the workplane, divided by

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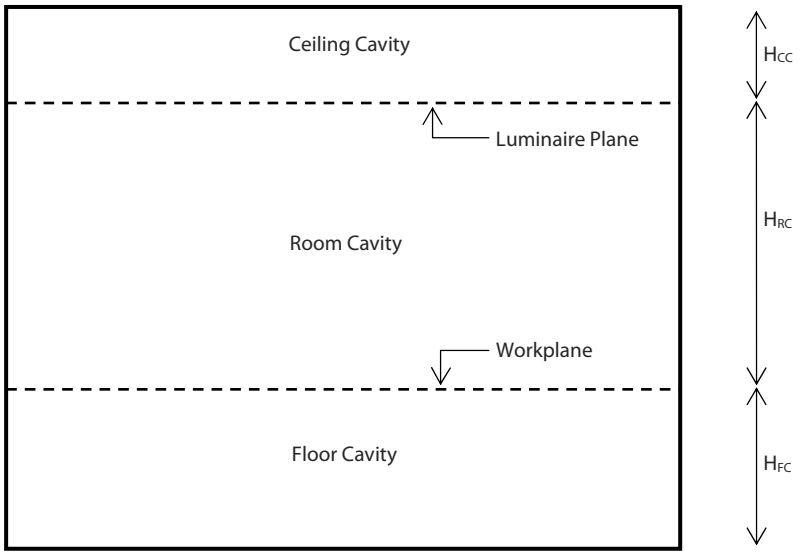


Figure 10.13 | Three Cavities Used in the Lumen Method
Vertical section through a rectangular room show heights used in the determination of room, ceiling, and floor cavity ratios for choosing an appropriate CU in the Lumen Method.

the area of the workplane. The average value determined this way might vary considerably from that obtained by averaging discrete values of illuminance at several points, especially if the number of points is small or the points do not extend over the entire workplane.

In the zonal-cavity method, the effects of room proportions, luminaire suspension length and workplane height upon the coefficient of utilization are respectively represented by the room cavity ratio, ceiling cavity ratio and floor cavity ratio. These ratios are determined by dividing the room into three cavities, as shown by Figure 10.13, and substituting dimensions (in feet or meters) into the following formula:

$$CR = \frac{5\,h\,(\text{cavity length} + \text{cavity width})}{\text{cavity length} \times \text{cavity width}} \text{ or } \frac{2.5\,(\text{perimeter length})}{\text{area}} \qquad (10.32)$$

Where:

h = h_{RC} for the room cavity ratio (RCR)
h = h_{CC} for the ceiling cavity ratio (CCR)
h = h_{FC} for the floor cavity ratio (FCR)

10.9.1.2 Effective Cavity Reflectances

A rectangular cavity consists of four walls, each having a reflectance of ρ_W, and a base of reflectance ρ_B (ceiling or floor reflectance). The effective reflectance, ρ_{eff}, of this cavity is the ratio of the flux reflected out to the flux entering the cavity through its opening. If the reflectances are assumed to be perfectly diffuse and the flux is assumed to enter the cavity in a perfectly diffuse way, it is possible to calculate the effective cavity reflectance using flux transfer theory. The result is

$$\rho_{eff} = \frac{\rho_B\,\rho_W\,f\left(2\frac{A_B}{A_W}(1-f)-f\right)+\rho_B f^2+\rho_W\frac{A_B}{A_W}(1-f)^2}{1-\rho_B\,\rho_W\frac{A_B}{A_W}(1-f)^2-\rho_W\left(1-2\frac{A_B}{A_W}(1-f)\right)} \qquad (10.33)$$

Where:

A_B, A_W = areas of the cavity base and walls, respectively,
ρ_B, ρ_W = reflectances of the cavity base and walls, respectively,
f = form factor between the cavity opening and the cavity base

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The form factor needed in Equation 10.33 can be approximated by

$$f \approx 0.026 + 0.502\, e^{-0.6750\frac{A_W}{A_B}} + 0.470\, e^{-0.2975\frac{A_W}{A_B}} \tag{10.34}$$

Equation 10.34 provides a means of converting the combination of wall and ceiling or wall and floor reflectances into a single effective ceiling cavity reflectance, ρ_{CC}, and a single effective floor cavity reflectance, ρ_{FC}. In lumen method calculations, the ceiling, wall and floor reflectances should be initial values. Note that for surface-mounted and recessed luminaires, the CCR equals 0 and the actual ceiling reflectance may be used for ρ_{CC}.

If the reflectance over one of the room surfaces varies considerably, an area-weighted average reflectance should be used. For example: when a high reflectance classroom wall is partially covered by a low reflectance chalk board.

10.9.2 Calculating Glare

The CIE has developed a unified glare rating (UGR) system intended for discomfort glare prediction that has been adopted by many nations. This formula is limited to those situations where the solid angle of the source, ω, is $0.0003 \leq \omega \leq 0.1$ steradian. For example, a troffer luminaire 0.6m x 1.2m (2ft x 4ft) in a 3 m (10 ft) high ceiling viewed from a distance of 9m (30ft) subtends a solid angle of 0.003 steradian. Extensions to this range of applicability have been suggested, but it is not yet clear how accurate they are [55]. Values of UGR range from 5 to 30, with higher numbers indicating greater discomfort glare.

UGR is calculated from

$$UGR = 8 \log_{10}\left(\frac{0.25}{L_b}\right)\sum_i \frac{L_i^2\, \omega_i}{P_i^2} \tag{10.35}$$

Where:

L_b =luminance of the field of view, in cd/m^2, which does not include luminaire luminance
L = luminance of a luminaire in the direction of the observer
ω = solid angle of a luminaire subtended to the observer
P = position index of luminaire

The position index of a source, P, is an inverse measure of the relative sensitivity to a glare source at different positions throughout the field of view. Selected values or families of curves were published in early references. P is given by the formula [56].

$$P = 10.36 \exp\left(\begin{array}{r}(35.2 - 0.31899\,\alpha - 1.22\, e^{-2\,\alpha/9})10^{-3}\,\beta + \\ (21 + 0.26667\,\alpha^2)10^{-5}\,\beta^2\end{array}\right) \tag{10.36}$$

Where:

α = elevation angle from line of sight, in the vertical plane, up to the source
β = azimuthal angle from the line of sight, in the horizontal plane, over to the source

In most applications, calculation and use of UGR has replaced VCP.

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10.10 References

[1] DiLaura DL. 2006. A history of light and lighting. New York. Illuminating Engineering Society. 402 p.

[2] [IES] Illuminating Engineering Society. 2005. Software survey. Light Des Appl. 35(9):69-77

[3] Ward GJ. 1994. The RADIANCE lighting simulation and rendering system. In: Proceeding of the 21st annual conference on computer graphics and interactive techniques. New York. ACM SIGGRAPH. 512 p.

[4] Sillion FX, Puech C. 1994. Radiosity and global illumination. San Francisco. Morgan Kaufmann. 251 p.

[5] Ashdown I. 1994. Radiosity: A programmer's perspective. New York. Wiley. 496 p.

[6] Lighting Technologies. 1987. Lumen Micro—User's guide. Boulder: Lighting Technologies. 71 p.

[7] DiLaura DL, Quinlan J. 1995. Non-Diffuse radiative transfer 1: Area sources and point receivers. J Illum Eng Soc. 24(2):102-113.

[8] Murdoch JB. 2003. Illuminating Engineering. 2nd edition. New York. Visual Communications. 750 p.

[9] .Hamilton DC, Morgan WR. 1952. Radiant-Interchange configuration factors. Technical Note 2836. Washington: National Advisory Committee for Aeronautics.

[10] Siegel R, Howel JR. 2002. Thermal radiation heat transfer. 4th edition. New York. Taylor & Francis.

[11] Gershun A. 1939. The light field. Moon P, Timoshenko GJ, trans. J Math Phys. 18(2):51-151.

[12] Yamauti Z. 1924. Geometrical calculation of illumination due to light from luminous sources of simple forms. Researches of the Electrotechnical Laboratory, 148. Tokyo: Electrotechnical Laboratory.

[13] Fock V. 1924. Zur Berechnung der Beleuchtungsstärke. Z Phys. 28:102-113.

[14] [IES] Illuminating Engineering Society. 2004. LM-46-04. IESNA Approved method for photometric testing of indoor luminaires using high intensity discharge or incandescent filament lamps. New York: IES. 15 p.

[15] Mistrick RG, English CR. 1990. A study of near-field indirect lighting calculations. J Illum Eng Soc. 19(2):103-112.

[16] Levin RE. 1971. Photometric characteristics of light controlling apparatus. Illum. Eng. 66(4):205-215

[17] Lautzenheiser T, Weller G, Stannard S. 1984. Photometry for near field applications. J Illum Eng Soc. 13(2):262-269.

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[18] Stannard S, Brass J. 1990. Application distance photometry. J Illum Eng Soc. 18(1):39-46.

[19] Ngai PY, Zhang JX, Zhang FG. 1992. Near-field photometry: Measurement and application for fluorescent luminaires. J Illum Eng Soc. 21(2):68-83.

[20] Ashdown I. 1993. Near-Field Photometry: A new approach. J Illum Eng Soc. 22(1):163-180.

[21] Ashdown I. 1998. Making near-field photometry practical. J Illum Eng Soc. 27(1):67-79.

[22] Murray-Coleman JF, Smith AM. 1990. The automated measurement of BRDFs and their application to luminaire modeling. J Illum Eng Soc. 19(1):87-99.

[23] Ward GJ. 1992. Measuring and modeling anisotropic reflection. Comp Graphics. 26(2):265-272.

[24] [IES] Illuminating Engineering Society. 2000. RP-8-00. Roadway lighting. New York: IES. 66 p.

[25] DeBoer J. 2006. Modeling indoor illumination by complex fenestration systems based on bidirectional photometric data. Energy Build. 38(7):849-868.

[26] Maamari F, Andersen M, de Boer J, Carroll W, Dumortier D, Greenup P. 2006. Experimental validation of simulation methods for bi-directional transmission properties at the daylighting performance level. Energy and Buildings. 38(7):218.

[27] [IES] Illuminating Engineering Society. 2002. LM-63-02. IESNA standard file format for the electronic transfer of hotometric data and related information. New York: IES. 16 p.

[28] Cohen MF, Wallace JR. 1993. Radiosity and realistic image synthesis. Boston, MA: Academic Press Professional.

[29] Dutré P. 2006. Advanced global illumination. Natick, MA: A K Peters. 366 p.

[30] Jongewaard M, Wilcox K. 2009. LED source models. LED Journal. Jan/Feb 2009 [Internet]. Available from: http://www.ledjournal.com/.

[31] Freniere ER, Gregory GG, Hassler RA. 1999. Polarization models for Monte Carlo ray tracing. In: Proceedings of the SPIE. 3780(22):148150.

[32] Jensen HW. 2001. Realistic image synthesis using photon mapping. Natick, MA: A K Peters. 181 p.

[33] Ashdown I. 1994. Radiosity: A programmer's perspective. New York: Wiley. 496 p.

[34] Pharr M, Humphreys G. 2004. Physically Based Rendering. Morgan Kaufmann. 1021 p.

[35] Birn J. 2000. Digital lighting & rendering. New Riders. 287 p.

[36] Kaneko T. 2001. Detailed shape representation with parallax mapping. In: Proceedings of ICAT 2001. pp 205-208.

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[37] Ruppertsberg AI, Bloj M. 2006. Rendering complete scenes for psychophysics using RADIANCE: How accurate can you get? J Opt Soc Am A. 23(4):759-768.

[38] Seetzen H, Whitehead L, Ward G. 2003. A high dynamic range display system using low and high resolution modulators. In: Proceesinds of the 2003 Society for information display symposium.

[39] Ledda P, Chalmers A., Trosciankko T, Seetzen H. 2005. Evaluation of tone mapping operators using a high dynamic range display. ACM Tran Graphics. 24(3):640-648.

[40] Johnson G, Fairchild M. 2003. Rendering HDR images. In: Proceedsing of Imaging Science and Technology & Society for Information Display. p 36-41.

[41] Reinhard E, Ward G, Pattanaik S, Debevec P. 2006. High dynamic range Imaging. San Francisco: Morgan Kaufman. 497 p.

[42] [CIE] Commission Internationale de l'Eclairage. 2006. Test cases to assess the accuracy of lighting computer programs. Austria: CIE. 99 p.

[43] Maamari F, Fontoynont, Adra N. 2006. Application of the CIE test cases to assess the accuracy of lighting computer programs. Energy and Build. 38:869-877.

[44] Slater A, Graves H. 2002. Benchmarking lighting design software. TM 28. London. CIBSE. 30 p.

[45] Geisler-Moroder D, Dür A. 2008. Validation of Radiance against CIE 171:2006. In: 7th International Radiance Workshop. Switzerland. 2008.

[46] Dau Design Consulting. 2007. Validation of AGi32 against CIE 171:2006. Calgary: Dau Design Consulting. 62 p.

[47] Laouadi A, Arenault C. 2006. Validation of skylight performance assessment software. ASHRAE Trans. July 2006

[48] [ANSI] American National Standards Institute. 2002. American national standard methods of measurement of fluorescent lamp ballasts, ANSI C82.2-2002. New York: ANSI.

[49] Lighting Research Center. 2000. Electronic ballasts. NLPIP specifier report. Troy, NY: Rensselaer Polytechnic Institute.

[50] Lighting Research Center. 2003. Adaptable ballasts. NLPIP lighting answers. Troy, NY: Rensselaer Polytechnic Institute.

[51] [IES] Illuminating Engineering Society. 2006. LM-61-06.IESNA approved guide for identifying operating factors influencing measured vs. predicted performance for installed outdoor high intensity (HID) luminaires. New York. IES. 15 p.

[52] [IES] Illuminating Engineering Society. 2001. IESNA/NALMCO RP-36-03 Recommended practice for planned indoor lighting maintenance. New York: IES. 34 p.

[53] [IES] Illuminating Engineering Society. 2001. LM-40-01, IESNA Approved Method for Life Testing of Fluorescent Lamps.

[54] [IES] Illuminating Engineering Society. 2001. LM-47-01, IESNA Approved Method for Life Testing of High Intensity Discharge (HID) Lamps

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[55] Eble-Hankins M, Waters CE. 2009. Subjective impression of discomfort glare from sources of non-uniform luminance. Leukos 6(1): 51-77.

[56] Levin RE. 1975. Position index in VCP calculations; An assessment. J Illum Eng Soc. 4(2):99-105.

[57] Siegel, R. 2010. Thermal Radiation Heat Transfer. 5th ed. CRC Press; 1012 p.

10.11 Formulary

10.11.1 Calculating Configuration Factors

Equation 10.9 gives the general form for calculating a radiative transfer configuration factor. For many geometric settings a convenient coordinate system can be found and each component of the integral made specific to that coordinate system. In many cases the resulting double (that is, area) integral has a closed form. Extensive tabulations of equations for specific geometries are available [57]. Equations are given here for commonly occurring geometric settings found in architectural ligthting.

Point in a Plane and a Rectangle in a Parallel Plane

$$c = \frac{1}{2\pi}\sum_{i=1}^{2}\sum_{j=1}^{2} F(x_i, y_j)(-1)^{i+j}$$

$$F(x_i, y_j) = \frac{x_i}{\sqrt{x_i^2 + z^2}}\arctan\left[\frac{y_j}{\sqrt{x_i^2 + z^2}}\right] + \frac{y_j}{\sqrt{y_j^2 + z^2}}\arctan\left[\frac{x_i}{\sqrt{y_j^2 + z^2}}\right] \quad \text{(F10.1)}$$

Point in a plane and a Rectangle in a Perpendicular Plane

$$c = \frac{z}{2\pi}\sum_{i=1}^{2}\sum_{j=1}^{2} F(y_i, z_j)(-1)^{i+j}$$

$$F(x_i, y_j) = \frac{-1}{\sqrt{x^2 + y_i^2}}\arctan\left[\frac{z_j}{\sqrt{x^2 + y_i^2}}\right] \quad \text{(F10.2)}$$

Point in a Plane and a Circle in a Parallel Plane

$$H = \frac{h}{a}; R = \frac{r}{a}; Z = 1 + H^2 + R^2$$

$$c = \frac{1}{2}\left(1 - \frac{1 + H^2 - R^2}{\sqrt{Z^2 - 4R^2}}\right) \quad \text{(F10.3)}$$

Point in a plane and a Circle in a Perpendicular Plane

$$H = \frac{h}{\ell}; R = \frac{r}{\ell}; Z = 1 + H^2 + R^2$$

$$c = \frac{H}{2}\left(\frac{Z}{\sqrt{Z^2 - 4R^2}} - 1\right) \quad \text{(F10.4)}$$

Figure F10.1 | Geometry for Equation F10.1

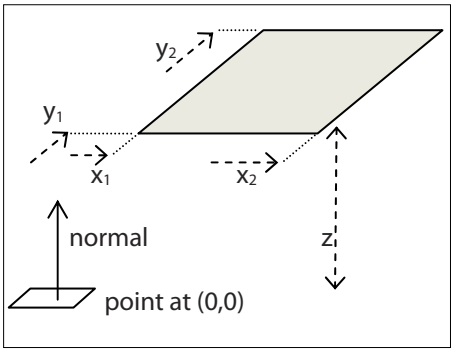


Figure F10.2 | Geometry for Equation F10.2

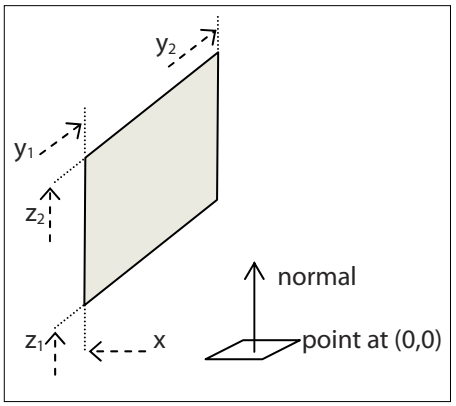


Figure F10.3 | Geometry for Equation F10.3

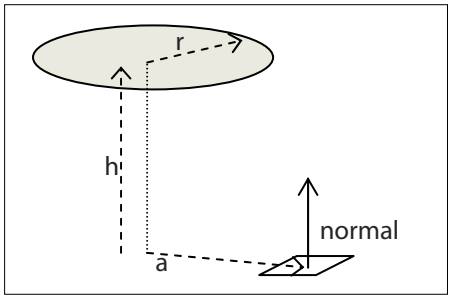
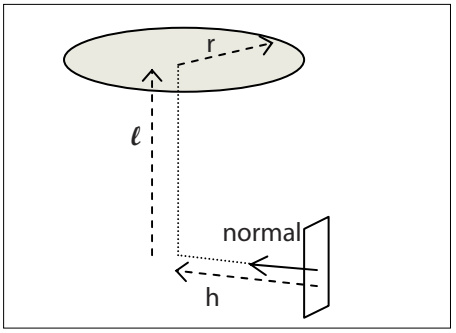


Figure F10.4 | Geometry for Equation F10.4



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Figure F10.5 | Geometry for Equation F10.5

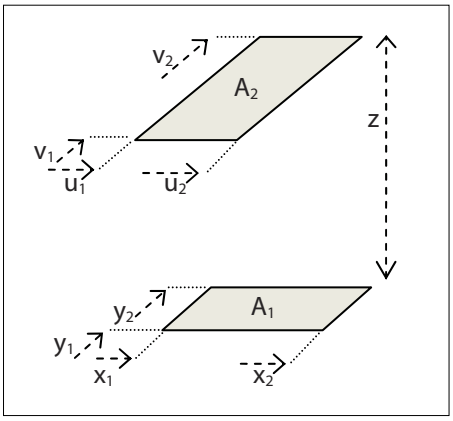
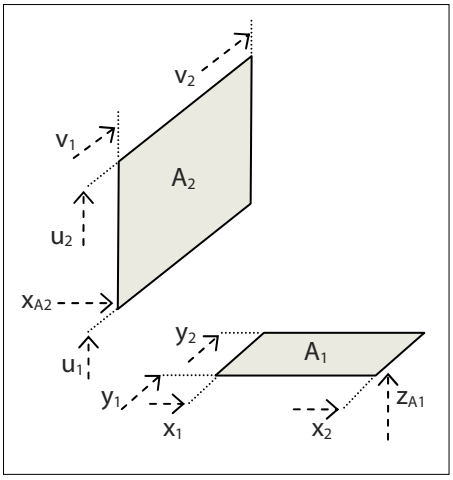


Figure F10.6 | Geometry for Equation F10.6



10.11.2 Calculating Form Factors

Equation 10.13 gives the general form for calculating radiative transfer form factors. As with configuration factors, some geometric settings permit closed form integration. Equations are given here for commonly occuring geometric settings found in architectural lighting. These equations assume that there are no occluding elements between the surfaces involved; any point on the first surface has a complete view of the second surface.

Rectangles in Parallel Planes with Parallel or Perpendicular Edges

$$F_{1\to 2} = \frac{z^2}{2\pi A_1}\sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2}\sum_{m=1}^{2} H(u_i, v_j, x_k, y_m)(-1)^{i+j+k+m}$$

$$a = \frac{x_k - u_i}{z};\ b = \frac{y_m - v_j}{z} \qquad \text{(F10.5)}$$

$$H(u_i, v_j, x_k, y_m) = b\sqrt{1+a^2}\arctan\left[\frac{b}{\sqrt{1+a^2}}\right] + a\sqrt{1+b^2}\arctan\left[\frac{a}{\sqrt{1+b^2}}\right] - \frac{1}{2}\ln\left[1 + a^2 + b^2\right]$$

Rectangles in Perpendicular Planes with Parallel or Perpendicular Edges

$$F_{1\to 2} = \frac{1}{2\pi A_1}\sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2}\sum_{m=1}^{2} G(v_i, z_j, x_k, y_m)(-1)^{i+j+k+m}$$

$$a = y_m - v_j;\ b = z_{A_1} - u_i;\ c = x_k - x_{A_2} \qquad \text{(F10.6)}$$

$$G(u_i, v_j, x_k, y_m) = a\sqrt{c^2+b^2}\arctan\left[\frac{a}{\sqrt{c^2+b^2}}\right] + \frac{1}{4}(a^2 - b^2 - c^2)\ln\left[a^2 + b^2 + c^2\right]$$

10.11.3 Calculating Lumen Method Coefficients of Utilization

Tables of coefficients of utilization (CUs) can be prepared by systematic procedures. It is desirable to standardize the process for producing published tables of these values to prevent misunderstandings and to facilitate direct comparisons of the data for different luminaires. These coefficients are derived from the equations described under radiative transfer theory in the section on Basic Principles above. The basic assumptions used to develop the zonal cavity coefficients are:

- Room surfaces are Lambertian reflectors
- The incident flux on each surface is uniformly distributed over that surface
- The luminaires are uniformly distributed throughout the room (uniformly dense but not necessarily in a uniform pattern)
- The room is empty
- The room surfaces are spectrally neutral

Full tables of CUs provide values for at least these ceiling reflectances: 0.80, 0.70, 0.50, 0.30, 0.10, and 0.0. At each of these ceiling reflectances, values are provided for at least these wall reflectances: 0.70, 0.50, 0.30, and 0.0. It is recognized that space limitations often necessitate abridgements. In that case, only the columns for ρ_{CC}=80, 50, and 10% are recommended for luminaires having 0-35% of their output in the 90-180° zone; and 80, 70, and 50% for luminaires having over 35% of their output in that zone. Also, the ρ_{CC}=10% columns are not required for abridged tables. It is recommended that CUs be published to two decimal places. The computation of CUs is performed according to the following algorithm.

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1. Define 18 conic solid angle zones of 10° width from the nadir to the zenith about the luminaire, where the index of each zone, N, is an integer between 1 and 18 inclusive.

2. Determine the flux Φ_N (lumens) in the various zones:

   - The flux in a conic solid angle is given by

$$\Phi_N = 2\pi\, I_{\theta_N}(\cos(\theta_N) - \cos(\theta_{N+1})) \qquad \text{(F10.7)}$$

   Where:

   $I_{\theta N}$ = midzone intensity, in cd, for the Nth zone,
   θ_N, θ_{N+1} = bounding cone angles.

   - If the intensity is not rotationally symmetric about the vertical axis, average the intensity about the vertical axis at each vertical angle θ. Note that the intensity must be sampled at equal angular intervals about the vertical axis. For example, if the intensity is known for three vertical planes [$I_{\theta,90°}$ (perpendicular), $I_{\theta,45°}$ and $I_{\theta,0°}$ (parallel)], then

$$I_\theta = \frac{1}{4}(I_{\theta,0°} + 2\, I_{\theta,45°} + I_{\theta,90°}) \qquad \text{(F10.8)}$$

   While three planes are sufficient for luminaires of nominal rotational symmetry, photometric data at 15° or 22.5° increments about the vertical axis are preferred for luminaires without this symmetry.

   - If the intensity is taken at 10° vertical intervals (θ=5°, 15°, 25°,...), then the flux Φ_N is determined by the application of F10.7 to the full zone. It is preferred to have intensity values at 5° vertical angles (θ=2.5°, 7.5°, 12.5°,...). Then zone N is divided into two parts, F10.7 is applied to each part, and the resulting flux is summed.

3. Determine the additional flux functions:

$$\Phi_{luminaire} = \sum_{N=1}^{18} \Phi_N \qquad \text{(F10.9)}$$

$$\eta_{down} = \frac{1}{\Phi_{lamps}} \sum_{N=1}^{9} \Phi_N \qquad \text{(F10.10)}$$

$$\eta_{up} = \frac{1}{\Phi_{lamps}} \sum_{N=10}^{18} \Phi_N \qquad \text{(F10.11)}$$

Where:

$\Phi_{luminaire}$=total flux emitted by the luminaire
Φ_{lamps}=total flux emitted by the lamps in the luminaire
η_{down}=proportion of lamp flux leaving the luminaire in a downward direction
η_{up}=proportion of lamp flux leaving the luminaire in an upward direction

Table 10.9 | Constants for Zonal Multiplier Equation

Zone (N)	A	B
1	0	0
2	0.041	0.98
3	0.070	1.05
4	0.100	1.12
5	0.136	1.16
6	0.190	1.25
7	0.315	1.25
8	0.640	1.25
9	2.10	0.80

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Table 10.10 | Form Factors for RCRs

RCR	Form Factor
0	1.000
1	0.827
2	0.689
3	0.579
4	0.489
5	0.415
6	0.355
7	0.306
8	0.265
9	0.231
10	0.202

4. Determine the direct ratio, D_{RCR}, related to the fraction of luminaire flux below the horizontal which is directly incident on the workplane:

$$D_{RCR} = \frac{1}{\eta_{down}\,\Phi_{lamps}} \sum_{N=1}^{9} K_{RCR,N}\,\Phi_N \tag{F10.12}$$

Where:

RCR = room cavity ratio, between 1 and 10 inclusive,
$K_{RCR,N}$ = zonal multipliers.

The zonal multiplier is the fraction of downwarddirected flux directly incident on the workplane (lower surface of room cavity) for each zone N. The zonal multipliers are functions of the RCR:

$$K_{RCR,N} = \exp[-A \cdot RCR^{B}] \tag{F10.13}$$

Where:

A and B are constants and are given in Table 10.9

5. Determine the parameters C_1, C_2, C_3, and C_0 as an intermediate step. In the formulas below, ρ_W is the wall reflectance, ρ_{CC} is the ceiling cavity reflectance, and ρ_{FC} is the floor cavity reflectance, which is taken as 0.2 for standard coefficient tables. $F_{CC\rightarrow FC}$ is the form factor from the ceiling cavity to the floor cavity shown in Table 10.10. For computer software F10.5 can be used to determine $F_{CC\rightarrow FC}$.

$$C_1 = \frac{(1-\rho_W)(1-f_{CC\rightarrow FC}^2)RCR}{2.5\,\rho_W(1-f_{CC\rightarrow FC}^2) + RCR\,f_{CC\rightarrow FC}(1-\rho_W)} \tag{F10.14}$$

$$C_2 = \frac{(1-\rho_{CC})(1+f_{CC\rightarrow FC})}{1+\rho_{CC}f_{CC\rightarrow FC}} \tag{F10.15}$$

$$C_3 = \frac{(1-\rho_{FC})(1+F_{CC\rightarrow FC})}{1+\rho_{FC}F_{CC\rightarrow FC}} \tag{F10.16}$$

$$C_0 = C_1 + C_2 + C_3 \tag{F10.17}$$

6. Determine the CU for each combination of reflectances and RCR:

$$CU_{RCR;\,\rho_{CC},\,\rho_W,\,\rho_{FC}} = \frac{2.5\,\rho_W C_1 C_3 (1-D_{RCR})\eta_{down}}{RCR\,(1-\rho_W)(1-\rho_{FC})C_0} + \frac{\rho_{CC}C_2C_3\eta_{up}}{(1-\rho_{CC})(1-\rho_{FC})C_0} + \left(1-\frac{\rho_{FC}C_3(C_1+C_2)}{(1-\rho_{FC})C_0}\right)\frac{D_{RCR}\,\eta_{down}}{1-\rho_{FC}} \tag{F10.18}$$

7. The above equations can be used to calculate the CU when the RCR equals zero, but the forms of the equations must be arranged to avoid division by zero. It is simplest to use the following relationships:

$$CU_{0;\,\rho_{CC},\,\rho_W,\,\rho_{FC}} = \frac{\eta_{down} + \rho_{CC}\eta_{up}}{1-\rho_{CC}\rho_{FC}} \tag{F10.19}$$

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10.11.4 Calculating Spacing Criterion

The calculation of luminaire spacing criterion is based on the following two premises:

1. When two similar conventional luminaires are near their maximum spacing, the illuminance directly under a luminaire is principally due to the overhead luminaire. Further, a very probable point of low illuminance will be at the midpoint between two luminaires. The maximum spacing at a given mounting height above the workplane is chosen such that the illuminance halfway between the two luminaires and due to both luminaires equals the illuminance under one due to that one luminaire only.

2. Another likely point for low illuminance is at the center of a square array of adjacent luminaires. The maximum spacing at a given mounting height above the workplane is chosen such that the illuminance at the center of the array of luminaires due to all four luminaires equals the illuminance under one due to that one luminaire only.

The maximum spacing (expressed as a spacing-to-mounting-height ratio) that fulfills each of the above conditions can be determined using the intensity distribution of the luminaire. For the purpose of establishing this criterion, it is assumed that the inverse square law is valid. This is the only assumption for the computations. For luminaires with azimuthally symmetric intensity distributions, a single azimuthal plane of data can be used. Otherwise, it is necessary to use three planes of data, usually $\psi = 0^{o}$, $\psi = 45^{o}$, and $\psi = 90^{o}$, and report two values of spacing criterion, one associated with $\psi = 0^{o}$ ("parallel") and one associated with $\psi = 90^{o}$ ("perpendicular").

For condition 1, assuming an arbitrary height, h, above the workplane:

$$E_{below} = E_{between}$$
$$\frac{I(0,\psi)}{h^2} = \frac{2\,I(\theta,\psi)\cos^3(\theta)}{h^2} \qquad \text{(F10.20)}$$
$$I(0,\psi) = 2\,I(\theta,\psi)\cos^3(\theta)$$

Where:

E_{below} = Illuminance directly beneath one luminaire due to that luminaire only
$E_{between}$ = Illuminance midway between luminaires, due to both luminaires
ψ = angle of azimuthal plane used to determine the criterion

The elevation angle, θ, is found that gives intensities that satisfy Equation F10.20.

$$I(\theta,\psi) = \frac{I(0,\psi)}{2\cos^3(\theta)} \qquad \text{(F10.21)}$$

Finding the value of θ that satisfies Equation F10.21 usually requires search and interpolation. The spacing criterion for two luminaires, SC_2, is then

$$SC_2 = \frac{h\tan(\Theta_2)}{h} = \tan(\Theta_2) \qquad \text{(F10.22)}$$

Where:

Θ_2 = angle θ satisfying Equation F10.21

This procedure is repeated considering four luminaires. In this case

$$I(\theta,\psi) = \frac{I(0,\psi)}{4\cos^3(\theta)} \qquad \text{(F10.23)}$$

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Where:

$\psi = 45^0$

Finding the value Θ_4 that satisfies Equation F10.23 gives

$$SC_4 = \frac{h \tan(\Theta_4)}{h} = \tan(\Theta_4) \qquad \text{(F10.24)}$$

The spacing criterion for the luminaire is the smallest of SC_2 and SC_4.

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Design

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Design

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DESIGN

This section of The Lighting Handbook brings together chapters dealing with those aspects of lighting design common to most applications. Two preliminary chapters place lighting design within the larger context of the building design process and set out those aspects of architecture and human perception that combine to produce the luminous environment.

The chapter on the application aspects of electric light sources is unique as a source of information about lamps. Importantly, it should be considered as one of a pair, along with the chapter on lamps in the *Framework* section of the book. There the user will find the technical issues of lamp operation and characteristics. Together, these chapters present information on how lamps work, their operating characteristics, and application issues such as lumen maintenance and dimming. As such, these chapters describe generic types of lamps; detailed and specific data for a particular lamp is best obtained from manufacturers' catalogs.

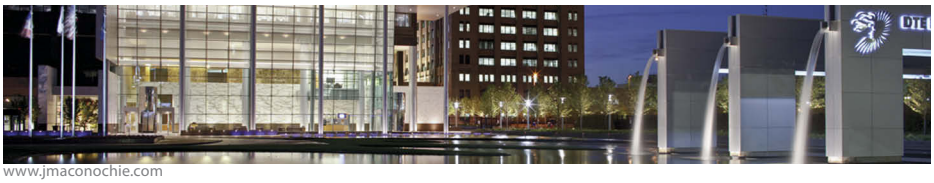
The chapter on daylighting design provides an extensive treatment that begins with the information, will, and considerations that must be an early part of the building design process if daylighting is to be a significant component of the lighting system. The design process, daylight delivery technology, and daylight performance measures are all subsequently covered.

The chapter on electric lighting design presents the general character and equipment of electric lighting. This is followed by a discussion of lighting designing, modeling methods to test designs, and some of the practical aspects of lighting systems that affect design. Other aspects common to most lighting designs are treated in chapters devoted to energy management, controls, economics, and sustainability.

Design chapters have been written as, and should be considered to be, not only a compilation of factors common to all lighting design but also as antecedent to all the chapters in the *Applications* section. The chapters there have been written with a reliance on the material presented here in the *Design* section, and should not be used without an understanding of this material.

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11 | LIGHTING DESIGN IN THE BUILDING DESIGN PROCESS

In theory, there is no difference between theory and practice. In practice there is.
Yogi Berra, 20th Century American Baseball Player

Theory—that body of lighting phenomena, facts, and principles—is the essence of this handbook. Knowing theory is one requisite of lighting design. Designing lighting in the vacuum of analytic checklists, principles, and rules increases the likelihood of a technically adequate solution, but not necessarily the right solution for a given building and group of users. Alternatively, designing lighting purely on aesthetics may result in a photogenic setting that lacks in sustainable and satisfactory performance. Successful lighting design blends the analytic and aesthetic aspects. Chapters 11 and 12 detail a design process and key analytic and aesthetic aspects useful in lighting design. Chapters 14 and 15 discuss equipment, techniques, and strategies for daylighting and electric lighting respectively. Whichever team member serves the role of the designer of the lighting, commonly referenced throughout as the *lighting designer*, on a given project may have an interest.

This introductory chapter to the Design Section is unlike any before it in the previous nine editions of the IES Handbook. The very nature of design is to explore individual and team ideas for solving design problems. Presentation of this material does not have the structure of engineering principles. This and other design chapters may read less like a handbook of rote procedures and formulae and more like a collection of notes: intended to stimulate and advance design. Some chapters in this Design Section exhibit quite a number of sidebars introduced for convenient reference of concepts and clarity of purpose when discussing issues of design practice more so than engineering.

11.1 Lighting Design

Who will champion lighting on a project? Architects, interior designers, electrical engineers, lighting consultants, owners, energy engineers, sustainability consultants, lighting product representatives, lighting manufacturers, contractors, and distributors are empowered with this handbook to make better-informed decisions about lighting. Any one of these members of the design and construction team can champion lighting. The material which follows here and in Chapters 12, 15, and 20 is *indicative* of how lighting design can be accomplished and assumes some *reader background* and familiarity with some keywords.

11.1.1 Design Process

Keeping an eye on the prize is crucial. If lighting design is not properly addressed, then the result can be sub-optimal lighting solutions and lost opportunity to maximize benefit of the building costs, embodied energy in the building, and lighting energy.

The process outlined here will help lighting designers establish lighting layouts and equipment choices based on a full set of criteria. Paralleling the building design process helps determine the priorities and design strategies that the team develops and uses for the overall project. Without knowing, understanding, assessing, and contributing to these priorities and strategies, it is misguided to take a plan, make a layout, specify the lights and expect

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Lighting designer is a reference to whichever team member is responsible for lighting design on a project.

Indicative meaning anecdotal, but backed by some research or influenced, if not quantified by fundamentals and rules outlined in this handbook. The material in these chapters is assembled into an approach to design and should not be considered *the* approach.

Reader background includes having some understanding of the material presented in the FRAMEWORK FOR LIGHTING Section of this handbook and a willingness to reference that section frequently. A common understanding of some key design terms as used here when discussing lighting is helpful, including:

Approach: also called technique (see below).

Concept: also called technique (see below).

Criteria: benchmarks for judging techniques or a design.

Design: complete composition of strategies.

Goals: objectives or intentions.

Scheme: untested partial composition of strategies.

Solution: tested design that satisfies all, most, or key criteria priorities as agreed by team and client.

Strategy: a method involving various techniques.

Targets: goals specifically associated with light levels or illuminances

Technique: means to address one criterion or perhaps several criteria.

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competent, integrated results, let alone a user-satisfying design. Except for the very talented few or lucky, lack of process contributes to less-optimal designs and ultimately a greater waste of earth resources.

11.1.2 Teamwork

Regularly-scheduled team communication and coordination are important. Communication and coordination can lead to improved building systems integration and design which is a hallmark of an Integrated Building Design Process. [1, 2] When such an integrated approach is lacking, it may be necessary for a lighting champion to engage in the communication and coordination chain.

11.1.3 Process Outline

What follows is an outline of a lighting design process in the context of a building design process. Lighting should inspire the building design process and vice versa. Great opportunity exists for architecture, interior design, and landscape architecture to help meet *clients*' lighting needs. Lighting uses earth resources in its manufacture, transportation, installation, and operation. Lighting is the building system that renders the visual scene and establishes the utility of that scene. So it is that more successful, efficient, sustainable *settings* are to be had where lighting influences architectural, interiors, and landscape designs.

Clients in this context refers to the end user or end users or to the client-entity known as the owner, developer, corporate project manager. An end user could be a homeowner. End users could be workers in a building.

Settings is used as reference to the built environment, whether interior or exterior. Used interchangably with environment and scene.

Progressive planning refers to a planning process that engages many disciplines, including lighting in the site selection and schematic design where lighting can influence siting and architectural form and geometry.

Conventional planning is a reference to the typical process of site selection and project design based on client programming requirements. Lighting is typically not a part of this planning process.

High performance buildings are defined by The Energy Independence and Security Act of 2007, TITLE IV - Energy Savings in Buildings and Industry, SEC. 401, as buildings that integrate and optimize on a life cycle basis all major high performance attributes, including energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations.

11.2 Planning

Planning on many building projects involves some form of site selection and then programming that is used to determine space types, sizes, and relative positions. This may involve new construction or renovation or rehabilitation construction. The planning approaches—*progressive* planning or *conventional* planning—and site selection, programming, and architectural schematic development significantly affect the degree to which the lighting succeeds.

11.2.1 Progressive Planning

A progressive approach to planning uses lighting as an influence in site selection, programming, building orientation and siting, and architectural schematics. 14 | DESIGNING DAYLIGHTING and specifically 14.3.1 Site and Climate and 14.4 Building Geometry and Materials identify synergies between daylighting and siting and facades. Some degree of lighting participation in programming assures exploration of the functional and aesthetic visual needs of clients. This in turn provides the basis for choosing lighting effects, lighting equipment, and layouts. Although practiced by few of the more experienced or avant-garde design teams, most progressive planning does involve greater risk of failure or greater time and fee to study out-of-the-box ideas and options. Figure 11.1 captures results of progressive planning addressing daylighting design aspirations.

Earlier and more extensive and intensive lighting participation in the planning process better enables the team to influence siting and landscape parameters that drive better daylighting and to influence architectural parameters that drive better daylighting and electric lighting. Lighting energy is highly scrutinized and sustainable design is epitomized by efficient daylighting and electric lighting, so progressive planning is an obvious and desirable tack and an approach to a *high performance building*.

11.2.2 Conventional Planning

With conventional planning, an architectural form is developed to hold the programmed spaces on the selected site for new construction. If renovated or rehabilitated construction is involved, then the interior architecture geometry is reconfigured to hold the programmed spaces. After some amount of design work and review with the clients, an architectural

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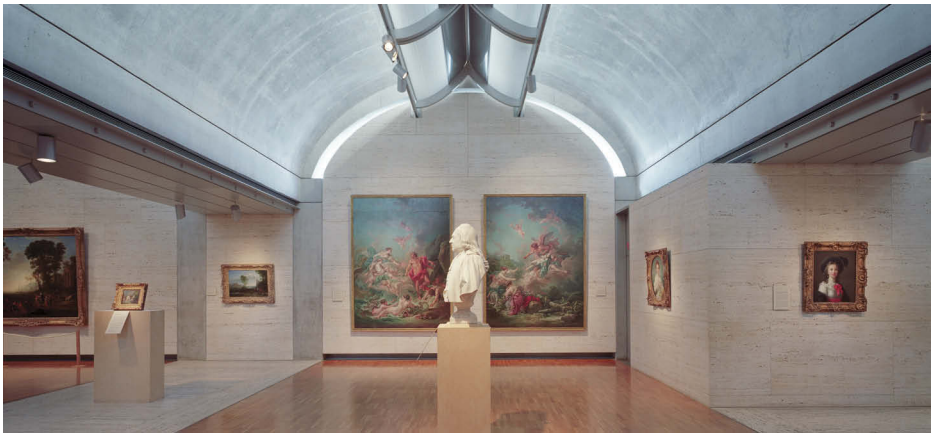


Figure 11.1 | Progressive Planning
Building planning and lighting design undertaken simultaneously present synergies that affect the design of both the architecture and the lighting with results that may be radical departures from convention. Here, in a timeless example, the concrete cycloid vault and the perforated diffusing reflector below the skylight slot harmonize to introduce daylight of controlled quantity and soft uniformity. Without such progressive and collaborative planning by the architect, Louis Kahn, and the lighting designer, Richard Kelly, the design may never have offered such daylighting opportunities at the Kimbell Art Museum in Forth Worth, Texas. [3]
» Image ©Dennis MarsicoCORBIS.

scheme is made available for design input by the various disciplines. In the conventional planning process, lighting is often excluded from the early and formative site selection, programming, and schematic design components. As a result, the degree of lighting success may well be hampered.

Conventional planning often limits daylighting opportunities to the given siting and window and skylight layouts that are usually established for reasons other than daylighting such as first cost, convenience of access, aesthetic or formality of orientation, and facade treatments.

These predetermined architectural forms and interior geometries are likely to limit daylight penetration and optimal electric lighting. Low ceiling heights are particularly debilitating to effective lighting distribution. Multi-storied building sections that are quite wide relative to window heights limit daylight to just perimeter areas. These can be simple to address, especially in new construction, but require lighting input during the earliest architectural design studies.

Priorities are managed in conventional planning by virtue of the limited number of opportunities made available. For example, nearly exclusive emphasis by a small team on first costs precludes exploration of architecture and systems offering beneficial life cost, sustainability, or system operations and installed life.

11.3 Building Design Process

Regardless of the planning strategy employed on a project, a lighting design process that parallels and complements the building design process will make the most of lighting and of the architectural resources involved. The process outlined here and the technical information embodied in this handbook can yield significant social, environmental, and economic benefit through better lighting design. At least six phases can be identified: pre-design; schematic design; design development; contract documents; construction administration; and post occupancy. Table 11.1 identifies the lighting-intensive building design and construction phases and offers an indication of some of the associated lighting *scope* and deliverables.

Scope determines which phases of design work are undertaken and how much of the project is involved. Scope, schedule implications, deadlines, and deliverables must be sorted out between all team members prior to project commencement. These aspects are related to roles, professional fees, services and duties, responsibilities, and liabilities. Although quite important to project execution, these administrative aspects are not covered here as part of a lighting design process. Also see Table 11.1 | Example Lighting Scope and Deliverables.

11.3.1 Pre-design

Before any planning commences, the scope, schedule, client, team, and project type and budget must be known. This investigative effort may be short and can be called Predesign. If the scope is huge (in area or in variety and number of spaces) and the schedule extraordinarily abbreviated or the budget too low, opportunities to review a host of

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progressive daylighting and electric lighting scenarios simply may not be available. The planning process is likely conventional. This is not to say the project will exhibit inferior lighting design or even conventional lighting in conventional architecture. However, it does suggest that some design opportunities will not be explored or even considered possible for this particular project in the time frame or budget allotted.

Knowing the project type provides additional insight on design possibilities. New construction on a new site is a cue that daylighting opportunities are possible and should be vigorously pursued. Existing construction on an existing site suggests that a good understanding of the extent of renovation or rehabilitation work is needed to determine the daylighting and electric lighting opportunities. For example, ceiling heights of 8' 6" or less and shallow plenums generally restrict perimeter daylight opportunity and limit electric lighting approaches. Serious design attention must be paid to these limitations rather than forcing various light shelf, ceiling configurations, and indirect ceiling-pendant-mounted electric lighting scenarios. Daylight opportunities might better arise from exploring novel daylight piping or re-direction strategies or reconfiguring interior walls to better reflect daylight or introduce high-reflectance floors with a matte finish. Electric lighting opportunities might better arise from exploration of unconventional direct/indirect lighting techniques. Conventional planning will require unconventional daylighting and electric lighting strategies.

Success requires highly coordinated teamwork. In the example discussed above, relatively low ceilings and the desire to reduce ceiling clutter along with technical lighting criteria best met with indirect lighting might be resolved with furniture-integrated direct/indirect lighting equipment (aka *task-ambient lighting*). If the interior designer and lighting designer (which could be one-in-the-same) are unable to collaborate on the type of furniture system and lighting system, such a resolution may never be explored, let alone implemented. Unconventional thinking and planning may require more time to explore lesser-known or discover unknown options, assess them, and design with them. It is possible, for example, that the furniture required to achieve the lighting in this example will take more time to space-plan by the interior designer with the available furniture pieces and layout configurations that also accommodate the integrated direct/indirect lighting. The lighting designer will likely take more time to assess the highly variable placement of lights (driven here by the interior designer's workstation placement and sizing). Both designers may need to compromise on some less-critical features of their respective layouts and criteria to come to a satisfactory conclusion. Here, keen understanding and passion are important. Schedule for design work could be an issue. If the interior designer and the lighting designer know in advance about the ceiling height limitation, they can make an early and crucial pact to explore a unique approach and not waste time on common but seriously flawed possibilities such as conventional indirect pendants hanging from an already-low ceiling.

Task-ambient lighting was popularized in the 1980s when its early incarnation also was furniture-based whereby the direct lighting equipment (task or local lighting) was integrated into the furniture systems to specifically light the task area. The indirect lighting equipment (ambient or general lighting) was also integrated into the furniture systems or freestanding to provide general overall light to the room or area. Considered then and now as a more visually comfortable approach by eliminating harsh glare from traditional ceiling-recessed direct lighting.

Restoration and adaptive reuse projects offer their own specific set of challenges. These projects may be limited by their landmark status in what changes are allowed to the buildings.

Adaptive reuse projects are special cases where, generally, site and architectural conditions limit daylight and even electric light opportunities to the selection of appropriate finishes and equipment rather than architectural reconfigurations.

11.3.2 Schematic Design (SD)

A knowledge base is necessary on any project to understand the client, the client's needs, and the client's existing lighting situation in order to develop design goals, strategies to meet those goals, proposed lighting schemes for team and client consensus.

11.3.2.1 Programming

Design commences after sufficient information is available to inform or direct the design effort. Programming is the research and decision-making process used to define a project's scope for which design is to be undertaken [4]. Table 11.2 outlines some lighting

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Table 11.1 | Example Lighting Scope and Deliverables

				Team Member Involvement					
	Phase	Scope	Deliverable	Architect	Electrical Engineer	Interior Designer	Landscape Architect	Lighting Designer[b]	Mechanical Engineer
Design	SD	Siting							
		• Daylighting	Assess site selection with respect to daylighting opportunities.	✔	✔	✔	✔	✔	✔
		• Outdoor Lighting Zone	Determine outdoor environmental lighting zone.	✔				✔	
		Basis of Design							
		• Programming	Summarize lighting-relevant information (see Table 11.1).	✔				✔	
		• Design Goals	Document goals, criteria, priorities and relevant lighting techniques.	✔				✔	
		Preliminary Schemes							
		• Lighting Schemes	Document recommended scheme or schemes.	✔				✔	
		• Accounting	Assist in green-rating, cost and energy budget exercises.	✔	✔			✔	✔
		Client Review	Present lighting schemes for client review.	✔	✔	✔	✔	✔	✔
	DD	Reconfirm or Revise SD							
		• Reconfirm	Reconfirm schematics. Other disciplines may affect lighting.	✔	✔	✔	✔	✔	✔
		• Revise	Revise schematic aspects that were rejected during SD.	✔	✔	✔	✔	✔	✔
		• Finalize Scheme	Document the final proposed lighting schemes.	✔				✔	
		Equipment Selections							
		• Luminaires and Lamps	Selections address lighting schemes, goals, criteria, and priorities. Iterate selections, layouts, calculations, and team reviews.	✔	✔	✔	✔	✔	✔
		• Layouts	Propose interior and exterior lighting layouts for team review and coordination. Circulate vignettes. Iterate to gain agreement.	✔	✔	✔	✔	✔	✔
		Layouts and Initial Specifications							
		• Lighting Plans	Document accepted lighting layouts.	✔	✔	✔	✔	✔	✔
		• Controls Schemes	Document control schemes for lighting layouts.	✔	✔	✔	✔	✔	✔
		• Finalize Design	Document proposed plans, controls, and luminaire selections.	✔	✔	✔	✔	✔	✔
		• Accounting	Assist in green-rating, cost and energy budget exercises.	✔	✔			✔	✔
		Client Review	Present lighting schemes for client review.	✔	✔	✔	✔	✔	✔
Administration	CD	Reconfirm or Revise DD	Reconfirm or revise to address client or team feedback.	✔	✔	✔	✔	✔	✔
		RCPs, Details, Elevations	Document relevant plan, detail, and elevation information.	✔	✔	✔	✔	✔	✔
		Quality Control	Round-robin plan reviews; clash detection	✔	✔	✔		✔	✔
		Lighting Specification	Document specification and, if necessary, luminaire schedule.	✔	✔			✔	
		Controls Specification	Document initial preset schedule and controls specification.	✔	✔			✔	
		Accounting	Assist in green-rating, cost and energy budget exercises.	✔	✔			✔	✔
	CA	Shop Drawings	Review and assess shop drawing submittals.	✔	✔			✔	
		Field Situations	Assist if/as field conditions require.	✔	✔	✔	✔	✔	✔
		Punchlist and Commissioning	Assist as situation requires.	✔	✔			✔	
		Training and Manuals	Assist as situation requires.	✔	✔			✔	

Legend

✔ Primary duty of the team member serving this role.

✔ Coordination by the team member serving this role and reciprocal coordination expected of other team members..

✔ Design direction and schedule sequencing by the team member serving this role to assure deliverables are timely and complete.

✔ Coordination and oversight by the team member serving this role.

a. This is an indication of various phases and related scope items and deliverables, and is not exhaustive. Actual scope and deliverables are based on specific client direction, schedule sequencing, and the coordination needs established by the team mamber in charge (typically the architect).

b. The lighting designer citation identifies what may be expected of the team member serving this role.

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programming items along with inventory scope and examples specific to the planning approach. Inventorying is essentially tracking and recording information. Where conventional planning is used, existing conditions or predetermined design elements are inventoried. Progressive planning also involves inventorying existing conditions, but the lighting design process influences, if not determines, some of the key direction necessary to proceed with design.

Where a client has an existing environment understanding the existing lighting of that environment may help guide design goals, criteria determination, and even how design presentations are postured. For example, if an existing community college cafeteria up for renovation has dark walls, floors, and ceilings, and users complain of glare and cramped quarters, luminance ratios from foreground areas (tables) to background surfaces and from luminaires to background surfaces will be much improved by establishing surface finishes that exhibit IES-targeted reflectances of 90-60-20 (ceiling-walls-floor). If, however, the college president's taste or interior decorator needs some amount of rich surface finishes to make this more like a dining room and less an institutional dining hall, then accenting key selected lower-reflectance decorative wall panels or ceiling elements will be necessary to improve the luminances of the background surfaces. In this example, we've leapt ahead from programming to design strategies to illustrate the value of the information gleaned in programming.

Programming is time-consuming and typically not exciting, but without it building designs and lighting designs are exercises in futility, wasting time, money, and earth resources to achieve ends that in all likelihood do not support the clients' lighting needs. References are available on programming related to lighting design, including the value of programming and lists of programming activities. [5, 6]

Table 11.2 | Programming: Inventory Scope and Specific Examples

Programming	Inventory Scope	Progressive Planning Inventory Specifics	Conventional Planning Inventory Specifics
Existing Conditions	• **Field Surveys**	• Space activities	• Space activities
		• Tasks involved	• Tasks involved
		• Occupants' ages	• Occupants' ages
		• User feedback	• User feedback
Design Givens	• **Geometry**	• Spatial forms and dimensions TBD[a]	• Spatial forms and dimensions
	• **Daylighting**	• Daylight aperture sizes, orientations TBD[a]	• Daylight aperture sizes, orientations
	• **Budget**	• Building US$/ft^2 TBD[a]	• Building US$/ft^2
		• Lighting hardware US$/ft^2 TBD[a]	• Lighting hardware US$/ft^2
	• **Surroundings**	• Daylight access TBD[a]	• Daylight access
Design Goals	• **Spatial Factors**	• Pleasantness, spatial order, spatial definition	• Pleasantness, spatial order, spatial definition
	• **Psychological Factors**	• Senses of spaciousness, relaxation	• Senses of spaciousness, relaxation
	• **Daylighting**	• Orientation, form, ceiling configurations TBD[a]	• Orientation, form, ceiling configurations
Criteria	• **Finishes**	• Surface reflectances TBD[a]	• Surface reflectances
	• **Illuminances**	• IES horizontal and vertical target values	• IES horizontal and vertical target values
	• **Surface Contrasts**	• IES luminance ratios	• IES luminance ratios
	• **Color rendering**	• IES CRI values	• IES CRI values
	• **Codes**	• Code requirements affecting lighting	• Code requirements affecting lighting
	• **LPD**	• ASHRAE/IES 90.1 or other mandated values	• ASHRAE/IES 90.1 or other mandated values
	• **Green Certification**	• LEED or other rating system	• LEED or other rating system

a. These specific items should be influenced by lighting design. Even under conventional planning, opportunities may exist for lighting to influence some Design Givens. For example, daylighting inventory should include assessment of the various sites under consideration for new or existing construction with respect to daylighting opportunity.

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11.3.2.2 Taking Inventory

An inventory of what's known about the project and its users will establish background that will better guide the project's design. Two inventories are of interest: that of the users' existing living or work environment and that of the project's design status.

An inventory of the client's existing environment can be accomplished through field surveys which might include site visits, *interviews*, and information from the architectural inventory made by the architect. Space activities and visual tasks that are anticipated in the project under consideration should be noted. Spot-check *illuminance measurements* should be made. Client input should be sought on her or his vision of the project, typical hours of space use, and reason for the project undertaking (for example, downsizing, up-sizing, better environment for work or for entertainment or for living). A review of old plans and specifications may offer insight on the original design's intended function and aesthetic. Identify any other knowns about the project, including budget and schedule status.

Interviews are part of existing conditions' surveys. [6] These interviews and surveys enable the designer to understand clients' living or working tasks and likes/dislikes and experience existing conditions first hand. Opportunities may arise to educate clients about various lighting techniques and technologies. This may have the added benefit of creating advocates for later lighting presentations and proposed solutions.

An inventory of the project's design status is made by reviewing available design documentation. This might consist of a project work scope or request for qualifications (RFQ) from which some very general design information may be gleaned such as size of project, estimated cost, types of spaces involved, and level of finish quality expected. If the project is one of conventional planning methods, then significant architectural, landscape, and interior design work already may be documented and will offer specifics about space finishes, available fenestration, ceiling heights, and extent and type of exterior walkways.

Illuminance measurements are discussed in 9.7 Measuring Illuminance. Illuminance readings on tasks, task areas, walls, lighted features or artwork, and even on ceilings can be helpful information in assessing criteria later in the design process.

Although inventorying can result in volumes of information, the benefit is familiarity with the client, the design team, and whatever details surround the project. This information should be used to establish design goals with other team members.

11.3.2.3 Establishing Design Goals

The designer is responsible for establishing design goals. Some of these are analytic while others are aesthetic and more about the look and feel of spaces or areas. References are available that explore the aesthetic aspects of lighting design [7, 8]. Lighting effects and lighting hardware influence how people perceive space and live or work within that space.

IESH/10e Design Goals Resources

> 12.2 Spatial Factors
  - for information on using light to define space
> 12.3 Psychological Factors
  - for information on subjective impressions
> 12.4 Physiological Factors
  - for information on circadian rhythm
> 12.5 Task Factors
  - for information on illuminance
> 12.6 Systems Factors
  - for information on systems" integration
> 12.7 Prescribed Factors
  - for information on required minimum criteria

Design goals related to aesthetic aspects are categorized as spatial factors and psychological factors. Those related to analytic aspects are categorized as physiological factors, task factors, and systems factors. A review of these factors should be made and priorities established on which best help address needs and wants identified in inventorying. See 12 | COMPONENTS OF LIGHTING DESIGN. Specific criteria and techniques are an outcome of this review.

11.3.2.4 Design Strategies

Since lighting affects architecture, interiors, and mechanical systems, deliberate and collective decisions should be made as early as possible about possible lighting strategies. Sometimes, the design strategies are defined as part of the client's scope. For example, "daylighting is desirable" or, usually more indirectly, "the building should achieve LEED gold certification" might appear in requests for proposals or project scopes.

IESH/10e Lighting Design Resources

> 14 | DESIGNING DAYLIGHTING
> 15 | DESIGNING ELECTRIC LIGHTING

Depending on the planning approach, the kind of project, and the personalities involved, a project may be designed from the inside out or from the outside in. Lighting strategies develop accordingly by pushing the overall design or responding to it.

Holistic daylighting design is the practice of developing the architecture, interiors, and electric lighting, if needed, to maximize the benefit of daylighting. Lighting is a design priority from project commencement.

Daylighting

When programming identifies daylighting as a most desirable lighting strategy, aggressive and early work is in order. With new construction, *holistic daylighting* is warranted where siting, orientation, and building form and geometry are influenced by daylighting design. [9] This requires early conceptual lighting design work.

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Conditional daylighting design is the practice of making the most of a given site and architectural conditions.

Fractional daylighting design is the practice of implementing daylighting strategies on a piecemeal basis too late in the project where little or no affect is allowed on architecture or interiors. As such, this is also the approach of least cost. Results are typically cosmetic with little energy, client-comfort, or productivity benefits.

Normal power architectural lighting is a reference to lighting used for non-emergency purposes. In other words, the daylighting and electric lighting used for living and working environments during normal situations. Also commonly called lighting or architectural lighting and is typically the scope of team member assigned the role of lighting designer.

HVAC is an acronym for Heating, Ventilating, and Air Conditioning.

AV is an acronym for Audio-Visual. A/V is also used.

Image board is a poster board with an artful arrangement of photographic images or renderings and product cutsheets and finish samples used to convey and seek feedback on a tentative design approach. Many times more than one board is used during a presentation. Also known as presentation boards and mood boards. See Figure 11.2.

When new construction design is well along prior to lighting design work, or when existing construction is involved, *conditional daylighting* requires even greater concentrated collaboration among interior design, architecture, and lighting. [9] Parochial views of division of work will not support the collaboration and advanced strategizing necessary for successful daylighting in these situations. Fenestration, glazing types and transmittances, light shelves, ceiling and window geometry, room and exterior surface reflectances, and seasonal shading all demand attention.

When the architecture and interiors are nearly complete and then lighting design commences, *fractional daylighting* is likely the extent of design intervention. Daylighting implementation is limited to strategies that have low or no impact on the established architecture and interiors. [9]

Electric lighting

Daylighting, whatever the extent of its availability, has its limits. If the project in question has operational components during dark hours or is located in a climate where daylighting is limited or unreliable, then electric lighting for purposes of *normal power architectural lighting* is also necessary. Whomever functions as the project lighting designer is encouraged first and foremost to consider daylighting the default lighting system to meet the project's lighting needs. Electric lighting is an adjunct to daylighting, used when and where necessary.

The design track for any electric lighting will best be served if it, too, follows that of daylighting with aggressive and early participation in design and concentrated collaboration among interiors, architecture, and lighting.

Integration of electric lighting with daylighting strategies is necessary to achieve full energy benefits by tailoring and controlling the electric lighting to respond to daylighting. Additionally, integration of related systems, such as automated daylight shading systems with electric lighting can yield optimal designs where glare is minimized and energy savings maximized.

Electric lighting integration with other systems is also critical to functional and aesthetic success of lighting and these other systems, such as *HVAC* and *AV*. Although the responsibility of overseeing the physical affects of these and other systems' integration is not one of lighting design, the lighting equipment selection, layout, effects and its control may be influenced.

11.3.2.5 Lighting schemes

In conventional planning, the architectural siting and form may be complete even prior to SD. Regardless of where lighting is introduced into the design sequence, some preliminary assessment of the program and its impact on lighting design strategies is necessary. If architectural siting and form are still fluid, lighting should influence those. If architectural siting and form are already completed, then an assessment of architecture and any interior work is in order.

Preliminary lighting design schemes are offered for team consideration and feedback. After several rounds of reviews and alternatives, a tentative final design direction is proposed to clients. Their feedback is accounted and revisions made accordingly. The more of this that is accomplished in charrettes or presentations with the benefit of all team members' input, including clients, the better the design synthesis for lighting and the other disciplines.

During SD and early design development, most clients and team members are curious about how these schemes will look. This is an important aspect of convincing the client of the validity of proposed design schemes, but there is a fine line between "the look" as a design direction for evoking a kind of style, and simply copying design schemes. The design should derive from the program. Seldom does a program direct that the project be visually stunning or be an award winner or be a facsimile of such-and-such project. So, with caution, an *image board* is used to illustrate styles and moods to a client or perhaps just the character of space and light, but not a finished design. However, the team must recognize

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and convey the stipulations to the client regarding photos of other projects. There is no telling what criteria and priorities drove the design seen in the imagery, especially if the design team members were not a part of that particular project. Some photos may be radically retouched or may exhibit a significant amount of photo-fill light unbeknownst to the team. Therefore, these images are potentially misleading the client to approve an unachievable lighting scheme.

11.3.3 Design Development (DD)

Once the design direction is finalized in SD and a scheme emerges, a number of design steps occur simultaneously and should influence each other. This is not and cannot be a linear process of developing the design, otherwise no allowance is made for a wrong step in luminaire or lamp selection or for a change in design direction that may be the result of client second-guessing, other design influences, priority shifts, or the general fallout that follows the simultaneous work undertaken by other disciplines. Additionally, a designer's own perspective and priorities will influence the number of steps involved and which ones take precedent over others. So, what follows is not in any fixed order. This is not intended to summarize contractual obligations which must be coordinated by the project leader or client during development of the scope, the chain of responsibilities, and the team structure and fee negotiations.

A first step in DD is reconfirmation of the SD. Team members' perspectives are vetted on what lighting effects are appropriate to support the schemes accepted by the client. Proposed selections of light sources and luminaires are now underway. These influence each other. One designer may decide that, given a very low ceiling, small-scale luminaires in the ceiling are an important contribution to a well-proportioned look and feel. Another designer with a different mind-set and priorities may determine that linear fluorescent lamps are most appropriate for a host of sustainability reasons. Neither is right or wrong. The idea is to establish a starting point based on some rationale that fits with project programming, planning, and priorities and begin to test its feasibility. Exploring additional imagery, including simple renderings, with the small-scale luminaires to assess design aesthetics, as well as develop some trial layouts and even calculations to assess its integrity. That is, determine if the selection meets the more technical requirements of the program, such as illuminances, luminances, and *LPD*, The calculations, depending on software used, also offer quick-study renderings to confirm (or deny) validity of the selection. Another designer may have greater comfort reviewing hardware samples and quick-study mock-ups instead of calculations at this stage. Still other designers will base selections and layouts on previous experience and may develop light-map sketches, digital renderings, and rough plans done by hand to illustrate lighting effects. All of these approaches to design subsequently lead to selection of luminaire types and lamping with an expectation toward meeting luminance and illuminance criteria.

Figure 11.3 illustrates some of the design development effort and finished result on a facade lighting project. A meeting with the architect who conveyed his vision and the owner's program established the basis for a schematic design which was to illuminate the architectural features in a way that accentuates their character without washing out the detail, without flattening the dimensionality, and with respect for the environment (later clarified to mean, "design an efficient lighting system worthy of a community landmark"). Prior to any computer renderings, site visits were made, photos taken, and the facade studied for its character, finish, and material qualities. The architecture composition consists of a pedestal or base, a facade, and a crown. It was agreed early that all three components deserved lighting to provide a complete render of the landmark at night. The warm brick and limestone demand accurate color rendering and *throw distances* at the base and the facade field require long-throw sources. The cornice throw distances are moderate while the detailing is highly dimensional. Access to the crown is limited to that available from a lift. This data (gleaned from the program, schematic design, and the first stage of DD)



Figure 11.2 | Image Board
Important information is conveyed in image boards that affect lighting. Proposed material selections indicate color schemes from which surface reflectance values can be assessed. Luminaire images are sometimes included. Photos of other projects may be used to illustrate the proposed "look" to a client.
» Image ©Jeff Von Hoene

LPD is an acronym for lighting power density. Typically reported in W/sf or W/ft² (watts per square foot) or W/m² (watts per square meter).

Throw distance refers to the distance required to project or throw light (taken from theater lighting) to create an accent effect. For many architectural lighting situations, short throw distances can be considered up to 10′, moderate throws are 10′ to 20′ and long throws are greater than 20′. Different sources when fitted with various optics exhibit a variety of throws. For short throws, *halogenIR$_{LV}$*, low-wattage CMH, and LEDs are common. For moderate throws, CMH and LEDs are common. For long throws, CMH is common. Where wide-area, soft lighting is desired from short to moderate throws, fluorescent or LED sources coupled with various optics can be successful.

halogenIR$_{LV}$ is used here and in application chapters as a reference to halogen infrared low voltage lamps. 120 V varieties are also available, and referenced in shorthand as halogenIR$_{120V}$. See Chapter 7 | LIGHT SOURCES: TECHNICAL CHARACTERISTICS and Chapter 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS for more about these lamps.

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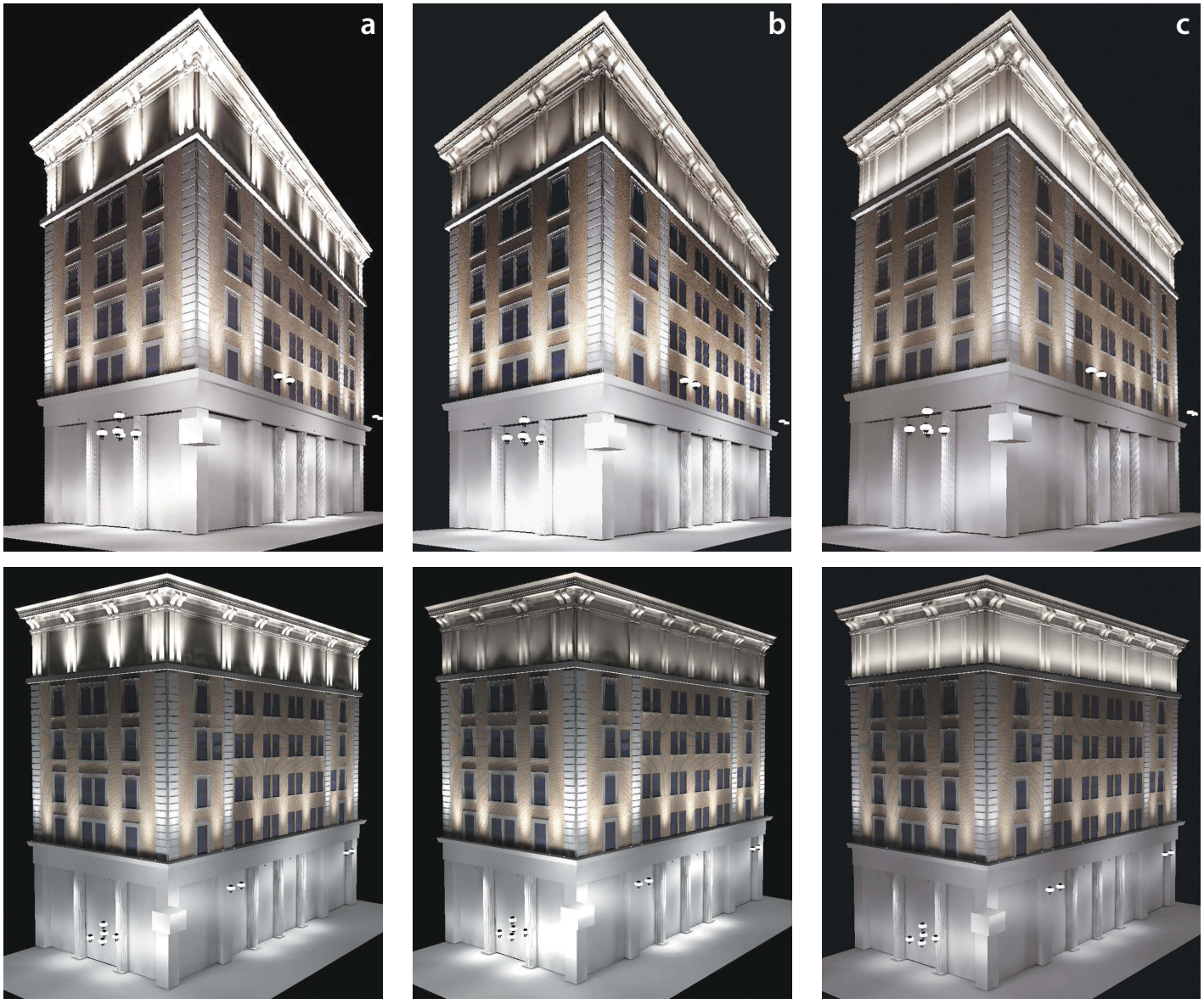


Figure 11.3 | Design Development
During the design development phase for the exterior lighting of an existing urban building, a series of views were made in AGi32 of various lighting options—all essentially the same scheme consisting of 1) downlighting pilasters and columns at the building base, 2) lighting quoins and piers on the main façade, and 3) lighting the building cornice or crown.

Near-right stacked images (a) represent CMH 20W/T4.5 flood downlights at base of building with CMH 39W/PAR20/NFL uplights at quoins and piers of main façade and at upper cornice. Middle stacked images (b) represent cornice lights changed to high output LED uplights at cornice pilasters. Third right stacked images (c) represent continuous LED uplighting at the cornice.

The concept illustrated in (c) was recommended. The softness of the continuous cornice lighting was considered more appropriate for the restored cornice. The LED promised longer maintenance cycles because of the very long lamp life claimed by LED manufacturers as well as better light control (the optics are a linear narrow flood distribution to concentrate light onto the cornice and eliminate light spill).

Field mock-ups were reviewed to confirm CRI, CCT, intensity, and beamspread and review hardware scale. 11.3d shows a mock-up with a few lighting samples. The mock-up was done prior to cornice build-out.

11.3e shows the finished project. On installation, the CMH uplights were fitted with glare snoots and angled toward the façade to control spill light. The downlights at the base of the building were fitted with full snoots for glare and light-spill control. The lighting is timed off at a late-night curfew.

» Renderings ©GarySteffyLightingDesign
» Mock-up Image ©GarySteffyLightingDesign
» Professional Image ©2010 Gene Meadows

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suggested *CMH* lamps be considered for their long and medium throw capabilities, their color rendering (80+) and CCT (3000 K), and relatively long life. *LED*s were of interest to light the cornice in either a discontinuous or accent mode or in a continuous cove mode since these were reported to have 50,000-hour life to 70% light output. Renderings showed CMH a good match for lighting the base and facade field, but too bright for the cornice. A continuous LED at the cornice appeared to suitably balance with the facade and base. This provided sufficient confidence to secure a few samples for mock-up.

The early phase DD then consists of a number of exercises with an end of documenting a proposed lighting design. Exercises include visualization and determining light sources, luminaires, controls, and details. Visualization is done with sketches, renderings, models, and mock-ups and results in determination of lamps, luminaires, control schemes, and detail concepts.

The later phase of DD consists of quantification and preliminary documentation. Quantification includes calculations and mock-ups and measurements. Documentation varies significantly depending on the client's or team's contractual obligations on deliverables, schedule, and the degree of estimating desired.

CMH is used here and in application chapters as a shorthand reference to ceramic metal halide lamps. See Chapter 7 | LIGHT SOURCES: TECHNICAL CHARACTERISTICS and Chapter 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS for more about these lamps.

LED is used here and in application chapters as a shorthand reference to light emitting diode lamps. See Chapter 7 | LIGHT SOURCES: TECHNICAL CHARACTERISTICS and Chapter 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS for more about these lamps.

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On some projects, the DD documents for lighting must be a near-finished and complete package. Here, interior and exterior lighting plans show all luminaires and control loop diagrams and electrical plans are coordinated to show control devices from wall switches and dimmers and presets to occupancy/vacancy sensors and photocells integrated with daylighting zones. Where the lighting designer and electrical engineer are one in the same, all of this information is shown on one set of DD documents. Architectural reflected ceiling plans then show lighting, HVAC diffusers, sprinklers, speakers, cameras, projectors, and other ceiling mounted devices. Preliminary lighting specifications show catalog cutsheets along with catalog numbers or luminaire schedules are added to the DD plans to assist in estimating. Lighting brochures, renderings, and installation photographs may be necessary to convey the design to clients and estimators and other team members. Similar depth and breadth of material may be required for controls. Where the role of lighting designer is filled by someone other than the electrical engineer, coordination on control devices, system capabilities, and expected performance is necessary so that the electrical engineer can develop the related DD documentation. A complete set of lighting calculations is made available for review and file.

Where the DD phase is more deliberately paced and CDs are allotted sufficient time and fees appropriate to finalizing design and completing documentation after formal client review, documentation includes proposed layouts usually by vignetting architectural or interior reflected ceiling plans (RCPs) and landscape plans. Vignettes include control looping to illustrate how luminaires are zoned and proposed daylighting coordinated. Luminaire cutsheets identify the proposed equipment. Renderings and selected support calculations for various, but not all areas are used to help justify the proposed designs. As necessary to convey the design, preliminary elevation, section, and detail sketches are developed. An outline specification and the vignetted plans serve as the basis for moving into construction documents.

In any of these DD documentation scenarios, the level of detail and relevancy of the lighting and electrical plans depends on the architectural backgrounds (also known simply as backgrounds). The state of completion of the backgrounds directly affects the state of lighting and electrical completion. The delivery of these backgrounds affects the time available to address lighting which in turn affects the time available to address the electrical plans. Regardless of which team member serves the role of lighting designer, a domino-effect of completion and timeliness begins with the backgrounds. The delivery and state-of-completeness of backgrounds should be discussed and coordinated with the team well in advance.

Cost (first and life-cycle) are typically an ongoing part of DD to continually test the design proposals and refinements against a budget or to help establish a budget. Where DD documentation approaches that of contract-document-quality, these budgets are likely closer to reality than where DD documentation consists of vignetted plans and outline specifications.

Throughout the design effort, regardless of the phase of work, there are a number of design meetings and presentations. Depending on the size and scope of the project these may be significant in-person meetings with the entire design team and client present or these may be web exchanges, teleconferences, or several-person phone calls. These should be milestones marking the progress of work and establishing revised or new design direction or approval of the presented design schemes. At the end of DD or the beginning of construction documents, a meeting is important to identify the design status (for example, 'all's well and move forward' or 'revisions are in order' or 'start anew').

11.3.4 Contract Documents (CDs)

Although much of the design work may be completed by the beginning of CDs, much work remains. During early CDs, some design refinement is likely. There is usually time to finesse lamp and wattage selections and finalize control schemes. For example, this is

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the time to finalize which areas near perimeter windows are on photocell control if the control function is continuous dimming or stepped-dimming. But time is short in CDs. Work, besides refining any outstanding elements of the lighting design, includes lighting layouts (finishing *RCPs*, exterior lighting plans), details, elevations, sections, lighting control zone diagrams to convey how the lights are to be controlled, and luminaire schedule or specifications citing the salient attributes and catalog numbers of the luminaires and lamps, ballasts, and other devices necessary for the procurement, installation, and operation of the lighting system.

RCP is a reference to the architectural reflected ceiling plan. The design team must agree on the definition of an RCP for the given project. Typically an RCP is a drawing of the ceiling and all devices in and on it as seen reflected from a mirror placed at some elevation below the ceiling plane. This mirror creates a reflected plan as it is "viewed" from above the ceiling.

Protocols for the use of design and engineering drawing and documentation software to document the lighting design must be coordinated with the design team. For interior lighting, illustrating luminaires on an RCP is common and expected. Issues may arise with documentation of non-ceiling luminaires, including wall sconces, steplights, lighted handrails, in-floor uplights, task lights (freestanding or architecturally-integrated types), and lighting details. These luminaires must be shown in a way that will be evident to the bidders and the installing contractor.

Building information modeling, or BIM, may be a part of the CD phase depending on the project scope and CAD production. BIM better enables coordination and integration of systems prior to construction through the use of 3D modeling. Some software offers clash detection whereby computer simulations of the various building systems can alert the design team to system conflicts.

11.3.5 Construction Administration (CA)

When CDs are completed, they are released for bidding and construction. Lighting design tasks during this phase parallel those experienced by other design team members. Questions may arise during bidding that require responses from the lighting designer. This is an opportunity to clarify lighting specifics for contractors. Depending on the size and scope of the project, some time may then pass until further lighting design work commences. On large projects, it may be necessary to work on addenda or design revisions as last-minute changes in CDs are resolved.

Shop drawing review is a significant task in importance and perhaps in time consumption, depending on the project size and scope. Large projects and custom luminaires will demand time and care in reviewing shop drawings which are the drawings, typically CAD or catalog datasheets illustrating the specific luminaires that the contractor intends to procure and install. The designer checks these shop drawings against the lighting specifications issued with CDs, notes any discrepancies, and indicates approval or rejection.

Throughout construction, field conditions may arise that require review by the lighting designer. The more serious conditions may require site visits. Near the end of the construction, the team member assigned the role of lighting designer may be asked to support the architect with the *punch list*. This is also the time to observe contractor's aiming of adjustable luminaires and programming of controls. Confirmation is made that luminaires are cleaned and installed level and plumb with no light leaks. Luminaires are checked for correct lamping and ballasts or drivers and, where specified, for correct accessories such as color filters, spread lenses, and louvers. Confirmation should be made that the contractor has delivered as-built documentation, including as-built plans, operating and maintenance manuals associated with luminaires and controls, and has provided training sessions for controls for the client.

Punch list for lighting includes confirmation that what was indicated on shop drawings was, in fact, installed, including proper lamps, ballasts, power supplies, and drivers. This also includes observation during final aiming of lights and programming of the control system. The more clearly some of these tasks are defined in the specifications and plans, the less observation may be necessary.

Commissioning may involve the lighting designer depending on the project size and scope and the extent of necessary lighting device commissioning. The lighting designer may need to assist in defining commissioning expectations and assist in identifying factory-startup contacts for programmable and interactive lighting-related equipment.

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11.3.6 Post Occupancy

Some project scopes call for post occupancy review. Post occupancy might also be a stand alone project. Here, the design team may be involved or independent consultants (researchers or designers) may perform the post occupancy. These may take several forms. A single evaluation several months after initial occupancy, several evaluations paced several months after occupancy and after the first evaluation. Periodically, a project may undergo a comprehensive assessment to explore many or all systems' performances and operating costs and occupants' performance. These evaluations help establish a baseline of performance to be checked against design predictions. Many such evaluations have been made by independent researchers. [10, 11, 12, 13, 14] Researchers typically have access to instruments capable of collecting significant quantity and breadth of building performance data and an ability to assimilate and study the data, all the while maintaining an independent role.

This entire design process (Pre-design and Programming to CA and Post Occupancy) constitutes lighting design. Sometimes just portions of this process constitute lighting design, depending on project size and scope. The best lighting design and illuminating engineering efforts are for naught if they cannot be assimilated with the overall project and properly documented and implemented as the lighting design.

11.4 References

[1] [DOE] US Department of Energy. 2001. DOE/GO-102001-1165. Greening Federal Facilities, 2nd Edition [Internet]. DOE. [cited May 2010]. Available from:http://www.eere.energy.gov/femp/pdfs/29267.pdf.

[2] [IESNA] Illuminating Engineering Society of North America. 2009. IES PS-01-09, IES position statement: Integrated building design [Internet]. IESNA. [cited May 2010]. Available from: http://www.iesna.org/PDF/PositionStatements/PS-01-09.pdf.

[3] Page C. 1973. Lighting starts with daylight. Prog Archit. 54(4): 82-85.

[4] Cherry E, Petronis J. 2009. Architectural Programming [Internet]. [cited January 2010]. Available from: http://www.wbdg.org/design/dd_archprogramming.php.

[5] Lam WMC. 1977. Perception and lighting as formgivers for architecture. New York: McGraw-Hill. pp 87-88.

[6] Steffy G. 2008. Architectural lighting design. 3rd Edition, Hoboken: John Wiley & Sons. pp 39-59.

[7] Michel L. 1996. Visual perception and light. New York: Van Nostran Reinhold. pp 49-67.

[8] Steffy G. 2008. Architectural lighting design. 3rd Edition, Hoboken: John Wiley & Sons. pp 107-128.

[9] Steffy G. 2008. Architectural lighting design. 3rd Edition, Hoboken: John Wiley & Sons. pp 151-153.

[10] Block J editor. 1994. A&P Food Market. DELTA Portfolio Lighting Case Studies. Troy: Lighting Research Center.

[11] Hunter C, editor. 1996. Prudential Healthcare. DELTA Portfolio Lighting Case Studies. Troy: Lighting Research Center.

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[12] Hunter C, editor. 1997. Sony Disc Manufacturing. DELTA Portfolio Lighting Case Studies. Troy: Lighting Research Center.

[13] Hunter C, editor. 1998. Mary McLeod Bethune Elementary School. DELTA Portfolio Lighting Case Studies. Troy: Lighting Research Center.

[14] Blair J, editor. 2001. Saratoga Medical Associates. DELTA Portfolio Lighting Case Studies. Troy: Lighting Research Center.

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12 | COMPONENTS OF LIGHTING DESIGN

Science is spectral analysis. Art is light synthesis.
Karl Kraus, 20th Century Austrian Journalist

Design can result from spontaneous inspiration or a nearly project-long effort. What defines design? A solution that is technically competent or that has "the right" look and feel? Is it the look of the lighting effects or of the lighting equipment or both? Is it the feel of the space or of the people and things in the space? Design is all of that. In the absence of spontaneous inspiration, a deliberate review of a variety of lighting design factors can help establish a design. Where inspiration seeds a design vision, a review of lighting design factors, however brief, can solidify a design. What follows will help the team member serving in the role of lighting designer assess and document various analytic and aesthetic lighting aspects. This material assumes some amount of reader background including familiarity with the FRAMEWORK FOR LIGHTING Section in this handbook and 11 | LIGHTING DESIGN.

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12.1 Lighting Design Factors

Key components of lighting design are presented here as factors. A review and prioritization of these various factors for a given project results in a schedule of criteria and collection of techniques that can then assist in developing a design. Some factors are subjective while others are objective. Some of the objective factors, such as those related to energy and code light levels or illuminances are requirements. Most factors are elective where the designer must carefully review, select, and apply these to address the project's scope and program. This chapter presents elective factors first and the prescribed, required factors last. Some designers may prefer to identify prescribed, required factors first. In any event, all lighting design factors should be considered and, as necessary, addressed on every project. A complete design is typified by some degree of inspiration, a determined review of lighting design factors, virtual trials and errors, and the exploration of ideas with other team members. The methods espoused here are for guidance to assist in the design flow diagrammed in Figure 12.1. In and of themselves, these methods will not necessarily lead to a complete or satisfactory design solution.

This chapter identifies important factors that should or must shape lighting designs: spatial, psychological, physiological, task, systems, and prescribed. For some, a design may emerge quickly and early on a project. For most, design will take some time, typically over the course of Schematic Design (SD) and Design Development (DD).

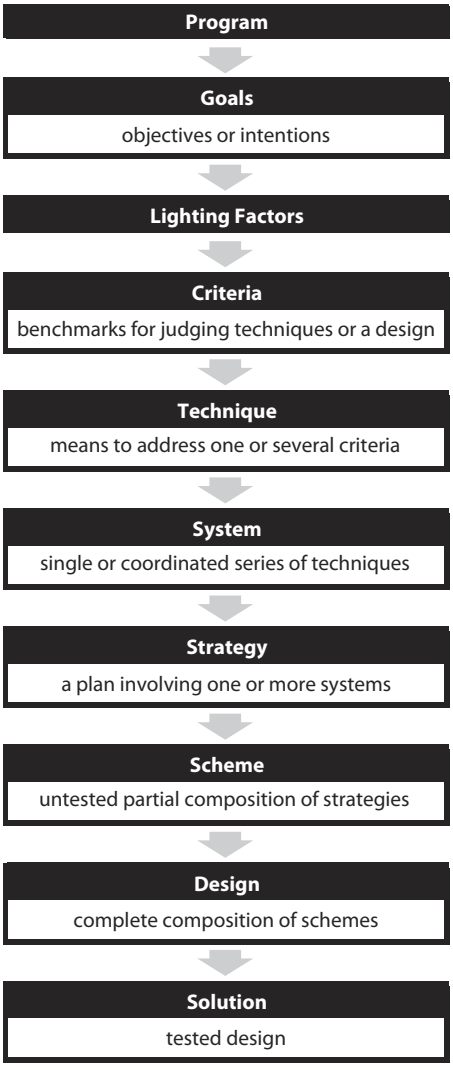
12.1.1 Design Process Context

Lighting design factors may comprise some part of schematic design and a significant amount of the design development effort. After programming, the designer typically has enough information to review the lighting design factors, establish their appropriateness for the project, determine priorities and criteria and propose lighting techniques.

12.1.2 Design Techniques

A lighting design solution will ultimately consist of a number of lighting techniques that are driven by various lighting design factors. For example, if luminaire scale is deemed impor-

Figure 12.1 | Simple Design Flow
Oversimplified progression of lighting design.



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tant because ceilings are low or spaces are physically small (see Table 12.1a | Spatial Factors: Part One, Pleasantness/Luminaires/Scale) a lighting technique to emerge is the use of small aperture luminaires. If the sense of spaciousness is also deemed important (see Table 12.2 | Subject Impressions, Spaciousness), then another lighting technique to emerge is the use of wall lighting. These two techniques are combined into a single lighting technique of small aperture luminaires to wash a wall or walls. Some further deliberation is warranted to refine the luminaire aperture size. The definition of small is relative. If the ceiling height is less than 10', then small is arguably equipment with its smallest dimension of 2" to 6". However, if ceiling height is greater than 10', then small is equipment with the smallest dimension of 6" to 8" or greater. A review in context either with renderings, quick sketches, or a survey of nearby existing installations can help such an assessment. The extent of these assessments, while seemingly endless or at least time-consuming, are an important part of establishing an appropriate lighting design. As lighting design factors are reviewed, a number of lighting techniques emerge and can collectively form a design strategy. It may be necessary to influence architectural design to implement some techniques. All of this, however, is typically done in the context of overall architectural style. Modern, post-modern, traditional, deconstructive, or any number of other design styles will influence lighting decisions. These are all intertwined and demand a degree of coordination and collaboration amongst the design team. Figure 12.2 illustrates a technique of lighting a wall with small-scale luminaires.

Illuminance is essentially a measure or prediction of the quantity of light falling onto a surface or object. Illuminance depends on the optics of the light source and its distance from the surface or object being illuminated. Defined by the metric lux or footcandles. See 5.6.1 Illuminance.

Luminance is essentially a measure or prediction of the quantity of light reflected from a surface or object or transmitted through a translucent or transparent surface or object. Luminance depends on the amount of light falling onto the surface or object and on the surface or object light reflectance value (LRV) or light transmittance value (T_{vis} for transmittance of visible radiation). Defined by the metric cd/m^2 or cd/ft^2. See 5.7.1 Luminance.

Photographic limitation is the degree to which reality is conveyed in a photo. A limited range of brightnesses are captured by cameras and displayed by the reproduction methods of paper and computer screens. Photographers of analog and digital images can and often do manipulate the images in an effort to fulfill their perceptions of light and color of the photographic scene. Some photographers use fill light to make dark areas appear brighter. Still other photographs have been altered to avoid artwork copyright infringement. The authenticity and accuracy of the scenes illustrated in some of the photographs in this handbook cannot be easily certified. However, these photographs effectively illustrate the lighting techniques discussed. A live view of a scene of interest is the only assurance of no manipulation.

12.2 Spatial Factors

Spatial factors are those related to the 3-dimensional and 2-dimensional nature of architectural layout and envelope. Lighting effects, hardware, and layouts can reinforce, detract from, or maintain neutrality with the architecture, interiors, and space planning. Pleasantness, spatial definition, and circulation are called spatial factors as these affect people's perception and use of built space. [1] In Table 12.1a and Table 12.1b, very brief presentations are made of these factors with relevant design media identified along with traits of interest, criteria, and techniques to consider. These tables can be used as checklists. For those factors the designer prioritizes as most important, resulting techniques can be collected for team discussion and contribute to a lighting strategy.

Other influences not cited here may be defined or deemed more appropriate based on the particulars of a project or on a designer's experience. The following material and the design discussions in this handbook should be considered indicative, since much is based on anecdotal trends, limited research, or some influence of fundamentals or rules in the FRAMEWORK FOR LIGHTING Section. Some guidance is little more than talking points for additional thought and discussion with the design team to advance a lighting design.

12.2.1 Pleasantness

Pleasantness is premised on people living or working more satisfactorily or longer in settings that are considered pleasant. Size, shape, configuration, and layout of daylight delivery and luminaires may be important. The significance of 2-dimensional scale and 3-dimensional shape of daylight delivery should drive the team to think about windows' and skylights' sizes relative to the architecture. So, based on dimensions and proportions of a given wall or ceiling and the proximity of the surface to people, what size windows or skylights will look appropriate and result in a comfortable feeling? How do these sizes compare to energy code allowances? A range of sizes and forms can then be tested in calculations to assess daylight *illuminances* and *luminances* and simultaneously HVAC implications. Figures 12.3 and 12.4 illustrate effects of daylight delivery scale and temporal aspects of luminances when these are addressed as part of the design problem. Figures 12.5 and 12.6 illustrate results that can be achieved when luminaire layouts, patterns, and rhythms and visual order and appeal criteria are considered. In these and other photographs in the handbook there is *photographic limitation* when illustrating lighting installations.

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Figure 12.2 | Lighting Technique
Multiple architectural and lighting design factors guided this lighting solution. The relatively low ceiling (9′ 6″) and narrow width along with the prominence of this corridor (leading from lobby to meeting room) pushed the team to address pleasantness/luminaires/scale in Table 12.1a and subjective impressions/spaciousness in Table 12.2. The curvilinear layout of the corridor is reinforced with a curvilinear layout of small luminaires. The colorful translucent glass wall exhibits a textural reflective quality that is well-featured with wall lighting. This was discovered during glass-sample reviews with various lighting techniques. The glass wall divides the corridor from an adjacent meeting room (not shown) where the wallwashing in the corridor produces a backlighting effect.

The wallwash effect is achieved on the glass wall with *nominal* 3″ diameter adjustable accents lamped with 20W CMH lamps.

Although floor illuminance is important and must be addressed, the lighting solution was driven by spatial and psychological factors and the architectural materials. Ultimately the floor is satisfactorily illuminated. The specularity of the glass wall sets up a classic angle-of-reflection-equals-angle-of-incidence situation which, given the corridor width and the geometric spacing of lights from the wall and their aiming angles to best light the wall, results in sufficient illuminance on the floor. No additional lighting for the floor plane is necessary. Had floor illuminance solely driven the lighting design to a series of downlights centered in the corridor, the result would have been a cave-like condition with dark, dull walls.

» Image ©Beth Singer Photographer, Inc.

Nominal in this sense is used as a general identification of size, but does not usually represent the exact size. In this example, the adjustable accent has an exact aperture opening of 2.9 inches and an exact overall outside diameter (edge of trim flange to edge of trim flange) of 3.875 inches.

12.2.2 Spatial Definition and Circulation

Lighting equipment and effects can delineate or enhance architectural configurations and help with defining space and circulation. Lighting can reinforce architectural planes, geometry and features. Lighting of space planning devices like partial-height walls, space dividers, and architectural objects can help define activity zones. See Table 12.1b. Figures 12.7 through 12.10 demonstrate lighting's contribution to spatial definition and circulation.

Lighted architectural planes enliven or define space boundaries and serve as reflectors to distribute light in the areas in which these techniques are employed. Planar lighting is especially helpful in settings where ambient illuminances on floors or workplanes are low, perhaps ≤100 lx, but the prominence of the space or duration of anticipated occupancy is high.

Planar intersections are themselves articulated more emphatically with light. Edge definitions help users comprehend changes in plane orientation and identify the extent of architectural boundaries as ceiling-wall or wall-floor junctures are highlighted.

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Table 12.1a | Spatial Factors: Part One

Factor	Design Media	Traits of Interest	Criteria	Techniques to Consider[a]
Pleasantness	Daylight Delivery	• **View**	• Define view	• Provide clear line-of-sight to horizon
				• Provide clear view of landscape
		• **Scale**		
		» 2-dimensional	• Define fit	❶ • Relate media dimensions to architecture- or people-scale
		• **Shape**		
		» 3-dimensional	• Define volume	❷ • Shape to enable view and control glare
		• **Layout** (see 14 | DESIGNING DAYLIGHTING)		
		» Orientation	• Daylight coverage	• Optimize distribution and area of coverage
			• Glare control	• Brise soleils, overhangs, automated shades
		» Relationship(s)	• Architecture	• Relate to walls, ceilings, coves, architectural modules/sizes
				• Plan in 3-D to avoid odd or harsh lighting effects
			• Interiors	• Relate to activity zones/planning for visual interest/efficiency
			• Landscape	• Relate to view and glare control during periods of daylight
		» Patterns	• Scale and frequency	• Relate to architecture, people, other lighting techniques
			• Function vs. aesthetics	• Address task/focal locations vs. attractive arrangement
		» Rhythms	• Groupings	• Relate to activity zones/planning for visual interest/efficiency
			• Repetitions	• Relate to architecture, people, other lighting techniques
		• **Luminances**		
		» Patterns	• Define visual order	❸ • Establish visual order vs. visual noise of daylight patterns
		» Magnitudes	• Define visual comfort	• Limit extent of glare during periods of daylight
			• Define visual appeal	❹ • Provide visual relief and interest during periods of daylight
	Luminaires	• **Scale**		
		» 2-dimensional	• Define fit	• Relate dimensions to architecture- and people-scale
		• **Shape**		
		» 3-dimensional	• Define volume	• Shape to relate to architecture- or people-scale
		• **Layout**		
		» Relationship(s)	• Architecture	• Relate to walls, ceilings, coves, architectural modules/sizes
				• Plan in 3-D to avoid odd or harsh lighting effects
			• Interiors	• Relate to activity zones/planning for visual interest/efficiency
		» Patterns	• Scale and frequency	• Relate to architecture, people, other lighting techniques
			• Function vs. aesthetics	❺ • Address task/focal locations vs. attractive arrangement
		» Rhythms	• Groupings	❻ • Relate to activity zones/planning for visual interest/efficiency
			• Repetitions	• Relate to architecture, people, other lighting techniques
		• **Luminances**		
		» Patterns	• Define visual order	❼ • Establish visual order vs. visual noise of lighting effects
		» Magnitudes	• Define visual comfort	• Limit extent of glare
			• Define visual appeal	❽ • Provide visual relief and interest

a. Numbered notes are keyed to Figures 12.3-12.6.

The enhanced visibility of an architectural mass, that is, an element of significant size, design, or color, can serve as focal point or backdrop. Important features identified by mass or frequency are made prominent with light. Lighting repetitive features is effective in establishing a focal cue or better identifying an area for a specific activity as Figure 12.10 illustrates.

Wayfinding with light involves patterns of luminance or color to attract visual attention. Color can be achieved with colored surfaces or colored light or both. Relatively high luminances or intense saturated color in spot or area applications attract visual attention. These techniques can be used to enhance or establish circulation paths or define destinations.

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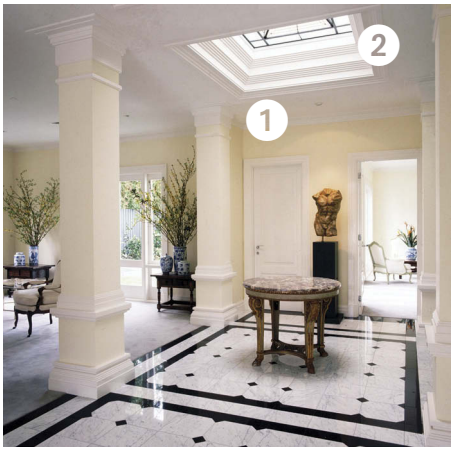


Figure 12.3 | Daylight Media Scale
Numbered notes are keyed to Table 12.1a. The scale of the skylight in two dimensions (in plan view) ❶ is based on the architectural bay defined by the columns. In three dimensions ❷, the skylight depth addresses glare control. The stepped well is a further refinement of scale, eliminating the blockiness of a less elegant straight-wall deep well and making the most of a relatively small skylight—a means of using standard-sized skylights but achieving a custom-look and a proportionally appropriate aperture in the ceiling. This stepped splay also reduces the harsh contrast between relatively dark ceiling plane (because it is unlit) and the bright exterior sky that is common with shallow- or no-well skylights.
» Image ©Rodney Hyett; Elizabeth Whiting & Associates/Corbis



Figure 12.4 | Daylight Luminances
Numbered notes are keyed to Table 12.1a. The wall luminance patterns ❸ are appealing and make sense visually (allowing for ready identification of solar orientation and time of day). The orientation, sun path, and skylight transmittance and the regular array of structural elements combine to achieve visual order and interest over time ❹. Skylights employed in these situations (residential, hospitality, lounge, waiting area) and in orientations where sun patterns only fall on wall surfaces or confined zones avoid the annoyance of direct glare and temporal pattern shift on occupied sitting/working areas.
» Image ©Rodney Hyett; Elizabeth Whiting & Associates/Corbis



Figure 12.5 | Luminaire Layout
Numbered notes are keyed to Table 12.1a. Layout relationships, patterns, and rhythms all contribute to the lighting approach. The planning and activity zones of the waiting area are defined by a collected light array consisting of coves and rectilinear downlights ❺. Seating areas are addressed—softly featured—with downlights ❻. Transitional circulation areas are addressed with cove lighting. The groupings and rhythm of the interiors planning then established the groupings and rhythm of the lighting.
» Image ©Adrian Wilson/Beateworks/Corbis

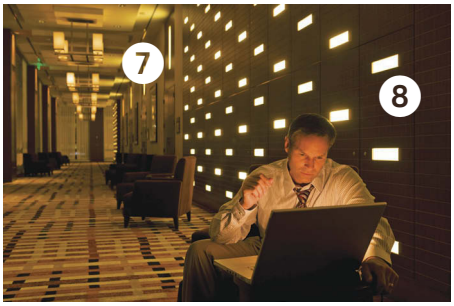


Figure 12.6 | Luminaire Luminances
Numbered notes are keyed to Table 12.1a. The visual appeal of this hotel lobby is, in part, due to the luminance patterns created by the more conventional chandeliers seen in the background juxtaposed with the more unique in-wall luminaires in the foreground. Patterns of luminaires and lighting effects ❼ make sense visually and reinforce the circulation and lounge seating. The in-wall lighting introduces strong visual attraction and combines with architectural finishes to establish appeal ❽. All of these techniques work together to break what could be monotonous application of a single lighting effect or treatment throughout the area. Other techniques resulting from review of spatial factors/pleasantness contribute to the success of the lighting solution. For example, in-wall lights that are within reach of users are scaled accordingly, depending on architectural setting and style. Here, larger in-wall lights in such close proximity to users may be considered physically overwhelming and annoying. Lamping and lensing of such in-wall luminaires are selected to avoid glare or visual discomfort.
» Image ©Mark Edward Atkinson/Blend Image/Corbis

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Table 12.1b | Spatial Factors: Part Two

Factor	Design Media	Traits of Interest	Criteria	Techniques to Consider[a]
Spatial Definition	**Planes**	**• Luminances**		
		» Uniformities	• Enhance planes	❹ • Use frontal wallwash across plane or planes of choice
		» Patterns	• Accent planar textures	• Use grazing wallwash on plane or planes of choice
	Planar Intersections	**• Ceiling-to-ceiling** **• Ceiling-to-wall** **• Wall-to-wall** **• Wall-to-floor**	• Articulate edges	❶ • Accent plane changes of choice
			• Articulate juxtapositions	❷ ❺ • Accent plane intersections
			• Articulate design style	• Use lighting effects or luminaires to complement style
	Design Features	**• 2-D Surface**	• Focus attention	❻ ❼ • Accent single large feature
		• 3-D Object		• Accent multiple features for "massing" effect
Circulation	**Wayfinding Markers**	**• Luminances**		
		» Patterns	• Define path	• Accent elements such as pilasters or niches
		» Magnitudes	• Define destination	❽ • Accent point or area of destination
		• Color		
		» Patterns	• Define path	• Accent colorful features such as artwork
		» Magnitudes	• Define destination	❸ • Accent or saturate color feature at destination

a. Numbered notes are keyed to Figures 12.7-12.10.

12.3 Psychological Factors

Attraction and subjective impressions are categorized as psychological factors and are premised on lighting influencing visual attraction and people's impressions or reactions to a setting [2[[3] [4] [5]. What follows should be considered indicative, since much is based on anecdotal trends, limited research, or some influence of fundamentals or rules in the FRAMEWORK FOR LIGHTING Section. Some guidance is little more than talking points for thought and discussion with the design team to advance a lighting design.

12.3.1 Attraction

Reflected approach means taking advantage of the surface's or object's reflective qualities and using front lighting techniques. Lighter-toned finishes reflect a lot of light and can be frontal lighted with relatively low-wattage accent or wallwash lights. Darker-toned finishes reflect little light, requiring relatively high-wattage accent or wallwash luminaires.

Transmitted approach means taking advantage of the surface's or object's transmissive qualities and using back lighting techniques. High-transmission materials such as clear, frosted, or pale-colored glass and acrylics transmit a lot of light and can be backlighted with relatively low-wattage luminaires. Cloudy, deeply-saturated-colored, or mostly opaque glass and acrylics transmit little light, requiring relatively high-wattage luminaires.

Color or luminance can be used for visual attraction. Variables include a *reflected* versus *transmitted* approach, colored materials lighted with white light, colored materials lighted with colored light, and ambient colors and luminances. The number of variables grows geometrically when considering the number of colors available in both surface finishes and lamps. Mockups are best to assess the attraction potential of a proposed design.

Reflected and transmitted approaches are most powerful when material color is matched with color of light. Colored light on neutral reflecting or transmitting surfaces exhibit more subtle results. The means of generating the colored light itself greatly affects the outcome. Many colored LEDs emit in very narrow bands of wavelength and therefore appear highly saturated. If these are combined with reflective or transmissive surfaces that are highly saturated and spectrally similar, the color effect is strongest. If spectral reflectance, transmittance, and radiation data were available for the respective surfaces and lamps, matching and energy optimization would be easy. Where neutral reflecting or transmitting surfaces are used, colored LEDs or other lamps exhibiting good color saturation (for example, colored fluorescent and cold cathode or neon lamps) will generally offer satisfactory results. Mockups are better and more certain than data matching or renderings based on data, however complete.

Figure 12.2 illustrates color effect of white-light from 3000 K and 80 CRI CMH lamps on saturated-color glass. Figure 12.9 illustrates color effect of white-light from 3000 K and 80 CRI CMH lamps and general background lighting beyond from 3000 K and 85 CRI T8 lamps on saturated-color glass similar to that in Figure 12.2. Figure 12.11a illus-

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Figure 12.7 | Planar Intersections
Numbered notes are keyed to Table 12.1b. Light reinforces the elegant modernity of sweeping architectural forms and the selective use of bold color. Where ceiling planes step up or down from one another, light coves differentiate these planar intersections ❶. The curvilinear and angular colored forms are visually strengthened with light slots at the juncture of the ceiling and the wall of the forms ❷. These lighted colored forms assist in assessing space depth and activity and help visually pull users into the space ❸. In the context of the seating area, uniform wall lighting establishes a comfortable backdrop against which observing and conversing amongst people is facilitated ❹. This uniform wall lighting also augments downlighting and cove lighting in the area for localized high quality facial modeling—an important aspect of conversing.
» Image ©Elliott Kaufman/Beateworks/Corbis

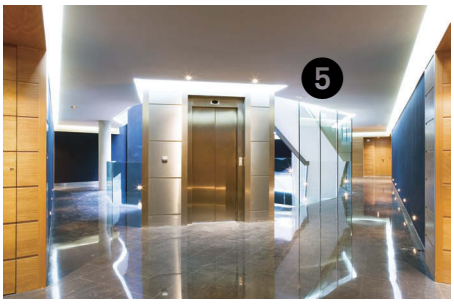


Figure 12.8 | Planar Intersections
Numbered notes are keyed to Table 12.1b. Light emphasizes the angular undulations of walls ❺ and readily defines the extent and configuration of space for users—particularly helpful for first-time users of hotels for example. Such a configuration of light works to "energize" the space. In this figure and in Figure 12.7, light patterns reflected in the polished floors add visual interest or visual noise, depending on one's design perspective and the intended audience. These patterns can be disorienting for visually impaired and older occupants and may have the unintended consequence of slowing circulation movement. With polished floors, any lighting in or on walls and in or on ceilings will created reflected patterns of light.
» Image ©Fernando Alda/Corbis



Figure 12.9 | Features and Planes
Numbered notes are keyed to Table 12.1b. The translucent feature wall exhibits significant depth when backlighted (white light backlighting fused, cast, multi-colored glass). The feature wall is completely lighted to serve as backdrop for the corporate logo ❻ which is front-accented and as the "welcome" focal point of the lobby ❼.
» Image ©Beth Singer Photographer, Inc.



Figure 12.10 | Wayfinding
Numbered notes are keyed to Table 12.1b. The repetitive use of triple-light arrays in the six vertical architectural elements ❽ identify this reception area. Although luminance of each triple-light is relatively sedate—this a reception to a spa where bright, harsh lighting would be inappropriate—their repetition identifies the significance of the destination.
» Image ©Atlantide Phototravel/Corbis

trates color effect of blue fluorescent lamps on various surfaces. Figure 12.11b illustrates color effect of good-color-saturation colored fluorescent lamps (red-sleeved-at-factory) backlighting a saturated-color acrylic transmissive surface.

For purposes of attraction, *luminance ratios* of at least 3-to-1 (object-to-background) are necessary for one object to exhibit some degree of prominence from its background. Where a distinct focal cue is desired, a luminance ratio of at least 10-to-1 is appropriate. For dominating focal points, a luminance ratio approaching 100-to-1 is needed. Figure 12.11a illustrates the visual effect of a focal object (the white glass bead panels) to background (the dark wood wall surround) where the luminance ratio reaches 70-to-1 at night.

Luminance ratio is the ratio of the luminance of one object or surface to that of its background or to another object or surface. Greater ratios result in more distinct visual difference.

Hierarchies of viewing can be established by considering the effect of various luminances or colors throughout a space. Figure 12.11a illustrates luminance hierarchies to compose a setting.

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Figure 12.11a | Color and Luminance Attraction
Color and luminance are used for visual attraction of the registration area in a hotel lobby, visible from a porte cochere off to the right. Static colored light in recessed ceiling slots and dynamic luminous panels set the scene in blue at dusk and through morning. Glass bead panels behind the front desk are strongly lighted for significant luminance. Layering luminances from the table luminaires at the front desk and along the leading edge of the front desk stone top help define and accentuate the 3-dimensional character of the lobby registration area. See an outline of techniques in Table 12.1b | Spatial Factors: Part Two.
» Image ©Kevin Beswick, www.ppt-photographics.com

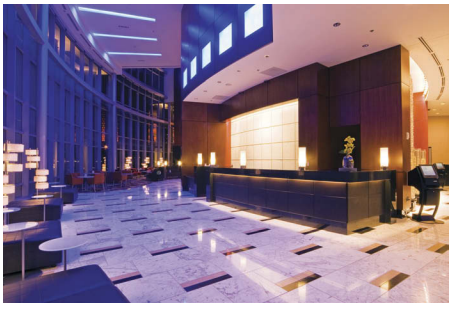
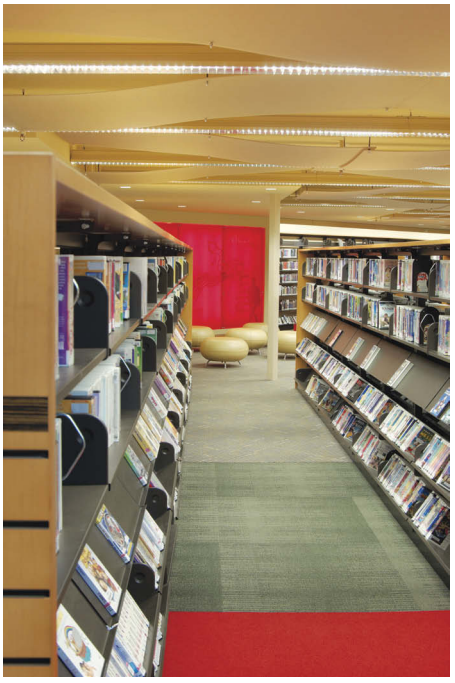


Figure 12.11b | Color Attraction
Color and luminance are used for visual attraction of the distant reading area from within the context of library stacks. Red translucent acrylic panels are backlighted with red-filtered fluorescent lamps for deeply saturated color.
» Image ©Balthazar Korab Photography Ltd.



12.3.2 Subjective Impressions

The design of lighting should not be limited to utility, task, and physiological needs. Indeed, a truly functional lighting design addresses qualitative factors affecting users' attitudes, preferences, well-being, and motivation. [6] [7] How people feel about a space and react to a setting, in part, appear related to so-called cue-patterns.

Cue patterns are categorized by three lighting modes: location (with central or perimeter cue patterns), uniformity (with uniform or nonuniform cue patterns), and relative strength (with bright or dim cue patterns). Cue patterns are relative terms and are not quantified. These may be generated by electric light or daylight. Perimeter means patterns of light are in the user's periphery, commonly at the perimeter of a space, but could be off to the side of a sitting area or work area. Central means the patterns of light are related to the central room area. Uniform as used here indicates that the patterns of light are consistently or regularly arranged. Nonuniform means the patterns of light are applied intermittently or irregularly, but not in a completely random or haphazard manner. Nonuniform patterns of light typically relate to surface materiality, objects, and focal points as shown in Figures 12.12 and 12.13.

Subjective impressions affected by the three lighting modes are preference, privacy, relaxation, spaciousness, and visual clarity. Each of these impressions is influenced by a distinct combination of lighting modes. For each of these subjective impressions, Table 12.2 identifies the supporting lighting modes in order of influence, design implications, techniques for consideration, and typical applications. [3] [5] [8] Any of these subjective

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impressions may be deemed important by the designer for a given project or space type. Listed applications are not exclusive. Additionally, some of these impressions are mutually achieved by using multiple lighting modes to address several impressions and to meet appropriate illuminance criteria discussed in 12.5.5 Illuminance and respective application chapters. Like other components of lighting design, addressing subjective impressions is but one means of establishing lighting techniques for consideration on a project. Using these techniques does not assure a successful lighting solution.

12.3.2.1 Preference

Evaluative impressions of preference are promoted by perimeter lighting applied in a nonuniform manner. Brighter lighting effects are helpful, but not necessary to elicit the impression. Preference impressions are appropriate in many settings. See Figure 12.12. Even in office situations, preference for the setting can be achieved with some wall or art highlighting.

12.3.2.2 Privacy

In situations where some sense of visual privacy is desired, for example, in some restaurants and some meditation settings, lighting can assist. Privacy is promoted by nonuniform lighting and further enhanced with dim lighting in the vicinity of users. Some perimeter lighting effects are helpful, but not necessary to elicit the impression. See Figure 12.13.

12.3.2.3 Relaxation

Impressions of relaxation are most appropriate in casual spaces including meeting rooms, dining rooms, and lounges. Perimeter lighting applied in a nonuniform manner promotes a sense of relaxation. Dimmer lighting effects are helpful, but not necessary to elicit this impression.

12.3.2.4 Spaciousness

Where physical space is limited or in spaces of any physical size where people assembly effectively creates cramped quarters, the sense of spaciousness can be promoted with uniform wall lighting. Brighter effects are helpful, but not necessary to elicit the impression. This technique, illustrated in Figure 12.14, is appropriate in high-traffic corridors and concourses, in waiting and lobby areas, in breakout areas in convention centers and hotels, or even in small conference rooms and offices. Spaciousness is most efficiently achieved when electric-lighted wall surfaces exhibit at least 60% reflectance or, better yet, where daylight is employed regardless of wall reflectance.

12.3.2.5 Visual Clarity

Visual clarity is promoted by a uniform lighting mode with bright ceiling and work planes. Some perimeter emphasis is helpful, but not necessary to elicit the impression. Visual clarity is appropriate for work spaces. See Figure 12.15.

12.4 Physiological Factors

Although much of vision is about physiology as detailed in 2 | VISION: EYE AND BRAIN, recent interest and research in circadian rhythm and seasonal affective disorder (SAD) deserves attention. Photosensitivity to UV radiation also deserves attention as this may arise as a programming item for clients with Lupus or a sensitivity to UV. This is not to diminish the foundation of vision and those factors on which basic design tenets have evolved, including accommodation, adaptation, color vision, among others discussed in Section 2.6 Consequences for Lighting Design. See Physiological Resources sidebar for additional references.

The circadian rhythm is driven by spectral power distribution, amount, exposure duration, and timing of light. Although exposure to significant amounts of white light during the day entrains the circadian rhythm, it is not practical to achieve these dosages exclusively with electric light common to architectural applications. Architectural lighting design practice

IESH/10e Physiological Resources

> 2 | VISION: EYE AND BRAIN
  - for more on light's effects on the visual system

> 2.6 Consequences for Lighting Design
  - for more on lighting criteria and application

> 3 | PHOTOBIOLOGY AND NONVISUAL EFFECTS OF OPTICAL RADIATION
  - for more on light's nonvisual effects on people

> 3.2 Nonvisual Response to Optical Radiation
  - for more on circadian rhythms

> 3.5 Phototherapy
  - for more on SAD

> 4.12 An Illuminance Determination System
  - for more on scotopic, mesopic, and photopic vision

> Table 2.1 | Vision Adaptation States
  - for more on scotopic, mesopic, and photopic adaptation states

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Table 12.2 | Subjective Impressions

Impression	Lighting Modes[a,b,c]	Design Implications	Example Reinforcing Techniques[d]	Typical Applications
Preference	• Perimeter • Nonuniform • Bright	• Use perimeter nonuniform lighting. Brighter effects help, but not necessary.	• A window wall or accenting a wall **AND** • Accenting wall art or accenting one or several architectural or material features and/or using decorative lighting, such as pendants, sconces, or table or floor lights placed intermittently around edges of room or area	• Most spaces • See Figure 12.12 • See Figure 12.13
Privacy	• Nonuniform • Dim • Perimeter	• Use nonuniform relatively dim lighting. Emphasis at periphery helps, but not necessary.	• Dim and somewhat spotty lighting effects from downlighting or using dim decorative lighting, such as pendants, sconces, or table or floor lights	• Upscale clubs • Upscale restaurants • Some residential spaces • Meditation spaces • See Figure 12.13
Relaxation	• Perimeter • Nonuniform • Dim	• Use perimeter nonuniform lighting. Dimmer effects help, but not necessary.	• Wallwashing one or two darker-toned walls or features or dim wallwashing one or two lighter-toned walls or features **AND** • Softly accenting select art and/or several architectural or material features and/or using decorative lighting, such as pendants, sconces, or table or floor lights placed intermittently around edges of room or area	• Casual areas • Conference rooms • Lounges • Sit-down restaurants • Waiting areas
Spaciousness	• Uniform • Perimeter • Bright	• Use uniform wall lighting. Brighter effects help, but not necessary.	• Window walls for at least two walls and/or wallwashing at least two walls ; consider wall reflectances of 60% or more for at least half the walls to be lighted	• Circulation • Assembly spaces • See Figure 12.14
Visual Clarity	• Bright • Perimeter • Uniform	• Create bright ceiling and worksurfaces with some emphasis on periphery. Uniform effects help, but not necessary.	• Skylights, relatively bright recessed lensed modular luminaires, recessed direct/indirect modular luminaires, or downlighting mixed with uplighting; consider ceiling reflectances of 90% **AND** • Window walls and/or wallwashing	• Work spaces • See Figure 12.15

a. Lighting modes are listed in order of most influential first.

b. Dim and bright are used in a relative sense. No quantitative design values are available. Surface reflectances affect senses of dim and bright.

c. Nonuniform as used here means that the patterns of light are applied intermittently, but not in a completely random or haphazard manner. Uniform indicates that the pattern or patterns of light are consistently or regularly arranged.

d. Daylight or electric light can be employed to achieve reinforcing techniques. Subjective impressions' techniques are combined with other lighting techniques as necessary to meet other design criteria.

can minimize disruption of people's sleep cycles. Complete dark in sleeping quarters is best. If outdoor lighting is in close proximity, blackout shades on windows and skylights are appropriate. If nightlights are desired, then long wavelength sources such as LEDs producing spectra at between 600 to 620 nm are appropriate. These can be specified in very-low-output well-controlled and no-glare steplights and controlled by occupancy sensor. Such an arrangement is highly efficient and does not create a burn hazard common with filament-lamp solutions or an over-lighted condition common with fluorescent. These are especially helpful in healthcare facilities and housing for population ages over 65 years where night lighting traditionally consisted of over-lighting and required fumbling for switches or brushing against hot luminaires all of which were a hazards. [9] [10]

SAD is a medical condition for which treatment is well beyond the capabilities of architectural lighting. Traditional treatment consists of 30- to 60-minute-duration exposures to high levels of most any polychromatic white light (daylight or electric light approaching

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Figure 12.12 | Preference
Nonuniform perimeter lighting patterns are achieved with varied effects. One effect results from spotlighting wood transoms at elevators in the background ❶. Another effect results from grazing a dimensional wood feature wall above the fireplace sitting area ❷ which introduces its own nonuniform but crisp brightness patterns. A third effect is achieved with small table and floor lights in the background ❸. These same techniques combine with dim lighting in this particular setting to elicit an impression of privacy (also see Figure 12.13 below).
» Image ©Kevin Beswick, www.ppt-photographics.com



Figure 12.13 | Privacy and Preference
In a dimmed meditation scene, nonuniform lighting is used to define a dim zone in the vicinity of users ❹. Here, the adaptation effect created by bright focals relative to the dim background makes the dim seating areas appear even dimmer. Strong luminances achieved with CMH spotlights on the altar and tabernacle ❺ relative to the uniform but low-level house lighting allow for personal meditation in anonymity. In the users' periphery, the fluorescent slot ❻, although on dim setting, provides subtle wall accenting and works with the accenting of the tabernacle and altar to enhance preference impressions.
» Image ©2005 Gene Meadows

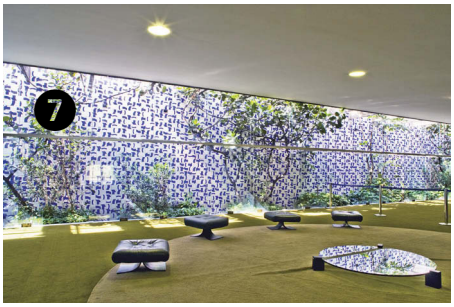


Figure 12.14 | Spaciousness
Uniform wall lighting elicits an impression of spaciousness ❼ at The Congresso Nacional do Brasil. Daylight is employed to achieve the uniform wall lighting in this lobby area.
» Image ©Alan Weintraub/Arcaid/Corbis



Figure 12.15 | Visual Clarity
A uniform pattern of skylights offer a bright ceiling plane ❽. Skylighting combines with down-lighting and table lights to create a bright work plane zone. Wall lighting is uniform and bright ❾. All of which contributes to an impression of visual clarity—deemed an important factor for this adult reading area in a community library.
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10,000 lx) [11]. More recently, much lower levels of narrow-band, blue light have been found effective [12]. If SAD arises as a programming item, the client should consult with a specializing physician or ophthalmologist.

Photosensitivity is sensitivity to ultraviolet radiation. If a user is known to be photosensitive, or such becomes obvious after project completion, it may be necessary to limit or eliminate radiation below 400 nm. In extreme cases UV radiation must be eliminated and filtration of lamps is necessary in direct or indirect architectural lighting applications which exhibit any amount of UV, including halogenIR_{LV}, CMH, and fluorescent types. Since photosensitivity may be drug induced or the result of underlying medical conditions, the client should consult a physician. The outcome may inform the architectural lighting solution.

12.5 Task Factors

Task factors revolve around the users' visual tasks. Luminances, illuminances and ratios are criteria of interest and depend on tasks and users' ages. A deliberate and detailed study of task factors can help identify lighting techniques most appropriate for the project. However, this involves much more than assigning a footcandle value to a room and applying lighting uniformly to meet that criterion.

12.5.1 Visual Tasks

Task and application lists from the respective application chapters in this handbook will provide some insight into the breadth of visual tasks and applications that may be involved in any project. In fact, the list is probably too broad to be of much use in immediately establishing lighting criteria and quickly narrowing design techniques for a specific project. Application lists are of little use until space planning has defined room types and the task areas within those rooms.

Perhaps the best way to understand clients' *work* or *living processes* and tasks is to visit their existing facilities as part of the programming (see 11.3.2.1 Programming). This will enable the designer to better determine the supporting IES tasks and applications and determine appropriate luminance and illuminance criteria. Better-suited lighting techniques are a likely outcome yielding better satisfied clients and better use of lighting energy.

Delineating tasks is recommended. An extensive review resulting in a list of tasks and existing conditions helps establish the range of tasks and enables specification of appropriate criteria and, later, of luminaires, lamps, and controls. Table 12.3 is a sample visual task survey.

During a visit to the clients' existing facility, the designer can also assess the existing illuminances, surface reflectances, and luminances, providing further insight into visual task requirements or users' expectations. Illuminances can be measured using an illuminance meter that is intended for architectural lighting use. See 9.8 Measuring Illuminance. Luminances and reflectances can be measured with a luminance meter. See 9.11 Measuring Luminance and 9.12 Measuring Reflectance and Transmittance.

The designer must manage and address expectations during the design process. Knowing these expectations and understanding them during programming can alleviate missteps in determining criteria and establishing design techniques. For example, users of a drafting studio may request 1000 lx in the project scope, but a review of the existing situation may determine that nearly all users work on computers, require minimal reference to paperwork, and work on screens that are set to *CSA/ISO* negative polarity mode (see Figure 12.16). These tasks require low illuminances for the screen viewing situation and only moderate illuminances for periodic reference to paper tasks, perhaps some degree of facial recognition for extemporaneous meetings, and to maintain comfortable states of adaptation. Discussion then may be appropriate on the 1000 lx criterion so that the designer can

Work process is the complete human task, not just one visual component of one visual task associated with work. For example, in a judicial facility a court reporter's office might be expected to include reading as a visual task. The work process, however, must encompass what is read, how it is read and reconstituted into an official record, the area over which it is read, addressed, and reconstituted, and the typical time allotted for this process. These components of the work process change with technology advancements, judicial requirements and procedures, and changes in personnel. Any or all of this may influence the types of IES tasks and applications used in determining appropriate illuminance criteria.

Living process is the complete human task, not just one visual component of one visual task associated with living. For example, in a residence, living includes eating, usually as a group. This activity might be expected to include identifying food. The living process, however, must encompass what is eaten, how it is eaten, the area over which it is eaten, the social activities involved, and the typical time allotted for this process. These components of the living process may change with technology advancements or with the individual or group involved. Social activities include conversation, which itself involves facial recognition, and perhaps watching television or Internet or reading. Any or all of this may influence the types of tasks used in determining appropriate illuminance criteria.

CSA/ISO is an acronym for Canadian Standards Association's adoption of an International Organization of Standardization standard. See Figure 12.16 for CSA/ISO definitions for computer screen qualities standardized throughout the handbook. [13] [14]

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Figure 12.16 | CSA/ISO Computer Screen Qualities

CSA/ISO Positive Polarity Screen

This bright-background VDT screen with dark text/graphics has an appearance similar to most paper tasks. This screen setup minimizes luminance ratios between computer screen, paper tasks, and lighter-toned background wall and ceiling surfaces. Some benefits of CSA/ISO positive polarity are: minimize transient adaptation; reduced eye strain; improved task visibility; reduced veiling-reflection effects; better visibility for most older observers. People with low vision typically prefer negative image polarity. CSA/ISO positive polarity screens have been shown to improve accuracy when reading text on screen [15].

» Image ©iStockphoto/Nikada

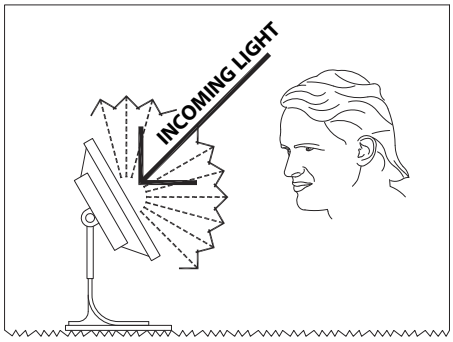


CSA/ISO Negative Polarity Screen

This dark-background VDT screen with bright text/graphics) is useful for detecting small detail, but makes for harsh contrast with any paperwork. This screen setup creates significant luminance ratios between computer screen, paper tasks, and light-toned background wall and ceiling surfaces. Such contrast can lead to visual fatigue and headaches. Most screens/software are user-adjustable and can be toggled between CSA/ISO positive polarity and CSA/ISO negative polarity.

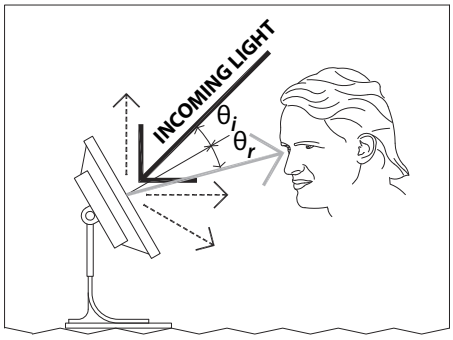
A further confounding aspect is the screen finish. Even flat screens exhibiting glossy screen surfaces can reflect glare and exhibit veiling reflections that degrade the image. See below.

» Image ©iStockphoto/Nikada



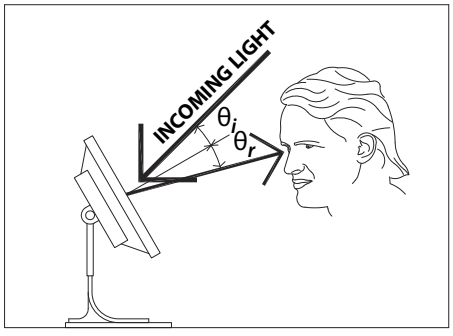
CSA/ISO Type I Screen/Matte Finish

The reflectance characteristics of a CSA/ISO Type I screen are graphically illustrated here. Type I monitor screens exhibit excellent anti-reflection/anti-glare properties. The screen has a matte or textured surface finish which diffuses incoming light and usually results in minimal veiling reflection or reflected glare. These screens are considered to have good screen reflection properties and are most forgiving under many lighting conditions.



CSA/ISO Type II Screen/Semi-specular Finish

This graphic illustrates reflectance qualities of a CSA/ISO Type II screen. These screens exhibit fair anti-reflection/anti-glare properties. The screen has a semi-specular surface finish. The angle of reflection (θ_r) for *some* portion of the incoming light is equal to the angle of incidence (θ_i), so the task geometry relative to direct luminaires and bright surfaces is somewhat sensitive. These screens are considered to have medium quality screen reflection properties and work best under most lighting conditions when set to positive polarity.



CSA/ISO Type III Screen/Specular Finish

This graphic illustrates reflectance qualities of a CSA/ISO Type III screen Type III screens exhibit little or no anti-reflection/anti-glare properties. The screen has a specular or glossy surface finish. The angle of reflection (θ_r for *most* of the incoming light) is equal to the angle of incidence (θ_i), so the task geometry relative to direct luminaires and/or bright surfaces is very sensitive. Reflected bright surfaces easily veil the text/graphics displayed on the screen. In extreme cases, reflected bright surfaces cause glare. These screens are considered to have poor quality screen reflection properties and are most problematic when set to CSA/ISO negative polarity except where lighting is dim and uniform.

» CSA/ISO screen graphics from *Architectural Lighting Design, 3rd edition*, reprinted with permission of John Wiley & Sons, Inc.

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learn about unseen or only periodically-performed tasks or so that the users can learn that 1000 lx is a criterion appropriate for extensive hand drafting and reading printed plans.

Prioritize tasks based on site visits, previous experience, and discussion with the client. It is common for people to cite anything and everything they might do or might like to do with respect to living and working tasks. In reality, however, the majority of visual tasks for room- or area-function are limited to a relatively short list. This design effort can avoid significant time and money spent on design and procurement of lighting that is seldom used or unnecessary.

During the visual task survey, it may be learned that reading printed plans in the aforementioned example is a necessary function, but one which happens infrequently and, when it does, can occur away from individuals' workstations. So, a single table lighted to accommodate periodic short-term viewing of plans for a group of workers eliminates the need for high illuminance everywhere.

Luminance gradients are the rate of change in luminance over a given area of luminaire or wall or ceiling surface. A high rate of change over relatively small areas may create reflected glare and/or veiling reflections in sensitive visual tasks, such as CSA/ISO Type III negative polarity computer screens displaying highly detailed graphics such as might be encountered in pharmaceutical drug design work. See Figure 12.17 for gradient illustration.

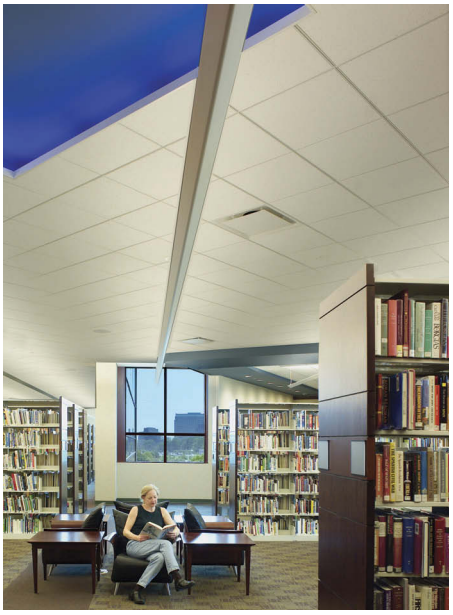


Figure 12.17 | Luminance Gradient
The bright area above the linear pendant fades softly over a relatively large area from left-to-right. This is a gradual rate of luminance change and is satisfactory for many paper and computer tasks. However, computer screens with CSA/ISO Type III negative polarity screens will likely reflect even this soft-wide-area ceiling wash to the user which could veil portions of the computer screen, thereby reducing task visibility.
» Images ©2003 Gene Meadows

12.5.2 Luminance

With respect to tasks, several luminance criteria are important: task luminance; background luminance; and light source luminance, patterns, and gradients. Any of these, if improperly addressed, can wreak havoc on an otherwise satisfactory setting. All of these collectively form the luminous environment or setting. Luminance is discussed in detail in 4 | PERCEPTIONS AND PERFORMANCE.

12.5.2.1 Task Luminance

Wherever some gain is to be achieved by seeing and comprehending the task, luminance is necessary. Task refers to the media comprising the visual work or chore, such as laser printouts, paper-based books, electronic books, computer screens, or spaghetti dough coming through the spaghetti maker. For many non-self-illuminated tasks, reflectance properties are known and, subsequently, the necessary illuminances can be specified to achieve acceptable task luminance. For many self-illuminated tasks, the task luminance and reflectance characteristics are known and the necessary illuminances can be specified to maintain acceptable task luminance. These illuminance targets are cited in respective application chapters and are intended for use in conjunction with the other criteria specifically detailed within respective application chapters or generally outlined here in Chapter 12.

12.5.2.2 Background Luminance

To maintain some degree of attention to tasks and to limit distraction and visual fatigue, particularly in work settings, luminance of backgrounds immediate to tasks is important. Luminance ratios, illuminance uniformity ratios, and background surface reflectances aid in maintaining appropriate background luminances.

Wall, ceiling, daylight delivery, and luminaire luminances are referenced as those of distant background surfaces since they are relatively distant from visual task areas. If these luminances are too great or too low relative to the task, then glare or visual fatigue or perceptions of environmental dimness or over-brightness are likely. Distant background surfaces are governed by the ratio of their luminance to that of the task. For opaque surfaces, like walls and ceilings, surface reflectances are important as are rates-of-change or *luminance gradients*. For transparent or translucent surfaces, like skylights and windows, and luminaires and lamps, average luminance is important.

For situations involving computer tasks, wall and ceiling luminance gradients that change very gradually and occur over relatively large areas are least disruptive. So, soft wide-area ceiling washes as shown in Figure 12.17 are less problematic than very bright narrow streaks in offices or other computer-intensive work settings. Gradual gradients are especially important where CSA/ISO Type III negative polarity screens are used. See Table 12.4 for ceiling luminance gradient recommendations for select indirect luminaire spacings.

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Table 12.3 | Sample Visual Task Survey

	Space[a]	Specifics of Interest[b]	Task Notes[c]	Application Notes[d]	Comments[e]	Assessments[f]: Daylight	Electric Light	Importance	Observer's Visual Age	Hours of Occupancy
Interior	Office	Circulation								
		• Floor	Tasks other than walking?	Dark or bright?	Horizontal illuminances					
		• Face	Periodic informal discussions?	Short or long meetings?	Vertical illuminances					
		Work Station								
		• Desk	Paper, computer, other tasks?	Finishes?						
		• Return	Paper, computer, other tasks?	Finishes?						
		• Size	Total area vs. visual-work area?	Visual-work-area relative to left-or-right of computer?						
		• Face	Periodic informal discussions?	Short or long meetings?	Vertical illuminances					
		Filing								
		• Archival	File labels legibility?	Tall files/narrow aisles?	Vertical illuminances					
		• Reference	File labels legibility?	Short files/reference tops?	Horizontal illuminances					
	Reception	Greeting								
		• Security	Facial recognition?	Discreet or overt security?	Vertical illuminances					
		• Sign-in	Ledger? Instructions? Forms?	Casual or formal?						
		• Verbal exchange	Assess demeanors?	Number of visitors?						
		Work Station								
		• Work area	Paper, computer, other tasks?	Finishes?						
		• Return	Paper, computer, other tasks?	Finishes?						
		• Service	Beverages?	Extent of setup?						
		Waiting								
		• Sitting	Lap reading? TV/VDT viewing?	Long/short waits?						
		• Meeting	Discussions? Mat'l exchange?	Standing/sitting?	Vertical illuminances					
		• Impressions	Wait time?	Visitors' status?						
Exterior	Parking	Layout								
		• Striping pattern	Density? Islands? Foliage?	Neighborhood nighttime activity level?						
		• Vehicle types	Heights and sizes?	Hours of operation?						
		Circulation								
		• Entry/exit points	Peak activity times?	Intersecting roadways?	Vertical illuminances					
		• Interface	Pedestrian/vehicular interface?	Repeat/first-time users?						
	Walkway	Layout								
		• Defined paths	Pedestrian density?	Neighborhood nighttime activity level?						
		• Building entries	Primary nighttime entry?	Hours of operation?						

a. Pull together a list of representative spaces or areas. What's shown is exemplary and not all-inclusive. Expand or contract as necessary. Spaces and tasks listed in nor particular order.

b. Identify specific tasks, functions, and facets of interest that may affect lighting needs.

c. Based on observation and inquiries, identify specific visual tasks.

d. Identify attributes of the application environment or tasks.

e. Make any additional comments to clarify the extent of the survey.

f. Assess these and other items that affect the lighting and operation of the lighting system. Where daylight is present, indicate time-of-day and sky conditions when illuminance measurements are made. If possible, extinguish electric lights to assess daylight contribution. Expand or contract the list as ncessary. Expand cell sizes as required to document the assessment in narrative form or in numeric form or both.

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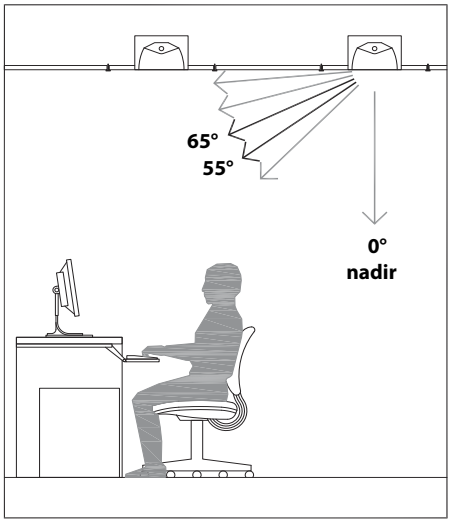


Figure 12.18 | Luminance-limit Angles
Luminance luminance limits are based on the angle of light distribution. Angles considered most critical are those at and above 55° or 65° depending on the criticality of the task.
» From *Architectural Lighting Design, 3rd edition*, reprinted with permission of John Wiley & Sons, Inc.

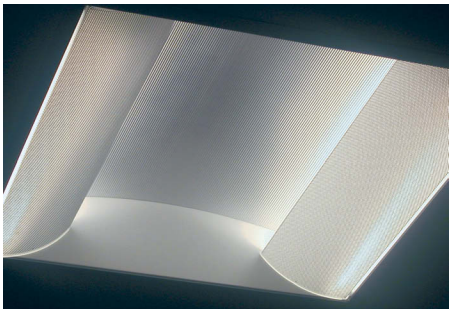


Figure 12.19 | Recessed Direct Architecturally-dimensional Luminaires
Depending on reflector finishes and lamping, versions of this and other recessed direct architecturally-dimensional luminaires might fail luminance assessments. An operational sample, if not a mockup, is appropriate before accepting or rejecting such a luminaire. Also see Figure 32.9.

The upper reflector on this 2′ by 2′ recessed direct architecturally-dimensional luminaire is ribbed metal finished in natural aluminum. This combined with the upper reflector contour can reduce luminaire luminances when compared to those of a white upper reflector. However, the streak of luminance seen at the interface of the perforated lamp basket and the upper reflector might exceed luminance criteria depending on lamping.
» Image ©Gary Steffy Lighting Design Inc.

12.5.2.3 Luminance Limits

In many casual situations, very great luminance magnitudes are tolerated. In work settings, however, luminances are carefully addressed to extract the most benefit from lighting. Where computers are used, luminances of luminaires, room surfaces, and daylight delivery are fundamental to people's comfort and productivity. Luminances which are too great will negatively affect visibility of some computer tasks. This is most important in applications where computers are prevalent and visual performance has economic, productivity, health, safety, or security implications. Generally, the more significant the VDT viewing task or the poorer the VDT screen quality, the more restrictive the luminance or candlepower limits. In the absence of definitive criteria in respective application chapters, Table 12.4 identifies default luminance limits for a variety of luminance sources: luminaires; room surfaces; and daylight media.

For luminaires, the direct component of light is of most concern. Figure 12.18 diagrams luminance limit angles of prime importance for the direct component of luminaires. There are two options available to assess luminaire direct-component luminances: average initial luminance and maximum initial candlepower. The average initial luminance assessment requires assumptions about the area of the luminaire optical media over which its luminance might be too great as well as assumptions about the types and layouts of computer screens. Some luminaires may appear to theoretically meet or beat the average initial luminance criteria, but which are simply too bright for use in some or all VDT applications. Alternatively, the maximum initial candlepower assessment is simpler to implement, only requiring photometric test reports from manufacturers. However, some luminaires (see Figure 12.19) may appear to theoretically fail the maximum initial candlepower criteria, but which are subjectively acceptable in some or all VDT applications. The designer can use one or both options to evaluate a number of luminaires under consideration on a given project. If a luminaire preferred for its appearance, size, lamping, and other criteria fails the luminance assessment, then viewing an operational sample, if not a mockup, of the failed luminaire is appropriate. Similarly, if a luminaire preferred for its appearance, size, lamping, and other criteria passes, then viewing an operational sample, if not a mockup, of the passing luminaire is appropriate.

Luminance limits of potentially bright room surfaces or daylight media are typically reported in units of candelas per square meter (cd/m^2). These luminance limits are considered maximum allowable averages over the entire surface of interest or over specific portions of the surface or luminaire. The luminance of an entire surface is relevant where there is a gradual rate of change in luminance. That is, the luminance exhibits a soft gradient or is quite uniform, such as might exist with a wall washed with north sky light or wallwash luminaires. In these situations, although the surface does not exhibit any harsh gradations or gradients, the overall luminance must remain below certain limits.

Luminance gradients of ceiling surfaces where uplights are used can be assessed by the rate of change in luminance across a given area of the ceiling.

Daylight media are by nature potential glare sources so significant as to be debilitating. If building orientation, daylight media positions, workstation locations and arrangements, or shading cannot be properly designed, glare will be a persistent difficult problem. This can easily derail any sustainability or energy-saving benefits. See 14 | DESIGNING DAYLIGHTING for guidance on daylighting design.

12.5.2.4 Luminance Contrast

Contrast is a physical property linked to inherent task characteristics, (see 4.2.4 Luminance Contrast and 4.2.5 Chromatic Contrast), illuminance, task reflectance, and color qualities of the lighting. If the contrast of the task is good-to-excellent, there is greater potential for users to perform the task in an accurate and timely fashion. If the contrast of the task is poor-to-fair, then there is greater potential for users to make errors or require more time in performing the task. See Figure 12.20 for some simple luminance contrast

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Table 12.4 | Default Luminance and Luminaire Intensity Recommendations for VDT Applications

Luminance Source	VDT Viewing Significance[a]	Application[b]	Average Initial Luminaire Luminance Option[c]				Maximum Initial Luminaire Candlepower Option[d]
			VDT Monitor Screen Reflection Properties				
			Medium-to-good[e] CSA/ISO Types I and II Monitors		Poor[e] CSA/ISO Type III Monitors		Luminaire Candlepower Limits
			Positive Polarity	Negative Polarity	Positive Polarity	Negative Polarity	
Luminaires (direct component)	Secondary	• Industrial	≤2570 cd/m² at 65° and above				NA
		• Conference Room • Transitional Space	≤1715 cd/m² at 65° and above				300 cd @65°, 185 cd @75°, 60 cd @85°
	Normal	• Classroom • High-tech Industrial • Office	≤1500 cd/m² at 65° and above	≤1000 cd/m² at 65° and above	≤500 cd/m² at 65° and above	≤200 cd/m² at 65° and above	300 cd @65°, 185 cd @75°, 60 cd @85°
	High	• Call Centers • Programming[f]	≤1500 cd/m² at 55° and above	≤1000 cd/m² at 55° and above	≤500 cd/m² at 55° and above	≤200 cd/m² at 55° and above	300 cd @55°, 220 cd @65°, 135 cd @75°, 45 cd @85°
	Critical	• Air Traffic Control • CAD • Programming[g] • Command Centers • Medical Lab • Monitoring	≤200 cd/m² at 55° and above				300 cd @55°, 220 cd @65°, 135 cd @75°, 45 cd @85°

Luminance Source	VDT Viewing Significance[a]	Application[b]	Average Initial Luminance	Maximum Ceiling Luminance Gradient from Uplights[h]							
				CSA/ISO Types I and II Monitors				CSA/ISO Type III Monitors			
				Positive Polarity		Negative Polarity		Positive Polarity		Negative Polarity	
				Typical Spacing of Uplights							
				8 ft	12 ft	8 ft	12 ft	8 ft	12 ft	8 ft	12 ft
				values below are rates of change in units of cd/m² *per meter of ceiling surface* —this constitutes the recommended maximum change in luminance over a meter of ceiling based on the luminance ratios cited in Table 12.5 to minimize veiling reflections							
Room Surfaces	Secondary		≤1715 cd/m²	1965	1275	1965	1275	1680	1100	1680	1100
	Normal		≤855 cd/m²	980	640	980	640	840	550	840	550
	High			980	640	840	550	840	550	840	550
	Critical		≤615 cd/m²	705	460	600	400	600	400	600	400
Daylight Media	Secondary	• Conference Room • Transitional Space	≤3425 cd/m²								
		• Industrial	≤2570 cd/m²								
	Normal		≤855 cd/m²								
	High										
	Critical		≤615 cd/m²								

a. The significance of viewing the VDT monitor screen with respect to the overall work.

b. Some applications share similar visual tasks of similar significance and therefore have similar luminance limits.

c. Values are based on several references [16] [17] [18] [19] [20] [21]. Conversions rounded to nearest five. Because of the nature of practical photometry and luminance calculations, the reference here to "average" is to the average luminance value reported in or calculated from available photometric data for the projected area of interest. Mockup anticipated VDT monitors with proposed luminaires to confirm interaction of latest computer, lamp, and luminaire technologies. See 10.2.5 Approximations. Figure 12.18 details luminance-limit angles.

d. Intensity maximums are based on guidelines introduced by the IES Office Lighting Committee in 2004 and since adopted by consensus [22]. Mockup anticipated VDT monitors with proposed luminaires to confirm interaction of latest computer, lamp, and luminaire technologies. Figure 12.18 details luminance-limit angles.

e. See Figure 12.16.

f. Computer programming of typical commercial software.

g. Computer programming of critical commercial or military software.

h. Luminance gradient on ceiling when using uplighting. Offered for typical luminaire spacings. Use reference formula for other spacings [23].

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Good-to-excellent inherent contrast is evident when white text like this is used on black paper like this (here the paper has a reflectance of 0%).

Good-to-excellent inherent contrast is evident when black ink like this is used on white paper like this (here the paper has a reflectance of 86%).

Poor-to-fair inherent contrast is evident when black ink like this is used on white paper like this (here the paper has a reflectance of 35%).

Poor to fair inherent contrast is evident when black ink like this is used on white paper like this (here the paper has a reflectance of 86%, but the ink is gray).

Figure 12.20 | Luminance Contrast
Inherent task qualities greatly influence how much light is necessary for task visibility. The top and second-from top text boxes exhibit excellent inherent contrast. The third and fourth text boxes from the top have progressively poor task contrast and require greater length of time for accurate reading or will require more light than the top two text boxes.

Task area is at once ambiguous and quite specific. This refers to the area or zone in which the task in question will be or is anticipated to be performed. In a corridor, the task area is typically considered the horizontal floor plane, although in many situations for security and/or social benefit, facial recognition is a task function, demanding light on the vertical plane at 5 feet *AFF* and perpendicular to the two main directions of travel. The task area cannot be specified any more finitely. In a private office, the task area is an area on the desk or perhaps consists of the entire desk. The task area is quite specific and must be planned during design. See Figure 12.22.

AFF is an acronym for above finished floor in interior situations. Complemented by *AFG* in exterior situations.

AFG is an acronym for above finished grade in exterior situations.

examples. Contrast is manifested by luminance or color. IES illuminance recommendations are based on assumptions about the intended task characteristics which are usually implied in the task name or description. For example, an analog-generated copy typically exhibits poorer contrast and image integrity than a digitally-generated counterpart. So, the IES recommended illuminance target is greater for analog copies than for digital copies. That is, digital copies may result in use of less lighting energy. Figures 12.21a, 12.21b, and 12.21c illustrate several examples of luminance contrast and luminance ratios. These figures also illustrate the affects of background surface finish selection.

12.5.2.5 Luminance Ratios

Luminance ratios for comfort are the luminance differences between objects, such as a paper task and the surface on which the paper sits. Luminance ratios are primarily responsible for visual comfort. As discussed above, luminance ratio is a convenient metric when establishing surface reflectances, transmittances, and illuminances of near- and distant-backgrounds. In areas of higher-concentration effort or where safety is critical, ratios from tasks to immediate-background surfaces are usually low (3-to-1 or less). Where little work occurs or in casual or slow-paced transient situations, people tolerate much greater ratios (40-to-1 or more).

Luminance ratios are expressions of average luminance of one zone or area to another. In the context of common visual tasks and work situations, the ratio of the luminance of the task to its background is limited if work is to be performed accurately, timely, and comfortably. These luminance ratios vary somewhat from application to application and are cited in respective application chapters. In the absence of specific application criteria and where reading and writing analog or electronic tasks are extensive, luminance ratios identified in Table 12.5 are appropriate.

Luminance ratios between tasks and daylighting are most likely to be problematic when not addressed. Here, daylight control is a critical component and can be achieved effectively for some tasks and activities with landscaping and view geometry (see Figure 15.3) or automated shade control to adjust to the varying sky luminance conditions.

Luminance is a function of illuminance and surface reflectance. For matte surfaces, illuminances and reflectances are reasonable methods to employ in order to maintain appropriate luminance ratios. Ratios are unitless. These ratios can be used to establish appropriate surface finishes or help determine an appropriate balance between task and ambient lighting.

From Table 12.5, a maximum luminance ratio of 3-to-1 is recommended for task-to-immediate-background-surfaces. That is, the reflectance of an office desk should be no less than one-third the reflectance value of the paper. Since most white paper typically exhibits 80% reflectance, the desk reflectance should be at least one-third of 80% or 27%. However, this assumes that the entire desk surface or *task area* will be lighted to the illuminance target value recommended by IES for the task or tasks of interest. See 12.5.5.5 Illuminance Ratios, 15.1.1.1 Ambient Lighting, and 15.1.1.2 Task Lighting.

12.5.2.6 Luminance Patterns and Gradients

Luminance patterns that are odd in shape or too bright, or exhibiting gradients that are too severe can be annoying, unacceptable, or even hazardous. A harsh luminance pattern is tolerated in transition areas when safety is not an issue. Luminance patterns should not interfere with users' spatial perception in a stair, on a train platform, or on an escalator, for example. Edge definitions should not be distorted or seen as alternating extremely bright and dark along their lengths. In work settings, a harsh luminance distribution can hinder visibility of computer screens. Since average luminance alone does not accurately represent the acceptability of a particular luminance pattern in these situations, gradients are used to distinguish the degree of harshness or smoothness of luminance distribution over an area. See Table 12.4 and Figure 12.17.

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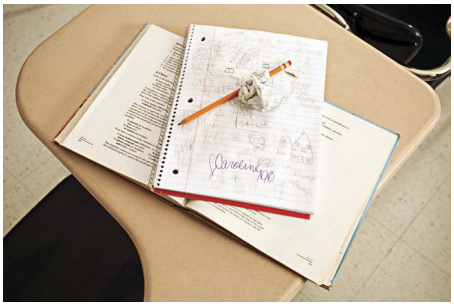


Figure 12.21a | Luminance Contrast and Luminance Ratio

1. Luminance contrast is the luminance difference between the ink or pencil grayscales themselves and the paper. Darker ink and/or lighter paper yields better luminance contrast. Adding more light than IES recommended illuminance target also yields better contrast, but is inefficient compared to using darker ink and/or lighter paper.
2. The task-to-background luminance ratio is the luminance difference between the task proper and the background work surface. Medium-to-light toned matte work surfaces (shown here) provide a soft, comfortable backdrop for extended periods of paper work and limit visual fatigue.

» Image ©Ocean/Corbis



Figure 12.21b | Luminance Contrast and Luminance Ratio

1. Business forms with colored backgrounds or on colored paper typically exhibit lower inherent contrast than white-paper counterparts. Darker backgrounds or colored ink are generally worse.
2. Dark work surfaces, while dramatic first-impressors, result in strong luminance ratios between paper tasks and the work surface background. Visual fatigue is likely with long periods of paper work. Since the work surface is partially responsible for the user's state of adaptation, impressions of "dimness" are common because of the dark background, even though illuminance meets IES recommended target value. Increasing illuminance is self-defeating and inefficient.

» Image ©Image Source/Corbis



Figure 12.21c | Luminance

Glossy work surfaces reflect luminaire and ceiling and wall luminances back to the user and may create veiling reflection (see 4.2.6 Veiling Reflections) and reflected glare conditions (see 4.10 Glare) that are distracting or annoying.

» Image ©Image Source/Corbis

12.5.3 Chromatic Contrast

Chromatic contrast is, essentially, the difference in color from one area of a task to another. Tasks with good to excellent inherent chromatic contrast qualities typically demand less light or result in greater speed and accuracy performance by users of the visual component of the task. Figures 12.23a, 12.23b, and 12.23c illustrate several examples of chromatic contrast and luminance ratios.

12.5.4 Veiling Reflections

Veiling reflections are functions of luminances of surfaces or objects surrounding a task, the reflectance character of the task, and the angle of view of the task. As Figure 12.24 illustrates, veiling reflections can impair task viewing. In these situations, the light reflected from the glossy task surface washes out the task contrast and veils the task. Understanding the clients' tasks is the first order of preparation to developing lighting techniques that will best render those tasks. Although daylight, in its unfettered state outdoors (top image in Figure 12.24) is frequently implicated in veiling reflections, daylight through windows, some shade treatments, and skylights as well as some electric lighting can also be problematic. With specular tasks, geometry of the task position relative to the light source can be a significant culprit. Multiple light sources of lower intensity and better diffusion are less likely to be a problem. Figure 12.18 illustrates the geometry issues associated with lighting and typical computer screen setups. Light coming from an area above and behind the observer, an area commonly called the offending zone, will readily create significant

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Table 12.5 | Default Luminance Ratio Recommendations

Intent	Areas of Interest	Maximum Luminance Ratio[a]
Maintain task attention	• **Paper task to VDT screen**	
	• paper to negative-polarity VDT screen	3:1
	• paper to positive-polarity VDT screen	1:3
	• **Task to immediate background surfaces**	3:1
	• **Task to distant background**	
	• task to dimmer distant background	10:1
	• task to brighter distant background	1:10
Maintain visual comfort	• **Task to light source**	
	• task to daylight media	1:40
	• task to luminaires	1:40
	• **Light-source-adjacent-surfaces to light source**	
	• daylight-media-adjacent-surfaces to daylight media	1:20
	• luminaire-adjacent-surfaces to luminaires	1:20
Minimize veiling reflections	• **All CSA/ISO III monitors** • **CSA/ISO I and II negative polarity monitors in critical/high situations** • brighter ceiling and/or wall zone to dimmer ceiling and/or wall zone	4:1
	• **All CSA/ISO I and II positive polarity monitors** • **CSA/ISO I and II negative polarity monitors in normal/secondary situations** • brighter ceiling and/or wall zone to dimmer ceiling and/or wall zone	8:1

a. The ratio of the average luminance of the task, area, or zone in question to the average luminance of the other task, area, or zone in question. Values are based on several references [24] [25] [26].

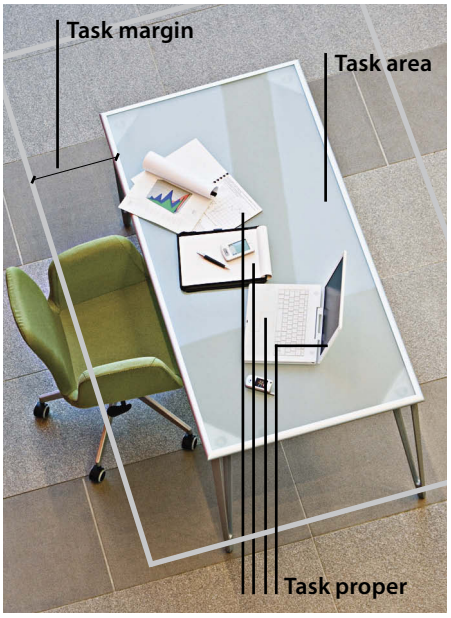


Figure 12.22 | Task Coverage Example
The distinction of task proper and task area establishes the area over which the IES recommended illuminance target criteria apply. See Table 12.6 for default illuminance ratios.
» Image ©Image Source/Corbis

veiling reflections if computer screens are CSA/ISO Type III negative polarity. Viewing conditions might only improve if the computer screen is reoriented, positive polarity screen settings are employed, or the offending light is moved.

12.5.5 Illuminance

Light levels have been variously revered as the holy grail in lighting or vilified for vapid lighting. Being easy to calculate and measure and, for those reasons, convenient to codify, illuminance has become nearly the one and only criterion used in normal power architectural "lighting design" on many projects.

Strict interpretations of the science and physiology of sight and technical requirements for illumination conclude that six or seven single-value light level targets can satisfy all users of all tasks all the time. However, this has proved too simplistic to address *user intent*, socioeconomic issues, and the multitude of tasks and applications, presented on nearly every project.

Illuminance is a very robust criterion when all of its components are fully reviewed and addressed. Horizontal and vertical illuminances and their respective uniformity ratios contribute to visual performance *and* visual comfort and concentration. Illuminance as presented in this handbook is better tuned for specific project situations and when coupled with other criteria outlined in the design chapters can lead to:

- Less-consumptive settings
- More user-centric settings

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Figure 12.23a | Chromatic Contrast and Luminance Ratio

1. Chromatic contrast is the color difference between the various colored graphics themselves and the paper. Color properties, such as hue, value, and chroma (see 6.4.1 Munsell Color System) and/or paper lightness or darkness can be tuned for optimal contrast) which is more efficient than increasing illuminance above IES recommended illuminance target value.
2. The task-to-background luminance ratio is the result of a luminance difference between the task proper and the background work surface. Typically, medium-to-light toned matte work surfaces (shown here) are best.

» Image ©Ryan Smith/Somos Images/Corbis



Figure 12.23b | Chromatic Contrast

Chromatic and luminance contrast are used for visual attraction and identification respectively. The illustrated task is commonly performed by elderly users. IES recommended illuminance targets are to be determined based on users' visual ages. Additional light will waste energy and/or result in greater potential of direct and/or reflected glare. Daylight and lamps with 80+ CRI are appropriate for these situations.

» Image ©Kristopher Grunert/Corbis



Figure 12.23c | Chromatic Contrast

Color helps in identification of various samples and assess test results. Chromatic contrast assists in determining the state of culture development. IES recommended illuminance targets for respective tasks account for such color discrimination, however, lamp color rendering and color temperature properties are critical here. Background surfaces should be neutral.

» Image ©Michael Rosenfeld/Science Faction/Corbis

4.12 Illuminance Determination outlines this more tailored procedure for establishing illuminance criteria—where the designer and client determine a need for light. Respective application chapters identify many tasks typical of those applications and offer recommended illuminance targets for various planes-of-interest, respective gauges of application such as average, minimum, and maximum, and uniformity ratios.

12.5.5.1 Applications and Tasks

Applications refer to the areas within which tasks occur. Tasks refer to items that convey visual information. It is not necessarily appropriate to assign the illuminance recommended for a specific task or application to cover an area larger than the expected task proper or task area (see Figure 12.22). The designer must determine how illuminance criteria are applied on each project. The following aspects should influence how illuminance criteria are applied:

- Sizes and orientations of tasks proper
- Sizes of task areas
- Density of task areas
- Flexibility of task areas
- Frequency of task area rearrangements
- Number of similar tasks involved
- Number of different tasks involved
- Number and ages of users involved

A reading task might have an IES-recommended illuminance target of 500 lx for users between 25 and 65 years of age. This is not to say that the entire room should be illuminated

User intent is a reference to what the user intends to do with a task which may have influence on illuminance criteria. For example, in a work situation where speed and accuracy are important, 300 lux is needed to read any text of the quality shown in the second-from-top passage in Figure 12.20. Yet, in a casual situation where speed or accuracy or both are not as important, 200 lux is sufficient. So, for example, criteria for reading in bed or in a chair in a lounge will be different than that for reading at a desk or library carrel.

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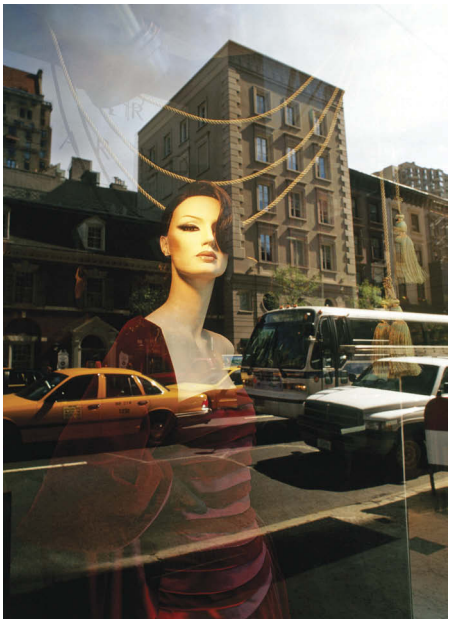




Figure 12.24 | Veiling Reflections
Display windows (top image) exhibit veiling reflections day and night. However, during the day these can be so significant that window shoppers cannot see merchandise or even determine if the store is open for business. Tilting the window out and down at the top, introducing awnings, and/or using low-iron/anti-reflective glass can mitigate some or much of the veiling reflection, depending on the extent of the solution.

Computer screens, TVs and other self-luminous displays are susceptible to veiling reflections (bottom image). Lighting conditions, angle of view, CSA/ISO screen qualities, and display resolution setting all affect the degree to which veiling reflections are problematic, if at all. Luminances of windows and skylights, luminaires, room surfaces, and/or viewer clothing can reflect strongly, subtly, or not at all from computer screens. Screens here are CSA/ISO Type III positive-contrast and are no match for daylight luminances.

» Top image ©Corbis

» Bottom image ©Frederic Cirou/PhotoAlto/Corbis

uniformly to 500 lx. Indeed, the 500 lx is intended for application to the task or to the reading area. If the reading area is a desktop, then the desk location and size is important to know. Illuminance is additive and several systems can be used to achieve the recommended target illuminance on the task. If the room in which the task is performed is densely furnished and relatively small in size, it might be determined that providing the 500 lx throughout the room is best. Then again, if the room is sparsely furnished and relatively large in size, 500 lx on a paper task may be achieved with at least two systems of lighting: an ambient system and a task system. Perhaps even a third system, accent lighting, may contribute a small amount of illuminance. Not all tasks are reading tasks. Figures 12.25 and 12.26 identify a variety of applications for which some or many key visual tasks do not involve reading.

While it may expedite the design process and accommodate various tasks at various locations, illuminating whole areas or rooms to address the task with the highest single-value of illuminance can work against efficient and sustainable practices. Delaying the interiors planning of desk or chair locations is no longer a luxury allowed by expending more watts. These items need to be planned in conjunction with architecture and engineering of building systems. Using task-ambient-accent systems results in more visually rich and varied environments. Typically illuminance targets for circulation areas are intended for the entire space.

12.5.5.2 Age-related Illuminance Determination

By the time the visual system reaches an age of 65 years, it may require four times the amount of light it required at 20 years of age. In this handbook, IES recommendations address this wide disparity by assigning three target values to each task or application based on observers' visual ages:

1. One target value for situations where the visual age of at least half the observers or users is <25 years.
2. A second target value where the visual age of at least half the observers is between 25 and 65 years.
3. A third target value where the visual age of at least half the observers is >65 years.

The distinction "visual age" supports settings where observers may be chronologically under 65 years of age, but their visual systems exhibit characteristics akin to those of individuals with a chronological age greater than 65 years. The designer must determine visual ages based on surveys of existing conditions and interviews with users. Regardless, recommendations in the handbook address the vision needs of normal-sighted individuals. See the IES document ANSI/IES RP-28 Lighting and the Visual Environment for Senior Living for recommendations related to the vision needs of partial-sighted seniors.

The distinction "half the observers" supports the need for significant illuminance deviations based on the users' visual ages and task and performance expectations of the group. The designer may determine that the age distinction applies to a unique user even where the tasks or application involve many users. Perhaps illuminance targets are based on that unique user's age because, for example, that user is of notable importance or performs tasks of great consequence. In some situations, such a distinction can be accommodated with appropriate task lighting. In other situations, such a distinction may be accommodated with appropriate ambient lighting. The lighting techniques and the solution will address the illuminance criteria. However, if greater luminance and contrast can be achieved with better surface reflectances and contrast techniques, these more sustainable practices should be pursued before increasing illuminance. For example, in a stair situation where more than half the anticipated users are over 65 years of age and finishes are monochromatic and low reflectance, increasing stair illuminance alone from a nominal 100 lx to 200 lx will not markedly increase visibility. If the stairs are finished with dark wood walls and dark granite floors, even 300 lx will not appreciably improve the luminances, contrast, and visibility in the stairway—the stairs will feel dark and will be dark. Using light-colored wall and floor finishes and adding edging of a contrasting color against the stair treads will greatly improve the luminances and contrast without increasing the connected lighting power.

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Another important design consideration is the context of the space. If users are entering a vestibule directly from daylit exteriors or bright atriums, then greater interior luminances are necessary during daylight hours. Older eyes take longer to adapt from one brightness to another. So, the vestibule where more than half the users are expected to be over 65 years old should be lighted to the "daytime" illuminance value for over 65-year-old observers and should be designed with high reflectance matte surfaces. Vestibules exhibiting greater distances to traverse between the entry/exit door to the next interior space assist in the adaptation process and should be considered by the architects and interior designers. Of course, during dark hours this same vestibule should be dimmed to avoid a reverse adaptation effect as people exit to the darker exterior. Day and night illuminance criteria citations are made where respective applications deserve such distinctions. The stair and vestibule situations are but a few examples. The designer is obligated to work through these scenarios in context with the adjoining spaces, intended uses, and the effects on the users' age group.

IES illuminance targets in this handbook are based on more than a century of research and application experience with sight and light and are indicative of appropriately safe, comfortable, and productive conditions during normal-power operation when properly designed. As has been practice in the past, particularly where multiple age groups are involved, the designer must assess the tasks and observers' visual ages, make preliminary judgment on illuminance targets and then review these with clients to establish direction.

Regardless of the IES illuminance recommendation, all code requirements with respect to illuminance and other lighting aspects must be met. Code authorities have final determination on illuminances. See 12.7 Prescribed Factors. Also see 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

12.5.5.3 Updated, New, or Undocumented Tasks

Many updated and new tasks and applications are cited with illuminance recommendations in this handbook. Tasks not cited or newer visual tasks require the designer to make field assessments of the task or tasks for horizontal and vertical illuminances, averages, minimums, and maxima to establish appropriate targets. If no field assessments are possible, then closely-associated tasks or applications might be considered as matches. If this fails to establish a target value with which the designer and client are comfortable, then a review of Table 4.1 | Recommended Target Illuminances is in order. An assessment of the new or unlisted visual task against the application and task characteristics and visual performance citations must be made to determine an illuminance target.

12.5.5.4 Vertical and Horizontal Illuminances

Illuminances are task-plane and orientation specific. Target values are typically cited for vertical and horizontal planes. Most tasks are primarily oriented in just one plane—known as the primary plane. Reading a paper book on a table places the primary plane on the horizontal surface. The target value for the secondary plane remains of interest for purposes of task viewing flexibility, assistance in maintaining some degree of background luminance, and performing associated secondary tasks such as facial recognition during conversations at the desk. Most lighting design software readily calculates horizontal and vertical illuminances.

12.5.5.5 Illuminance Ratios

IES recommended illuminance targets are intended to address the task proper or the task area. Illuminance ratios are used to limit illuminance variances to maintain visibility and visual comfort in the vicinity of the task. Applying illuminance ratios to task areas offers some degree of local flexibility for the user to multi-task and adjust tasks. An illuminance ratio of 1.5-to-1 (1.5:1) average-to-minimum (avg:min) across the task area is appropriate for typical work situations. If no specific planning information is available, the task area is considered to extend 1' 6" in front of the observer's position and 0' 9" to either side for a total task area footprint of 1' 6" by 1' 6". [27] To further limit distraction and discomfort, a margin or perimeter of 1' 6" around the task area should exhibit an illuminance that is two-thirds that of the task illuminance. Figure 12.22 identifies task proper, task area, and

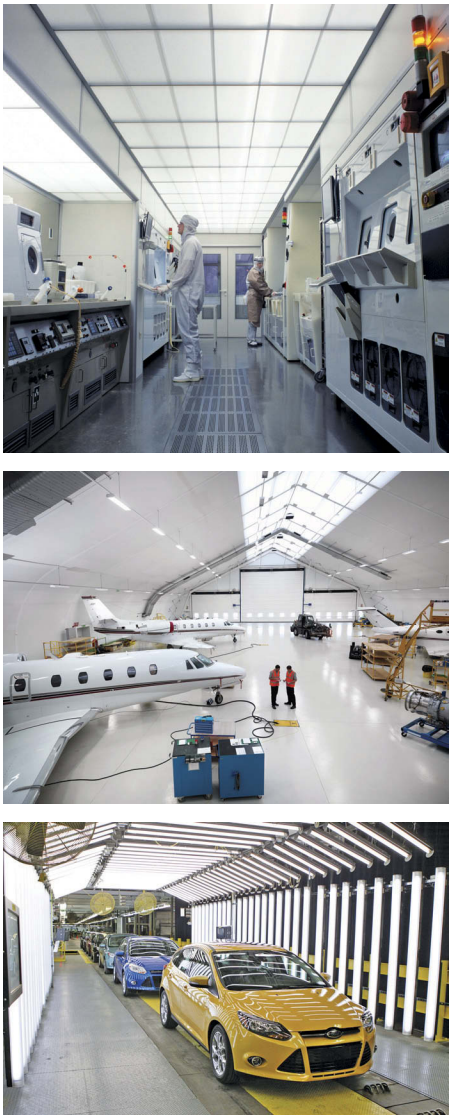


Figure 12.25 | Visual Tasks
Many of the visual components of applications involve tasks other than reading. The top image illustrates a cleanroom application found in biotechnology facilities and semiconductor production or research facilities Many cleanroom tasks are of a critical nature and involve task benches with overhead localized task lighting for close inspection.

An aircraft hangar in the middle image might be used for cleaning and maintenance of craft. High reflectance surfaces, diffuse daylight and electric light facilitate inspections and maintenance work.

In vehicle production, quality control involves a number of visual inspection tasks for: fit; finish, color, dents, scratches, and damage. Illuminances, uniformities, and lamp selection and luminaire luminances are used to facilitate the visual tasks.

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» Image ©Monty Rakusen/cultura/Corbis
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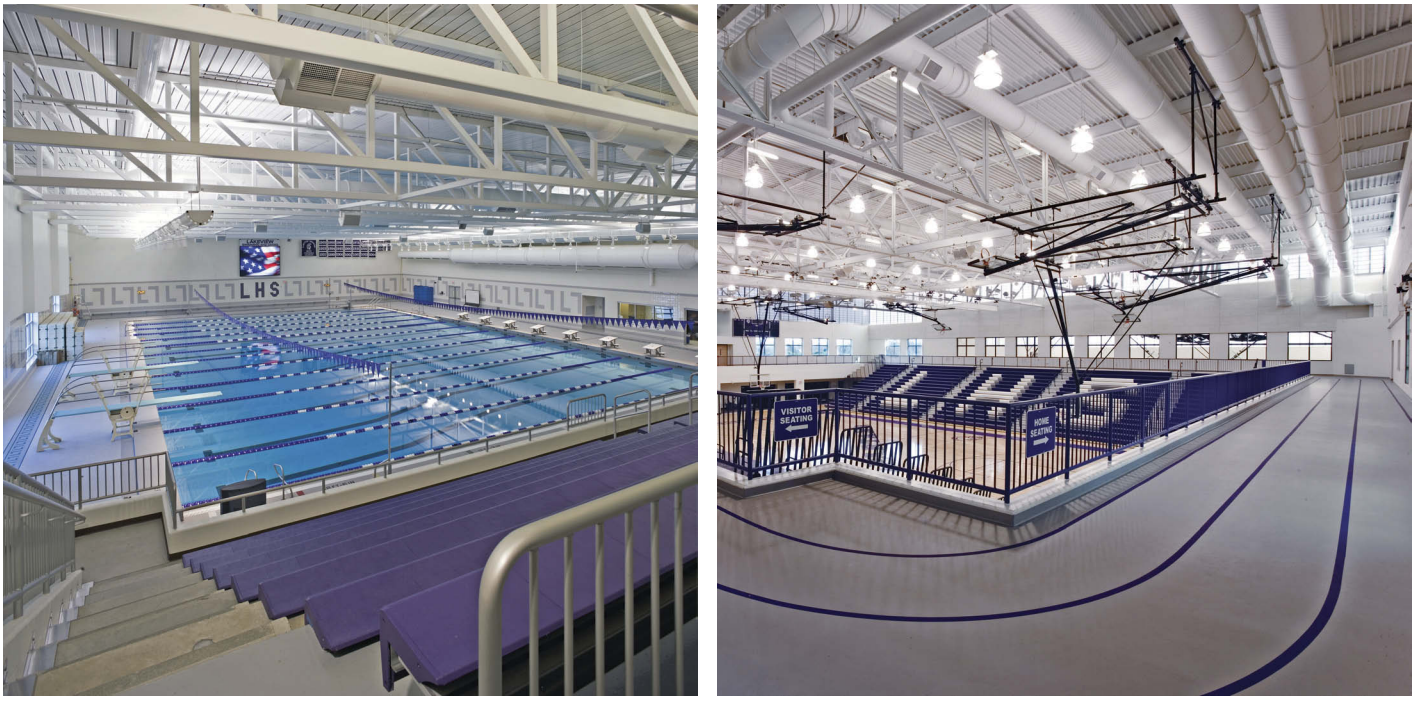


Figure 12.26 | Visual Tasks
In the image on the left, metal halide uplights meet the illuminance criteria for the pool and deck addressing target criteria of 500 lx maintained horizontal average illuminance (E_h) and 200 lx maintained vertical average illuminance (E_v) across the pool and deck. E_v at 5′ AFF. Accenting is used to feature the starts and turns, addressing a target criterion of 1000 lx maintained horizontal average illuminance at the pool-deck interface. Electric lighting and any daylighting are arranged to minimize veiling reflections from the water surface to the bleachers.

Visual tasks associated with indoor sports are accommodated by a "task-oriented" system of direct/indirect metal halide pendant refractor luminaires located over the hardwood floor in the image on the left. An "ambient" system of indirect metal halide luminaires located in the joists introduce background luminance to limit luminaire glare. These lighting systems were designed to address target criteria of 1000 lx maintained horizontal average illuminance on the hardwood court. The indirect luminaires when used alone also provide relatively low-level illuminance for non-sports situations. Luminaires are held well inboard of the perimeter clerestory, taking advantage of daylight and the lower-illuminance criteria needs for track and general circulation.

» Images ©Bill Lindhout Photography

task margin in a task coverage example. An illuminance ratio of 5-to-1 maximum to minimum at task plane height over an entire room or large area is appropriate for typical work environments. [28] Many of the IES illuminance recommendations cited in respective application chapters include illuminance ratios. In situations where performance of reading and writing analog or electronic tasks is sustained over time or where concentration is required, illuminance ratios summarized in Table 12.6 are appropriate.

12.5.5.6 Nighttime Outdoor Illuminances

In addition to task characteristics, task importance, and observer characteristics (see 4.12 An Illuminance Determination System), nighttime outdoor illuminance criteria should be based on the expected level of nighttime outdoor activity and on the outdoor ambient lighting conditions of the locale. Activity levels are likely to change over the course of an evening or from night to night. Lighting in these situations should respond to the varying activity levels in order to minimize the effects of light on the outdoor night-environment, minimize effects on indoor sleeping quarters, and reduce energy use.

One additional modifier to illuminances accounts for users' adaptation states. When users are mesopically adapted, the luminous efficacy of a light source is strongly affected by where in the mesopic range the user is adapted. As noted in 4.12.3 Spectral Effects, adaptation for foveal tasks is driven by the luminances in the central 10° of the visual field and is in a mesopic state when those luminances are in a range between approximately 10 cd/

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Table 12.6 | Default Illuminance Ratio Recommendations

Intent	Areas of Interest	Maximum Illuminance Ratio
Maintain visibility	• **Task proper**	
	average-to-minimum across task proper	1.5:1
	• **Task area**	
	average-to-minimum across task area	1.5:1
Maintain concentration	• **Task margin**	
	average-to-minimum across task margin	2:1
	• **Task proper to task margin**	
	average-to-average between task proper and task margin	1.5:1
	• **Throughout entire work space comprising the task areas**	
	maximum at task proper or area to minimum throughout work space	5:1

m^2 down to 0.001 cd/m^2. See Table 2.1 | Vision Adaptation States. These are luminances that are experienced, for example, when viewing low reflectance pavement illuminated in a range between approximately 5 lx down to 0.0005 lx. For comparison, nautical twilight might produce 1 lx, a full moon might produce 0.5 lx, and a full clear sky at astronomical twilight might produce 0.001 lx.

Generally, the lower the adaptation state, the more efficacious is short wavelength light and the less efficacious is long wavelength light. The scotopic/photopic (S/P) ratio is an indicator of the relative amount of short wavelength light produced by a source. Some typical S/P ratios are shown in Table 6.8 | Colorimetric Properties for Some Lamps. Many lamp specification sheets report the S/P ratio. If the observer adaptation state and the S/P ratio of the source are known, then the efficacy of the lamp at that adaptation state can be determined relative to its efficacy for the usual assumption of photopic adaptation on which IES illuminance recommendations are based. Figure 4.27 identifies multipliers that express this changing efficacy; both with respect to S/P ratio and the adaptation state expressed as luminance.

An example for determining illuminance criteria might take this form. A small college campus in a rural setting is in the process of refurbishing and expanding the campus. A project includes designing lighting on the central walking paths that connect several classroom buildings with central administration, a community theater, an auditorium, a library, a dining hall, a residence hall, and a parking lot. With input from the design team, college administrators decide to illuminate only one key path that connects all of these facilities. The path is adjacent to one edge of the parking lot, but is distant from any streets and roads. A process for determining illuminance on this particular project is outlined in Table 12.7.

Using the method outlined in 4.12.3 and Figure 4.27, mesopic multipliers adjust the illuminance criteria to account for the anticipated photopic background luminance and the spectra of the lamps under consideration. In the example in Table 12.7, in the design phase, this means illuminance criteria would need to be increased if HPS lamps with S/P of 0.60 are under consideration for the specific design situation discussed here or decreased if CMH lamps with S/P of 1.38 or 1.81 are under consideration. This can affect lamp wattages, luminaire selections, and luminaire layouts and may greatly affect connected loads or control schemes for night operation. If LED lamps are under consideration, then their S/P data and photometry are required.

Very low illuminances in this example result in mesopic adaptation states and the designer should note the effect of lamp selection on illuminance criteria. Ultimately the lighting designer reviews all of this with the campus planner, the landscape architect, the building

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Table 12.7 | Pedestrian Way Mesopic Multiplier Example Worksheet

Step	Process	For This Example
1	**Establish Recommended Photopic Illuminance Criteria** Illuminance affects photopic luminance. Identify horizontal (E_h) and vertical (E_v) photopic illuminance criteria.	Establish illuminance criteria for a rural small-college campus pedestrian way distant from roads or streets.
1a	**Determine Nighttime Outdoor Lighting Zone** Generally, lower-ranked outdoor lighting zones are inherently darker than higher-ranked counterparts. Illuminance criteria can and should be lower in lower-ranked outdoor lighting zones.	• LZ1 lighting zone
1b	**Determine Nighttime Outdoor Activity Level** Generally, lower activity-level, less crowded situations need less light than higher-activity, more crowded counterparts. Illuminance criteria should be lower in lower-activity outdoorsettings.	• Low activity level
1c	**Determine Observers' Visual Ages** Younger observers typically require less light than older observers.	• Visual ages <25 years of age
1d	**Finalize Recommended Photopic Illuminance Criteria** Based on results from 2a, 2b, and 2c, identify photopic horizontal (Eh) and vertical (Ev) illuminance criteria for rural small-college campus pedestrian way distant from roads or streets.	• $E_{hphotopic}$ = 2 lx average, maintained • $E_{vphotopic}$ = 1 lx average, maintained
2	**Estimate Surface Reflectances** Reflectances also affect photopic luminance. Propose preliminary reflectances.	
	• Path and ground-cover reflectance (ρ_{ground})	10 percent (0.10)
	• Surrounding vertical elements ($\rho_{surround}$)	5 percent (0.05)
	• Surrounding overhead elements ($\rho_{surround}$)	0 percent (0)
3	**Determine Photopic Luminance** For the average $L_{photopic}$ in observer's field of view, sum and average relevant luminances.	
	a. $L_{photopic}$ of ground = $(E_h \times \rho_{ground}) \div \pi$	0.064 cd/m^2
	b. $L_{photopic}$ of sky = $(E_v \times \rho_{sky}) \div \pi$	0 cd/m^2
	c. $L_{photopic}$ of vertical surroundings = $(E_v \times \rho_{surround}) \div \pi$	0.016 cd/m^2
	d. $L_{photopic}$ of environment = Average contribution of $L_{photopic}$ identified in a, b, and c above. $L_{photopic}$ of environment = ((2x$L_{photopic}$ of ground)+(2x$L_{photopic}$ of sky) +(1x$L_{photopic}$ of vertical surroundings))÷5	0.029 cd/m^2
4	**State of Adaptation** Confirm luminance of environment puts observer in mesopic state of adaptation (≤3 cd/m2).	Yes, adaptation state is mesopic.
5	**Mesopic Multipliers** Determine multipliers to adjust recommended photopic illuminance target values for mesopic adaptation.	
	• 2000 K HPS illuminance criteria multiplier	1.3
	• 3000 K CMH illuminance criteria multiplier	0.84 (55% better than the 2000 K HPS)
	• 4000 K CMH illuminance criteria multiplier	0.71 (83% better than the 2000 K HPS)
6	**Recommended Mesopic Illuminance Criteria** Adjusted recommended illuminance target based on lamp selection.	
	2000 K HPS (multiply photopic illuminance targets by 1.30)	• $E_{hmesopic}$ = 2.6 lx average, maintained • $E_{vmesopic}$ = 1.3 lx average, maintained
	3000 K CMH (multiply photopic illuminance targets by 0.84)	• $E_{hmesopic}$ = 1.7 lx average, maintained • $E_{vmesopic}$ = 0.8 lx average, maintained
	4000 K CMH (multiply photopic illuminance targets by 0.71)	• $E_{hmesopic}$ = 1.4 lx average, maintained • $E_{vmesopic}$ = 0.7 lx average, maintained

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Reference and Rationale

This is a "what-if" exterior lighting scenario to determine if observers will be in a mesopic state of adaptation and, if so, the extent of light source spectral effects on illuminance criteria. Mesopic adaptation is typical in situations where illuminance is likely to be 10 lx or less, average, maintained. The outdoor lighting zone, outdoor activity level, and observers' ages should affect the illuminance criteria that the lighting designer proposes. Illuminance criteria for pedestrian ways are based on 26.2.9 Pedestrian Ways and Bike Ways, Table 26.2 | Exterior Illuminance Recommendations/PEDESTRIAN WAYS AND BIKE WAYS, and Table 4.1. See Table 26.6 | Parking Deck Mesopic Multiplier Example Worksheet for low-light interior/exterior situation.

The Lighting Zone or LZ for the rural small-college setting is proposed to be 1 by the individual responsible for the lighting design. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions.

The activity volume is proposed as low by the lighting designer. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

On this college campus, more than half the observers' visual ages are under 25 years of age. See Section 4.12.1.2 Observer Characteristics.

Designer's recommendation to team and client based on Table 4.1 Category C, average maintained illuminance, visual ages of at least half the observers are <25 years old, low activity level, LZ1 nighttime outdoor lighting zone. Illuminance to be applied uniformly (4:1 avg:min and 10:1 max:min) and continuously.

Designer's discretion and typically ⅓ to ½E_h. Illuminance to be applied uniformly (4:1 avg:min and 10:1 max:min) and continuously.

Gravel path surface and grass and dark green ground cover are presumed to exhibit an aggregate reflectance of 10 percent.

Trees and some dark-brick building surfaces are presumed to exhibit an aggregate reflectance of 5 percent.

Sky comprises most of the overhead surrounds and exhibits a reflectance of 0 percent.

Observer's binocular field of view can be defined for some location on a pedestrian way with the ground and overhead surroundings subtending about 2 steradians each of solid angle and the vertical surroundings subtending 1 steradian of solid angle for a total of 5 steradians.

Averaging photopic luminances by solid angles (in steradians) yields the photopic luminance value to be used in Figure 4.27.

See Table 2.1 | Vision Adaptation States.

Use the "$L_{photopic}$ of environment value" of 0.05 cd/m2 from Step 4 to determine multipliers from Figure 4.27.

Multiplier to adjust recommended photopic illuminance target value for mesopic adaptation for 2000 K HPS lamps with S/P of 0.60 for this specific example.

Multiplier to adjust recommended photopic illuminance target value for mesopic adaptation for 3000 K CMH lamps with S/P of 1.38 for this specific example.

Multiplier to adjust recommended photopic illuminance target value for mesopic adaptation for 4000 K CMH lamps with S/P of 1.81 for this specific example.

Recommended mesopic illuminance criteria if 2000 K HPS lamps with S/P of 0.60 are proposed for this specific example.

Recommended mesopic illuminance criteria if 3000 K CMH lamps with S/P of 1.38 are proposed for this specific example.

Recommended mesopic illuminance criteria if 4000 K CMH lamps with S/P of 1.81 are proposed for this specific example.

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committee, and perhaps the president. Revisions would be made as needed, including any post-curfew criteria. Although here the 4000 K CMH solution may offer the lowest connected load, a mockup is in order to assess its color qualities. The team might determine that a 3000 K solution offers a better balance between color characteristics, efficiency, and illuminance criteria. At such low illuminances, any high intensity discharge lamp may not be available in sufficiently low wattage to meet uniformity criteria. Here, CFL and LED options may be best. Also see Table 26.6 | Parking Deck Mesopic Multiplier Example Worksheet.

12.5.5.7 Illuminance Calculations

Illuminance depends on daylight or electric light or some combination. In most interior situations, walls, ceiling, and floor reflectances affect illuminance. In many exterior nighttime situations, little or no "reflected bounce" component contributes to illuminance. Where electric light is involved, photometry for the luminaires is used to make calculations. The *photometric pedigree* is important to the accuracy of calculations—the latest photometry by third-party testing laboratories that is available from luminaire vendors should be used. See 10 | CALCULATION OF LIGHT AND ITS EFFECTS, 15.1.2.5 Photometric Pedigrees, and 15.3 Modeling.

Photometric pedigree is a reference here to current formal documentation of the light output data for a specific luminaire, lamp, and ballast/driver/transformer combination tested to IES test procedures.

The photometric pedigree is important to the accuracy of calculations. The latest photometric tests are available from the luminaire vendors. These tests should generated by third-party testing laboratories or other labs accredited by government approved certification programs, such as the National Voluntary Laboratory Accreditation Program in the United States. Photometric testing should be in accordance with IES testing methods.

12.5.5.8 Guidance for Various Tasks and Users

Most spaces are used by a variety of occupants. These users might be of significantly varying visual ages performing a number of tasks some of which do not demand the same illuminance for satisfactory performance. There are any number of methods to handle the potential illuminance inequities between different users' ages and different tasks. Whichever method is employed and documented, it should be rational and reasonable, but, more importantly, offers an efficient and practical solution that is reviewed and accepted by the client.

One method for addressing inequities between different users' visual ages and different tasks is explored here. Where multiple tasks and visual ages occur, establish the users' visual ages and group these according to the IES visual age categories—at least half the observers exhibit a visual age of <25 years; or 25 to 65 years; or >65 years (see Section 4.12.1.2 Observer Characteristics). Within each visual age group make a list of tasks and cite the horizontal and vertical illuminance targets for the anticipated users' visual ages, along with the target gauge of average, minimum, or maximum and the illuminance ratio associated with each task. Group tasks that demand the same illuminance criteria. It is reasonable that two or three tasks demand one set of illuminance criteria while two or three other tasks demand another set of illuminance criteria for a particular users' group visual age. Outliers (single tasks) might exist which demand yet different illuminance criteria for a particular users' group visual age. From this list, prioritize tasks based on expected time of duration, on importance, or on client direction. Similarly, prioritize visual ages based on expected time of duration, on importance, or on client direction. If all tasks and visual ages converge to the same illuminance, then this is the design target for the task area. If the target illuminance for the task requiring the most light for the highest visual age will accommodate all tasks and visual ages, then, review this option with the client. "Accommodate" here means that the visual tasks' illuminances are no more than three categories apart and no task, visual-age group, or other criteria will be adversely affected with the established illuminance design target, including power budgets.

Review both horizontal and vertical plane illuminances. Where an illuminance design target is quite high relative to those for other tasks, or is on a different plane, consider if ambient and task lighting systems can address the inequities. An ambient lighting system can address all but the highest illuminance requirements which can then be addressed with

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task lighting, for example. Further, dimmable task lighting can accommodate tasks where lower illuminance targets are recommended if those tasks are performed for long stretches of time (for example, anything more than an hour). If illuminances of the various visual tasks are more than three categories apart, then task and visual-age priorities should be used to establish the most-frequently performed or most-important task or tasks. Illuminance should be established accordingly. These and other techniques should be reviewed with clients for concurrence.

12.5.6 Color Considerations

A number of considerations related to color involve room surface color, color rendering, and color temperature. Light, no matter its genesis, will affect surface color and exhibits its own distinct color-of-light quality embodied by color rendering and color temperature. After some experience, which may be nothing more than viewing a variety of modern lamps and assessing their color characteristics, it will be apparent that the color differences in lamps are visually significant, may be annoying, and can affect users perceptions. Lamp color rendering influences surface colors by neutralizing them or by saturating them. Lamp color temperature influences the "coolness" or "warmth" of a space, although this depends to some extent on the room surface colors and the lamp's color rendering.

Match lamps' CCTs to avoid apparent intensity and shade-of-white variations of white light from lamp-to-lamp or luminaire-to-luminaire. Lamps within 200 K of each other will appear to match fairly well unless these are placed in very close proximity to each other or they are in a group of lamps illuminating a white surface, in which case the reflected light is noticeably different between the mismatched lamps. Matching CRI also minimizes shade-of-white and apparent intensity variations. Lamps with same or nearly identical CCTs should exhibit CRIs of at least 80 and that are within 10 points of each other.

Matching electric light sources' CCTs and CRIs to daylight is impractical. Color qualities of daylight vary so significantly over time of day, time of year, and sky conditions, that electric lights, even if matches were technically achievable efficiently, could not track the wide variations in daylight. Any attempt to use 4100+ K lamps with daylight must be tempered with the knowledge that these lamps are likely to be extinguished during most daylight conditions when such a match is visually obvious. During dark conditions, 4100+ K lamps exhibit an appearance that may be considered harsh and institutional.

Some clients dismiss fluorescent lamps. Among the reasons: color of light; color rendering; and ballasting. For example, enough previous-generation lighting equipment remains in place today that a client comment disparaging fluorescent lighting may be based on his recent experience. Reviewing existing conditions may reveal electromagnetic ballasts, typically exhibiting a slight audible hum and producing lamp flicker visible to some people, and a pale, cool-greenish-white light from low-CRI halophosphate and even some standard triphosphor fluorescent lamps. A simple mockup of 82+ CRI deluxe triphosphor lamps on electronic ballasts may then be in order to educate the clients on advancements in lighting. Where a match to incandescent quality is in order, 2700 K and 3000 K lamps exhibiting 82+ CRI are appropriate. Where a match to halogen quality is in order, 3000 K lamps exhibiting 82+ CRI are appropriate. 3500 K lamps available with 82+ CRI offer a neutral-white light quality. 4100 K lamps available with 82+ CRI offer a cool-white light quality. 5000 K lamps exhibiting 80+ CRI offer a crisp, blue-white light quality. These higher color temperature lamps may be considered harsh, cold, and institutional in appearance if no daylight is present for contrast.

Many studies over the last century on users' preferences, perceptions, and performance with respect to CCT and CRI have not yielded consistent or definitive support of one particular CCT and CRI over another within the range of commercially available efficient lamps. Arguably, a "middle-of-the-road" approach of 3000 K to 3500 K with 80+ CRI

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> 4.8.4 Depth Perception
  - for more on colored surfaces

> 6.2.5 Color Temperature and Correlated Color Temperature
  - for more on energized lamp appearance

> 6.3 Color Rendition
  - for more on energized lamp effect on surfaces

> 6.4 Materials Color Specification
  - for more on surface color and reflectance

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appears best supported by some of the studies some of the time to meet preferences and performance reasonably well. Claims of health or efficiency benefits of lamps exhibiting particular CCTs, CRIs, or SPDs should be scrutinized. Although many studies center around 4100 K lamps, it isn't clear if this is self-perpetuated, that is, researchers are allowing common practice to drive these selections in studies. Regardless, mockup reviews of anticipated project finishes under project target illuminances using proposed or various lamp CCTs and CRIs are recommended with clients prior to finalizing selections.

12.5.6.1 Lighting for Color Appraisal, Color Matching, and Color Reproduction
The type and degree of color appraisal, matching, or reproduction affects surface color selections and color temperature and color rendering criteria. First, room surface finishes will affect or skew color appraisal unless neutrals are used. In some situations, surface reflectances must be moderate (20% to 60%) to avoid veiling reflections which may adversely affect color discrimination. Second, illuminance affects the success of color appraisal, matching, or reproduction and this is accounted in IES recommended illuminance targets for these kinds of tasks.

In areas where color appraisal is critical (for example, patient exam room, high-end retail clothier), highest practical CRI lamps are recommended (85+ CRI) with broad SPDs or at least SPDs exhibiting strength in red, green, and blue wavelengths. Lamp color temperature is dependent on historical precedent, learned behavior, or designer or client preferences and exemplified by CCTs such as 5000 K for many clinical procedural applications or 3000+ K for many retail applications or 2700+ K for many hospitality applications. Mockup reviews with clients are recommended.

In areas where color matching and color reproduction are critical (for example, graphic layout and pre press rooms), graphic industry standards apply, for example, CIE D50 illuminant of 5000 K and 90+ CRI. [29]

Where color appraisal is not a critical component of the task, but desirable (for example, typical office applications, many hospitality situations), 80+ CRI is recommended. Many of today's most efficient, white-light lamps exhibit 80+ CRIs. Color temperature is dependent on designer's or client's preferences. Mockup reviews with clients are recommended.

12.6 Systems Factors

Although the intent of any lighting solution is to light the tasks, areas, and spaces for efficient, productive, comfortable, and satisfactory function by people, it must also address aesthetic and installation integration. Additionally, controllability of daylight and electric light is key to utility and efficiency. These and other such systems factors are a significant part of the architectural and engineering scopes and require coordination by respective disciplines. The hidden infrastructure of other building systems and the ephemeral aspects of still others, such as AV, should not so readily dictate lighting equipment selections or layouts. Lighting is likely to be the most regularly-used, visibly-obvious system remaining in place for decades. A brief presentation of the factors, components typically involved, the attributes affecting lighting, their relevance, and significance is made in Table 12.8a and Table 12.8b.

12.6.1 Flexibility

Physical flexibility of lighting may influence the luminaire selection and how luminaires are connected to the electrical system. Flexibility of ceiling mounted lighting is also tied to ceiling system design, ceiling layout, and layout of other systems in or at the ceiling. Since lighting flexibility can also be addressed with controls, defining flexibility with the team and clients for the specific project is recommended. Some tasks or applications may not benefit from flexibility in physical movement of luminaires or in controllability.

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12.6.2 Controls

Lighting controls improve lighting functionality by tailoring the luminances, illuminances, and ratios to address a host of tasks or applications within a given space or area. Controls can significantly cut energy use by addressing electric lights based on daylighting, time-of-day, and occupancy. See 16 | LIGHTING CONTROLS.

12.6.2.1 Daylight-based Control

Coupling control of daylight delivery and electric luminaires allows these lighting systems to interact effectively. When daylight is too intense, shade devices automatically respond to limit glare, but still allow daylight to entirely or partially service the tasks. When daylight is less intense, shade devices automatically respond to admit more daylight to service the tasks. As daylight diminishes or becomes nonexistent, electric luminaires are switched on or brightened up to augment the reduced daylight to service tasks. A control system, photocells, perhaps sun-trackers, shade systems, and stepped-dimming or continuous-dimming electric luminaires zoned in functional groups related to task areas or proximity to daylight are required for maximum energy benefit while maintaining comfort, satisfaction, and function.

12.6.2.2 Temporal-based Control

Astronomical time clocks are used to track time-of-year sunrise and sunset, making adjustments for daylight savings time. The devices are programmed to operate interior lights and exterior lights with different schedules. These devices can be programmed to dim or extinguish some or all exterior lights, for example, at some predetermined curfew and brighten up or reenergize exterior lights at some predetermined start time, such as 6 a.m. Time clock dusk-to-dawn tracking functions or photocells are typically interfaced to keep lights extinguished at 6 a.m. if daylight is sufficient.

12.6.2.3 Occupant-based Control

Automated and manual controls extinguish, dim, or energize lights on an area-by-area basis. Occupancy sensors best limit energy use. However, manual controls that offer more than on/off switching will best tailor lighting for intended activities, such as meeting, presentation, and AV situations in conference rooms. Here, dimmable lights in groupings specific to the requirements of each activity can be set up in scenes so that users need only activate the "meeting" scene for meetings. Some occupancy sensors can be programmed to automatically extinguish lights after some period of vacancy, but require users to manually switch lights on when entering the space. These sensors are also known as vacancy sensors.

12.6.3 Acoustics

Lighting equipment or lighting details can negatively affect acoustical attributes in spaces. The ceiling can absorb or reflect sound. In areas of concentrated work, ceiling materials that absorb sound are typically used. Close coordination between the acoustician, architect, and lighting designer is recommended on ceiling finishes and luminaire trim types.

Vaulted and domed ceilings which might support lighting coves to highlight their interesting configurations reflect sound in specific directions if finished in hard materials. Depending on geometry, room use, and lighting equipment, these hard surfaces are problematic. The acoustician and architect coordinate these ceiling treatments, but interface with the lighting to assess the affect of ceiling materials and finishes on lighting and vice versa.

Luminaire surfaces themselves can reflect sound from one position to another with good clarity; which is unacceptable. In work spaces where acoustical ceilings are used for acoustic dampening, introducing large-scale luminaires with wide-flat-bottom metal, glass, or acrylic surfaces may degrade the integrity of the room acoustics. Close coordination between the acoustician, architect, and lighting designer is required.

Many electromagnetic ballasts and transformers tend to produce audible hum unless suitably potted or encased. Most electronic ballasts and transformers are better and generally more efficient. All ballasts should exhibit a sound-rating of A.

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Table 12.8a | Systems Factors: Part One

Factor	Component	Attribute	Relevance	Significance
Flexibility	• Physical	• Modularity	• Ceiling integration	• Aesthetic integrity • Convenient rearrangement
			• Segmented	• Convenient disassembly
		• Scale	• Volume and weight	• Convenient rearrangement
		• Electrical connection	• Plug and play	• Convenient rearrangement • Code compliance
	• Functional	• Individual addressability	• Luminaire-by-luminaire control	• Redefine control zones
		• Dimmability	• Tune lighting	• Reprogram intensities
Controls	• Daylight response	• Shading	• Glare	• Comfort
			• Intensity modulation	• Energy reduction
			• Blackout	• Limit light pollution • AV or other task functions
		• Electric lighting	• Intensity modulation	• Continuous dimming • Stepped dimming • On/off
	• Temporal response	• Anticipated occupancy	• Nominal base lighting	• Energy reduction • Extend in-service life • Code compliance
		• Setbacks	• Modulate demand	• Energy cost reduction
			• Limit available lighting	• Energy reduction • Limit light pollution • Extend in-service life • Code compliance
	• Occupancy response	• Actual occupancy	• Need-only	• Energy reduction • Extend in-service life • Code compliance
Acoustics	• Architectural details	• Ceilings • Coves • Domes • Vaults	• Material type	• Absorb or reflect sound • Access above ceiling
	• Plenums	• Sound insulation	• Thermal influence	• IC-rated luminaire • Enclosure around luminaire
	• Luminaire surfaces	• Scale	• Housing • Lens • Louver	• Reflect sound
	• Luminaire ballast/transformer	• Sound rating	• Electronic (preferred) • Electromagnetic	• Sound-rated A for quiet
HVAC	• Load influence	• Lighting watts	• Heating • Cooling	• System size • Energy use
	• Layout appearance	• Style and scale	• Grilles	• Pattern/size relative to luminaires
		• Symmetry	• Grille/duct interference	• Proximity to lights
	• Ambient temperature	• Vicinity of lamp	• Optimal operating temp	• Reduced light output
		• Vicinity of ballast or driver	• Optimal operating temp	• Premature failure
	• Luminaire air-function	• Air supply or heat extraction	• Air-luminaire integration	• Limits luminaire selection • Limits lighting technique

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Table 12.8b | Systems Factors: Part Two

Factor	Component	Attribute	Relevance	Significance
Ceiling Systems	• Drywall	• Finish	• Direct lighting trim	• Flangeless
				• Flanged
			• Indirect lighting	• Level 5 finish
				• Egg-shell or matte ceiling finish
	• Lay-in	• Grid	• Style	• Luminaire integration
		• Module size	• Scale	• Luminaire selection
		• Finish	• Painted mineral board	• Warp potential
			• Painted cloth	• Indirect lighting
			• Fabric	• Fit/finish
	• Tech-modular	• Linear zone for all services	• Style	• Luminaire integration
			• Scale	• Luminaire selection
				• Luminaire layout
	• Decorative	• Stone	• Direct lighting trim	• Flangeless
		• Wood		• Flanged
			• Indirect lighting	• Honed/satin
				• Flamed/rough
Installation	• Sequencing	• Availability	• Leadtime	• Order timing
	• Integration	• Physical	• Fit	• Wall/ceiling fit/finish
				• Interferences
				• Plumb/true/square
			• Luminaire layout	• Hardware arrangement
				• Lighting effect arrangement
			• Attachment	• Infrastructure
	• Field results	• Aiming observation	• Adjustments	• Lighting effects
		• Punchlist		• Illuminances
				• Luminances
Sustainability	• Energy	• Controls	• Limit electricity use	• Astronomical time clocks
				• Photocells
				• Preset scenes for function
				• Occupancy sensors
	• Efficiency	• Room surfaces	• Maximize interreflection	• ≥90%/≥60%/≥20% ceiling/walls/floor
		• Ballasts/drivers/transformers	• Select most efficient in class[a]	• Highest system LPW
		• Lamps	• Select most appropriate for class[a]	• Accent: Best CP[b] and/or highest LPW
				• Ambient: Highest LPW
		• Luminaires	• Select most efficient in class[a]	• Best CP distribution[c] and/or highest efficiency
		• Layout	• Establish efficient layout[a]	• Optimize effect(s) and layout
	• Embodied energy	• Production	• Limit high-energy processes	• Minimize overall carbon footprint
		• Transportation	• Limit volume and weight	
			• Limit shipping distance	
Maintenance	• Cleaning	• Cycle	• Luminaires	• Maintain lighting system efficiency
			• Room surfaces	
	• Replacement	• Access	• Lamps	• Maintain lighting system efficiency
		• Cycle/recycle	• Ballasts/drivers	
			• Luminaires	

a. Determine class of respective parameter based on design needs, then select most efficient equipment available. For example, where extensive wall lighting is to be achieved with linear slots at ceiling/wall junctures using lamps classified as dimmable linear fluorescent, select the most efficient approved-for-dimming linear fluorescent lamp available exhibiting CCT and CRI that meet the design intent. Similarly, select the most efficient dimming ballast for this situation.

b. In many accent lighting applications lamp candlepower (CP) is as or more important than lamp efficacy. For example, where art at a reception area is accented, the candlepower "punch" available from halogenIR$_{LV}$, CMH, or LED accent equipment typically provides superior luminance results than the use of CFL accent or wallwash equipment even though the CFL lamps exhibit best LPW.

c. In many general applications luminaire candlepower (CP) distribution for the area and tasks being addressed is of primary importance.

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12.6.4 HVAC

The lighting load affects HVAC system design. The lighting equipment style, size, and layout influences the look of the ceiling, as do HVAC grilles. Close coordination of the lighting and HVAC devices is required for best appearance.

Luminaires are affected by HVAC. If lamps operate in temperatures that are too warm or too cool compared to optimal lamp tolerances, light output may be degraded, perhaps significantly. If ballasts and drivers are operated in temperatures above their respective tolerances, premature failure is possible. Where environmental dirt is entrained and captured on luminaire surfaces due to proximity to air diffusers, periodic cleaning is in order to maintain optimal luminaire efficiency.

Some ceiling recessed luminaires are intended to help supply or extract air from the room or area. Although styling and types are limited, this can clean up the visual aspects of the ceiling by integrating air diffusers with lights.

12.6.5 Ceiling Systems

Ceilings influence the overall aesthetic of the space and greatly affect lighting system efficiency. Ceilings with matte finishes and with IES-recommended LRVs of 90% or greater are desirable in many work settings to take best advantage of indirect or indirect/direct lighting systems.

Drywall ceilings are typically considered a cost-effective high-quality treatment without the expense of wood, metal, or stone. For drywall surfaces, levels of finish are specified by the architect or interior designer, with level 5 exhibiting the highest quality [30] [31]. Where electric lighting or daylighting is proposed to wash drywall ceiling or wall surfaces or where daylighting is extensive, small imperfections in finish will visually telegraph and may be undesirably accentuated. Flangeless or trimless lights further refine the look of drywall ceiling or wall installations. However, if access panels are required to gain access to plumbing or HVAC equipment in the plenum, then careful planning and integration of these accesses is needed to maintain the appearance of a contiguous ceiling plane, particularly where grazing or indirect lighting techniques are employed.

Lay-in or acoustic tile ceilings offer some degree of acoustic treatment, above-ceiling-access, and a modular grid and tile layout which may assist lighting layouts. The type of grid, slot-T, narrow-T, or standard-T, and type of ceiling panel, tegular edge, standard edge, affect the look and influence luminaire integration. Where grazing or indirect lighting techniques are used, integrity of ceiling tile, particularly over time (e.g., no sagging or warping), is important as is installation quality (e.g., plumb and true grid and tile).

Specialty ceilings, such as metal, stone, or wood, demand greater integration effort and care. Although flangeless luminaires look best, these require far greater accuracy in cutting holes to accommodate luminaire trims. Where grazing or indirect light is used, the finishes of the ceilings must be evaluated in mockups.

12.6.6 Installation

Although many aspects of construction must converge prior to lighting installation, sequencing is a consistent and persistent aspect. Acknowledging lighting equipment availability is important and establishing and sharing likely lead times is appropriate.

Physical aspects of lighting integration affect overall appearance. Where luminaires are out of plumb or exhibit light leaks at ceiling or wall junctures, the fit and finish are considered substandard and may detract people from living or working functions.

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The installation is not complete until luminaires are adjusted (aimed or oriented) to perform the intended lighting function. Professional contractors will appreciate the aiming (tilt and rotation) or orientation aspects, but the designer generally observes some amount of this effort to confirm the full effects and, therefore, energy optimization are achieved. Field measurements help calibrate prediction techniques and may be used to confirm functional performance of lamps, luminaires, ballasts, surface finishes, and controls.

12.6.7 Sustainability

Energy, efficiency, and embodied energy are affected by sustainability aspects of design, procurement, and maintenance. Although many so-called energy codes are simply wattage limits or power budgets, energy is the use of watts or power over time, generally expressed as kilowatt-hours (KWH). Controls, when fully exploited, perhaps now play the single largest role in energy use, with potential average energy reductions ranging to 60 percent depending on space types and the types of controls employed. [32] [33] [34] [35]

Embodied energy in lighting equipment includes the energy to extract and refine raw materials, manufacture, and distribute. Where several products are under consideration for a given lighting function, some conclusions might be drawn from an assessment of production efficiencies, and transportation distances and efficiencies. However, recognize that product size and volume, material types and gages, and finishes which are unlikely to be exactly identical from product to product, affect embodied energies.

12.6.8 Maintenance

Maintenance is the link between predictive design and actual performance over the long term. Without persistent professional care, lighting equipment degrades or fails and building surfaces degrade. Without spot relamping, group relamping, regularly-scheduled luminaire and room-surface-finish cleaning, most lighting systems would perform to just 70 or 80 percent of their predicted performance within three to five years of service, depending on the application. This is an effective loss in efficiency of 20 to 30 percent! Looking at this another way, if designs accommodated such significant degradation in lighting equipment and building surface integrity, then initial installation quantities of luminaires would need to increase 20 to 30 percent. This, in turn, would require 20 to 30 percent greater embodied energies because of the increased requirements in raw materials, their refinement, production of the additional luminaires and their transportation to the site *and* would consume 20 to 30 percent more energy once installed and operating regardless of system efficiency and extent of controls. Respective increases in power distribution and HVAC systems would also be necessary.

Spot and group relamping demand recycling of lamps. Luminaire replacement cycles, typically 20 years or hopefully much greater, are increasingly dependent on the luminaire's inherent construction in quality and ability to accommodate future component retrofits. Given the nature of electrical safety testing, retrofits should be done under the auspices of the original equipment manufacturer (OEM) or the retrofits tested and labeled for compatibility with the original equipment.

Specification of luminaires with appropriate access for periodic maintenance are important. The means of access, however, may not be obvious and instruction manuals are often necessary as part of the project documentation obtained by the contractor for the client. Appearance or performance may trump ease of maintenance. For exterior or even interior luminaires adjacent to building entries and exits, gasketing or IP6X-rated luminaires may be appropriate where insect ingress is expected to be a significant burden. See Table 15.4 | IP Rating System ("X" depends on water ingress requirements, if any).

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> 13.11 Sustainability
- for more on lamps

> 19 | SUSTAINABILITY
- for more on energy
- for more on earth resources
- for more on recycling
- for more on Life Cycle Analysis
- for more on lighting design

> 19.2 Elements of Sustainable Lighting Design
- for more on controls

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12.7 Prescribed Factors

Prescribed factors are those codes, building safety standards, ordinances, federal mandates, and certification programs that affect lighting. In general, where these are a requirement of the jurisdictional building authority or client or where deemed appropriate to managing professional risk, they offer non-negotiable criteria. Table 12.9 identifies several such codes, standards, and certification programs. A review of all such applicable prescribed factors with the team's registered professionals is necessary early in project planning. New prescribed factors are introduced from time to time and most of these change regularly, so a periodic review is a must. Where the lighting design role is performed by a team member other than the architect or electrical engineer, the registered professional in charge (typically the architect, but perhaps the electrical engineer) must be consulted for guidance on which prescribed factors are in force for the project underway.

These and other directives establish specific lighting criteria that must be accommodated by the lighting design. From time to time, federal mandates with lighting-related provisions are declared and these, too, must be accommodated. See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

12.8 References

General:

Brandston HM. 2008.Learning to see: A matter of light. New York: IESNA.

Lam WMC. 1997. Perception and lighting as formgivers for architecture. New York: McGraw-Hill.

Lam WMC. 1986. Sunlighting as Formgiver for architecture. New York: Van Nostrand Reinhold.

Michel L. 1996. Light: The shape of space. New York: Van Nostrand Reinhold.

Veitch JA, Newsham GR. 1996. Determinants of lighting quality II: Research and recommendations. [Internet]. cited February 2010. Available from: www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc40343.pdf.

[1] Steffy G. 2008. Architectural lighting design. 3rd Edition, Hoboken: John Wiley & Sons. p 48.

[2] Flynn JE. 1973. The psychology of light II, Orientation as a visual task. Electr Conslt. 89(1):10-21.

[3] Flynn JE. 1973. The psychology of light V, AttituderReinforcement through lighting design. Electr Conslt. 89(5):42-45.

[4] Collins B. 1993. Evaluation of subjective response to lighting distributions: A literature review, NISTIR 5119. Gaithersburg, MD: National Institute of Standards and Technology.

[5] Flynn JE and others.1973. Interim study of procedures for investigating the effect of light on impression and behavior. J Illum Eng Soc. 3(2): 94.

[6] Nasar JL, editor. 1988. Environmental aesthetics. Cambridge: Cambridge University Press. pp 156-170.

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Table 12.9 | Typical Prescribed Lighting Design Factors

Sponsor	Relevant Directive(s)	Exemplary Document(s) and/or Citations[a]
ASHRAE American Society of Heating Refrigerating and Air Conditioning Engineers	• **Energy Standard**	• ANSI/ASHRAE/IESNA Standard 90.1
	• **Sustainability Standard**	• ANSI/ASHRAE/IESNA Standard 189.1
ASME American Society of Mechanical Engineers	• **Elevator/Escalator Codes**	• ASME A17.1/CSA B44
CaGBC Canada Green Building Council	• **Sustainability Initiative**	• Leadership in Energy and Environmental Design (LEED)
CCNNIE Comité Consultivo Nacional de Normalización de Instalaciones Eléctricas	• **Electrical Code**	• NOM-001-SETE-2005 Mexican Electrical Code (MEC)
CONAE Comisión Nacional para el Ahorro de Energía	• **Energy Code**	• NOM-007-ENER-2004 Mexican Energy Efficiency Standard
CSA Canadian Standards Association	• **Electrical Code**	• Canadian Electrical Code (CEC)
	• **Product Standards**	• Safety requirements for luminaires, lamps, control gear
ICC International Code Council	• **Building Code**	• International Building Code (IBC)
	• **Energy Code**	• International Energy Conservation Code (IECC)
	• **Sustainability Code**	• International Green Construction Code (IGCC)
NFPA National Fire Protection Association	• **Electrical Code**	• National Fire Protection Association (NFPA) 70
	• **Health Care Facilities**	• NFPA 99
	• **Life Safety Code**	• NFPA 101
NRC National Research Council Canada	• **Building Code**	• National Building Code of Canada
	• **Energy Code**	• Model National Energy Code of Canada for Buildings (MNECB)
UL Underwriters Laboratories	• **Product Standards**	• Safety requirements for luminaires, lamps, control gear
USDOJ U.S. Department of Justice	• **Accessible Design Standards**	• Americans with Disabilities Act (ADA)
USGBC U.S. Green Building Council	• **Sustainability Initiative**	• Leadership in Energy and Environmental Design (LEED)
Various	• **Municipal Ordinances**	• Light pollution and/or light trespass requirements
		• Exterior illuminances
	• **State/Provincial/Territorial Codes**	• Energy standards
		• Hazardous disposal regulations
		• Life safety codes
		• Sustainability standards

a. Prescribed factors are continually updated. Use the most current prescription or that required of the client or jurisdictional building authority.

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[7] Davis RG. 2009. Cognitive factors in lighted architectural environments: Context-specific preferences for lighting. In: Conference Proceedings—2009 IES Annual Conference. New York: IESNA.

[8] Flynn JE and others. A Guide to methodology procedures for measuring subjective impressions in lighting. J Illum Eng Soc. 9(1):95.

[9] Brainaird GC and others. 2001. Action spectrum for melatonin regulation in humans: Evidence for a novel circadian photoreceptor. J Neurosc. 21(16): 6405–6412.

[10] Figueiro MG, and Rea MS. 2005. New research in the light and health field is expanding the Possibilities for LED lighting in healthcare environments. In: CIE Midterm Meeting Conference Proceedings, Leon, Spain. [Internet]. cited February 2010. Available from: http://www.lrc.rpi.edu/programs/lightHealth/overview.asp.

[11] Lamberg L. 1998. Medical News and Perspectives: Dawn's Early Light to Twilight's Last Gleaming. J Am Med Assoc. 280(18): 1556-1558.

[12] Glickman G and others 2006. Light therapy for seasonal affective disorder with blue narrow-band light-emitting eiodes (LEDs). Bio Psych. 59:502-507.

[13] [CSA] Canadian Standards Association. 1998. CAN/CSA ISO 9241 -7-00 (IS0 9241 -7:1998) (Reaffirmed 2005). Ergonomic requirements for office work with visual display terminals (VDTs) - Part 7: Requirements for display with reflections. Mississauga, Ontario: CSA.

[14] [ISO] International Organization for Standardization. 2008. ISO 9241-303:2008(E). Ergonomics of Human-system Interaction—Part 303: Requirements for Electronic Visual Displays. Central Secretariat. Geneva, Switzerland: ISO. p. 11.

[15] Buchnera A, Mayra S, Brandt M. 2009. The advantage of positive text-background polarity is due to high display luminance. Ergon. 52(7):882–886.

[16] Newsham GR, Marchand RG, Vietch JA. 2004. Preferred surface luminances in offices, by evolution. J Illum Eng Soc. 33(2):14-29.

[17] Steffy GR. 1995. Lighting the electronic office. New York: Van Nostrand Reinhold. pp 79-84.

[18] [CIBSE] Chartered Institution of Building Services Engineers. 2001.Addendum to CIBSE Lighting Guide 3. London: CIBSE. p 4.

[19] Mark S. Rea, ed. 2000. The IESNA lighting handbook: Reference and application. 9th Edition. New York: IESNA. Ch 11.

[20] European Committee for Standardization. 2002. European Standard EN 12464-1, Light and lighting - Lighting of work places - Part 1: Indoor work places. Brussels: European Committee for Standardization. p 12.

[21] CIBSE Chartered Institution of Building Services Engineers. 2006. Society of Light and Lighting, Code for lighting 2006/CD-ROM. London, CIBSE.

[22] [IESNA] Illuminating Engineering Society of North America. 2004. American National Standard Practice for Office Lighting, ANSI/IESNA RP-1-04. New York: IESNA. p. 45.

[23] Ashdown I, Franck PJ. Luminance gradients: Photometric analysis and perceptual reproduction. In: Conference Proceedings—1995 IESNA Annual Conference. New York: IESNA.

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[24] Luckiesh M, Guth SK. Brightnesses in visual field at borderline between comfort and discomfort (BCD). Illum Eng 44(3):650-670.

[25] Mark S. Rea, ed. 2000. The IESNA lighting handbook: Reference and application. 9th Edition. New York: IESNA. pp 11-3, 19-4.

[26] [IES] Illuminating Engineering Society. 1952. IES Lighting Handbook, 2nd edition. New York: IES. pp 10-58, 10-69.

[27] CIBSE Chartered Institution of Building Services Engineers. 2006. Illuminance Variation. In: Society of Light and Lighting, Code for lighting 2006/CD-ROM. London, CIBSE.

[28] CIBSE Chartered Institution of Building Services Engineers. 2006. Specification and Interpretation of Illuminance Variation. In: Society of Light and Lighting, Code for lighting 2006/CD-ROM. London, CIBSE.

[29] [ISO] International Organization for Standardization. 2009. ISO 3664:2009(E) Graphic technology and photography—Viewing conditions. Geneva, Switzerland: ISO.

[30] Gypsum Association. 2007. GA-216-2007. Application and Finishing of Gypsum Panel Products. Washington, DC: Gypsum Association.

[31] Gypsum Association. 2007. GA-214-07. Recommended Levels of Gypsum Board Finish. Washington, DC: Gypsum Association.

[32] Leslie R, and others. The potential of simplified concepts for daylight harvesting. Light Res Tech. 37(1): 21-40.

[33] Fetters JL. 2010. Lighting controls: Reducing cost, saving energy. Maint Sol. [Internet]. cited March 2020. Available from: http://www.facilitiesnet.com/energyefficiency/article/Lighting-Controls-Reducing-Cost-Saving-Energy--8086.

[34] Piper J. 2006. Lighting control systems drive energy savings. Build Oper Man. [Internet}. cited March 2010. Available from: http://www.facilitiesnet.com/lighting/article/Lighting-Control-Systems-Drive-Energy-Savings--5764.

[35] [NEMA] National Electrical Manufacturers Association. 2002. NEMA LSD 22-2001, Demand Reduction and Energy Savings Using Occupancy Sensors. , Washington, DC: NEMA Lighting Controls Council.

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13 | LIGHT SOURCES
APPLICATION CONSIDERATIONS

What is true by lamplight is not always true by sunlight.
Joseph Joubert, 19th Century French Moralist

There are several thousand commercially available light sources. With such a wide selection it is likely that several different choices could be made for a given lighting application. The goal of this chapter is to identify the salient considerations involved in selecting a light source, based on a consideration of the trade-offs in the major performance and operating characteristics. This chapter is intended to help facilitate light source selection for those involved in the design of the luminous environment, including architects, interior designers, engineers, lighting designers, owners, sustainability consultants, energy engineers, landscape architects, lighting product representatives, lighting manufacturers, contractors, and distributors. For fundamental details about the light sources that are compared in this chapter see 7 | LIGHT SOURCES: TECHNICAL CHARACTERISTICS.

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13.1 Summary

Tables 13.1a and 13.1b summarize typical applications and performance and operating characteristics for the most commonly specified lamps in each of the major categories of filament, fluorescent, high intensity discharge (HID), and solid state lighting (*SSL*). The columns of the tables list key design and application considerations: initial lamp and system efficacy; auxiliary gear and dimmability; lumen maintenance; lamp life at full output and when dimmed; warm-up and restrike times; a summary of CRI, CCT, color consistency, and color stability; availability of directional emitting types; and lumen output sensitivity to ambient temperature.

Additional application considerations discussed in this chapter but not summarized in Tables 13.1a and 13.1b include: physical environment factors such as vibration and weather; potential damage to objects and physical harm to people from optical radiation; lamp geometry; sustainability considerations such as hazardous waste content and disposal; legislation; standards; and the cost of light.

Different design situations call for different lamp performance and operating characteristic priorities. Lamp choice is related with the selection of luminaires, controls, and system layout. Local conditions as diverse as ambient temperature, codes, product availability, and/or the owner's disposition toward maintenance may also influence lamp selection. Once the lighting approach best suited to the lighting requirements of the project emerges as part of schematic design, the preliminary selection of lamp type(s) can also be made for overall compatibility with design objectives. As examples of prioritization of lamp characteristics based on application, lighting the suspension cables of a bridge would typically require lamps that have long lives and are resistant to vibration, whereas general office lighting typically requires high efficacy lamp/ballast systems with very good to excellent lumen maintenance and color characteristics.

SSL A family of lighting products that includes semiconductor light emitting diodes (LEDs), organic light emitting diodes (OLEDs), and polymer light emitting diodes (PLEDs). The term "solid state" is a reference to the fact that these devices are built entirely from solid materials, within which the charge carriers (that is, electrons and holes) are confined.

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Table 13.1a | Lamp Performance and Operating Characteristics: Filament and SSL

Chapter Section →		13.2		13.4		13.3	13.3	
Lamp Category ↓		Initial Efficacy (lumens/watt)		Auxiliary Equipment & Dimmability		Lumen Maintenance	Life (hours)	
		Lamp	System	Auxiliary Equipment	Dimmability		At Full Output	When Dimmed
FILAMENT	Standard Tungsten	**Applications:** Historic Landmarks. Used rarely in special historic or public monuments for historic and/or dimmable lighting effects.						
		8-13	N/A[b]	None	Yes, simple	Fair	750-1,500	Increases
	Halogen	**Applications:** Historic Landmarks, Hospitality, and Residential. Used rarely in residences or historic or public monuments for traditional dimmable, color, and sparkle lighting effects.						
		10-15	N/A for line voltage[b]. Reduced by transformer losses for low voltage	None; low voltage versions require transformer	Yes. Low voltage versions require controls compatible with transformer	Excellent	3,000-5,000	Increases
	HIR	**Applications:** Hospitality, Residential, Retail. Used sparingly for instant-on, dimming, color-sensitive accenting and general lighting (for example: restaurants, ballrooms).						
		15-36	N/A for line voltage[b]. Reduced by transformer losses for low voltage	None; low voltage versions require transformer	Yes. Low voltage versions require controls compatible with transformer	Excellent	3,000-5,000	Increases
SSL	LED	**Applications:** Exterior, Commercial, Hospitality, Retail, Residential. Performance data change continuously. Independently verifiable data for efficacy, CCT, CRI, color consistency (binning) and stability should be sought when making specifications.						
		25-75 (rapidly changing)[c,d]	Reduce by at least 15%	Driver	Yes, with the appropriate driver and control equipment	Fair to Poor	20,000-50,000	Increases
	OLED	**Applications:** At this writing there are few architectural products. Suitable for short throw distances (for example, task lights) or direct view applications.						
		N/A[f]	10-25	Architectural products are sold as systems that include the driver and light emitting OLED.	Yes, with the appropriate driver and control equipment	Poor	5,000 to L_{50} is typical for architectural products	Increases

13.2 Efficacy

Efficacy is a ratio of lumens per watt. The choice of lumens for the numerator and watts for the denominator yields several versions of efficacy, each with a different meaning, as summarized in Table 13.2. Lamp efficacy (also known as luminous efficacy) has historically been the version most thoroughly characterized and is useful as a first order quantity early in the design process. It does not account for the directional distribution of flux (see 13.7 Directional Intensity) or the effect of auxiliary gear, a luminaire, or a design application. System, luminaire, and application efficacy are progressively more informative in assessing the suitability of a lighting system for a given application. With an increasing focus on the optimization of lighting system energy use, it is important to employ these more application-specific versions of efficacy when making equipment selections. See also 8.4 Luminaire Performance.

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13.5		13.6				13.7	13.8
Starting Time		Color				Directional Intensity Distribution Availability	Sensitivity to Ambient Temp.[a]
Warm-Up	Restrike	CCT (K)	CRI	Consistency	Stability		
Instant	Instant	2,500-2,800	97+	Excellent	Excellent	No	None
Instant	Instant	2,800-3,200	97+	Excellent	Excellent	Diffuse and reflectorized available	None
Instant	Instant	2,800-3,200	97+	Excellent	Excellent	Diffuse and reflectorized available	None
Instant	Instant	1,100-9,000+	20-95+	Poor to very good, depends on bin tolerances	Good to poor	Optical elements control dist., which may be directional	High[e]
Instant	Instant	Limited data. Some products are about 2,800	Limited data. Some products are about 80	Fair to poor, depends on bin tolerances	Limited data, expect color shifts	Diffuse distribution from OLED surface, which may be shaped	High[e]

a. The luminaire has a significant effect on the local ambient condition experienced by the lamp.
b. System efficacy is not applicable for line voltage filament lamps because they do not employ auxiliary equipment.
c. The rapid change is due to the pace of technology develoment.
d. As of publication, higher efficacy is tied to higher color temperatures.
e. The colder, the better. Color and lumen output vary with temperature. Higher temperatures reduce life.
f. Lamp efficacy is not applicable for OLEDs because the lamp cannot be treated independently from the system.

Any change in lamp efficacy will have a concomitant change in system, luminaire, and application efficacy, all of which worsen with lamp life as a result of lamp lumen depreciation (see 13.3 Life and Lumen Maintenance). Some products maintain constant lumen output, or increase lumen output in discrete steps over time, by increasing the wattage to the system. Although efficacy still decreases over time with these systems, this strategy can save energy in comparison to standard design practice since the illuminated area will not be over-illuminated when lamps are new (see Sections 7.2.5.4, 7.3.6, and 7.4.5). The rate and degree of lamp lumen depreciation (see Figures 7.24, 7.33, and 7.40) may influence the quantity of lamps required to deliver the target illuminance and/or the control strategy (see 16.2.8 Lumen Maintenance). Codes, standards, regulatory policies, and sustainability guidelines do not yet consider lifetime changes in efficacy, though this is clearly an important aspect of energy management (see 17 | ENERGY

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Table 13.1b | Lamp Performance and Operating Characteristics: Fluorescent and HID

Chapter Section →		13.2		13.4		13.3	13.3	
	Lamp Category	Initial Efficacy (lumens/watt)		Auxiliary Equipment & Dimmability		Lumen Maintenance	Life (hours)	
		Lamp	System	Auxiliary Equipment	Dimmability		At Full Output	When Dimmed
FLUORESCENT	Screw-based CFL	**Applications:** Hospitality, Residential. Low cost lamp retrofit for interior general lighting for sockets originally designed for filament lamps.						
		35-65	N/A[b]	Integral ballast	Most are not dimmable; those that are dim poorly	Fair	6,000-8,000	Life decreases for the few types that are capable of dimming
	Pin-based CFL	**Applications:** Commercial, Hospitality, Residential, Retail. Used in many applications for interior and exterior lighting.						
		50-80	Reduce by about 5%	Ballast	2-pin versions are non-dim; 4-pin versions are dimmable with dimming ballasts	Fair to Good	10,000-16,000[d]	Life decreases for the 4-pin types that are capable of dimming
	Linear	**Applications:** Commercial, Hospitality, Residential, Retail, Industrial. Used in many applications for interior and exterior lighting, and for lighting surfaces.						
		70-100	Reduce by about 5%	Ballast Note: The choice of instant, rapid, or program start may influence lamp life.	Varies, check with lamp and ballast manufacturers	Good to Excellent	15,000-46,000 Life may be dependent upon ballast starting method and operating cycle.	No change for most types. Check with manufacturer especially for T5 lamps.
	Induction	**Applications:** Exterior, Industrial. Used in outdoor pedestrian, roadway, parking lot, and industrial applications, especially where long life is a priority.						
		N/A[f]	48-75	Most specified as systems with high freq. generator. Integrated screw-based also available, comparable to retrofit CFLs.	Most are non-dimming	Fair to Good	15,000 (integrated screw-based lamps) - 100,000 (non-integrated component-based systems)	Most are non-dimming
HID	High Pressure Sodium	**Applications:** Industrial, Exterior. Used to replace failed lamps in existing luminaires.						
		70-145	Reduce by about 10%	Ballast	Dimming to 50% with special equipment	Good to Excellent	16,000-55,000	No change with appropriate equipment down to 50%
	Quartz Metal Halide	**Applications:** Industrial, Exterior, Sports. Extensive use in roadway, parking, sport field, and industrial, applications.						
		68-120	Reduce by about 10%	Ballast	Dimming to 50% with special equipment	Fair to Good	10,000-20,000 (for ≤ 400 W)	No change with appropriate equipment down to 50%
	Ceramic Metal Halide	**Applications:** Commercial, Hospitality, Retail. Use in many applications for interior and exterior general and accent lighting.						
		80-125	Reduce by 5-10%	Ballast	Dimming to 50% with special equipment	Good	10,000-30,000	No change with appropriate equipment down to 50%

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13.5		13.6				13.7	13.8
Starting Time		Color				Directional Intensity Distribution Availability	Sensitivity to Ambient Temp.[a]
Warm-Up	Restrike	CCT (K)	CRI	Consistency	Stability		
Nearly instant, time to full output depends on	Nearly instant	2,700-6,500	low 80s	Excellent	Excellent	Reflector lamps available, but with weak intensity	Moderate to High[c]
Nearly instant, time to full output depends on	Nearly instant	2,700-5,000	low 80s	Excellent	Excellent	No	Moderate to high[c]
Nearly instant, time to full output depends on temp.	Nearly instant	2,700-7,500	50-90+	Excellent	Excellent	No	High[e]
Nearly instant, time to full output depends on temp.	Nearly instant	3,000-4,100 (also 2700 in the int. type)	low 80s	Excellent	Excellent	Diffuse and reflectorized[g] available.	High
< 5 min.[h]	< 1 min. restrike, several mins. to reach usable output	1,800-2,550	low 20s (mid-60s for improved color)	Excellent	Very good	No	Once started, none
< 5 min. for low wattage lamps[h]	5-20 minutes[h]	2,700-10,000	60-90 (65-75 typical)	Fair	Fair	Diffuse and reflectorized available	Once started, none
< 5 minutes[h]	3-5 minutes[h]	2,700-5,600	80-98	Good	Good	Diffuse and reflectorized available	Once started, none

a. The luminaire has a significant effect on the local ambient condition experienced by the lamp.

b. System efficacy is not applicable for screw-based CFL because the ballast is an integral component.

c. The lumen output of CFL lamps without amalgam technology is highly sensitive to ambient temperature. Amalgam CFL lamps have moderage sensitivity, but a longer warm-up time.

d. Based on 3 hours per start.

e. Cold weather ballasts are available. An ambient temperature derating factor should be employed for cold applications such as freezer cases.

f. Lamp efficacy is not applicable for non-integrated induction lamps since the lamp cannot be treated independently from the system. For integrated screw-based induction lamps, typical initial lamp efficacy is 45-50 lumens/watt.

g. Reflectorized only available in low wattages, and only in a flood beam distribution.

h. < 10 mins for lamps ≥ 400W. These are times to reach usable lumen output. Time to reach fully stable output may be 30 minutes to an hour, or more.

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Table 13.2 | Types of Efficacy in Units of Lumens Per Watt (LPW)

Type of Efficacy	Numerator (Lumens)	Denominator (Watts)	Description
Lamp (Luminous)	lumens generated by lamp	Input watts to lamp	Formally called luminous efficacy, it is a measure that isolates lamp performance without referece to auxiliary gear, a luminaire, or a design application. Standardized thermal, electrical, and photometric conditions are employed for measurement.
System	lumens generated by lamp	Input watts to auxiliary equipment[a]	A measure of lumens generated by the lamp when operated by auxiliary gear, but in isolation from a luminaire and design application.
Luminaire	lumens exiting luminaire	Input watts to auxiliary equipment[a]	A measure of lumens emitted from the luminaire accounting for absorption and other losses, but in isolation from a design application.
Application	lumens delivered to target plane(s)	Input watts to auxiliary equipment[a]	A measure that considers the lumens that directly strike a target plane (or planes), while also considering the input power required to deliver those lumens.

a. Auxiliary equipment may include a transformer, ballast, driver and/or high frequency generator. A single piece of auxiliary equipment may drive more than one lamp, as with a 2-lamp ballast, LED driver, or a transformer for low voltage track. A single lamp may require more than one piece of auxiliary equipment, as with an LED lamp that requires a transformer and driver.

MANAGEMENT). HID light sources consume more power as they age in addition to producing fewer lumens, which further contributes to a decline in all versions of efficacy.

The luminous efficacy of *LED lamps* is rapidly changing. As of mid-2011, published efficacy of some commercially available LED lamps exceeds 100 lumens per watt. The theoretical limit, assuming perfect conversion efficiencies, for an LED lamp with a CCT of 3800 K, CRI of 85, R9 of 21, and which employs RGBA spectral components, is approximately 400 lumens per watt. 250 lumens per watt is a more likely upper limit for commercial products, though such performance is not expected in the near future. [1]

LED Lamps may be Integrated or Non-Integrated

- **LED Lamp, Non-Integrated** A lamp with LEDs, without an integrated LED driver or power source and with an ANSI standardized base designed for connection to an LED luminaire.
- **LED Lamp, Integrated** A lamp with LEDs, an integrated LED driver or power source and with an ANSI standardized base designed for connection to an LED luminaire.

Ceramic metal halide systems are also advancing rapidly. The maximum practical efficacy of a white light metal halid lamp with a CRI greater than 80 is about 230 lumens per watt [2]. Low wattage metal halide systems have already been developed that exceed 150 lumens per watt, producing white light with a CRI above 85 [3]. As with LEDs, the greatest advances will occur when a system approach is employed, such that the lamps, ballasts, controls, and luminaires are developed and optimized as a system rather than as independent parts [4].

13.3 Life and Lumen Maintenance

For incandescent, fluorescent, and HID lamps, rated lamp life is the total operating time at which, under normal operating conditions, 50% of any large group of initially installed lamps is expected to have failed. This is a statistically determined estimate of median operational life. Figure 13.1 plots ranges of typical lamp life for various light sources. With SSL systems, life is defined as the time in hours to which lumen output has degraded to

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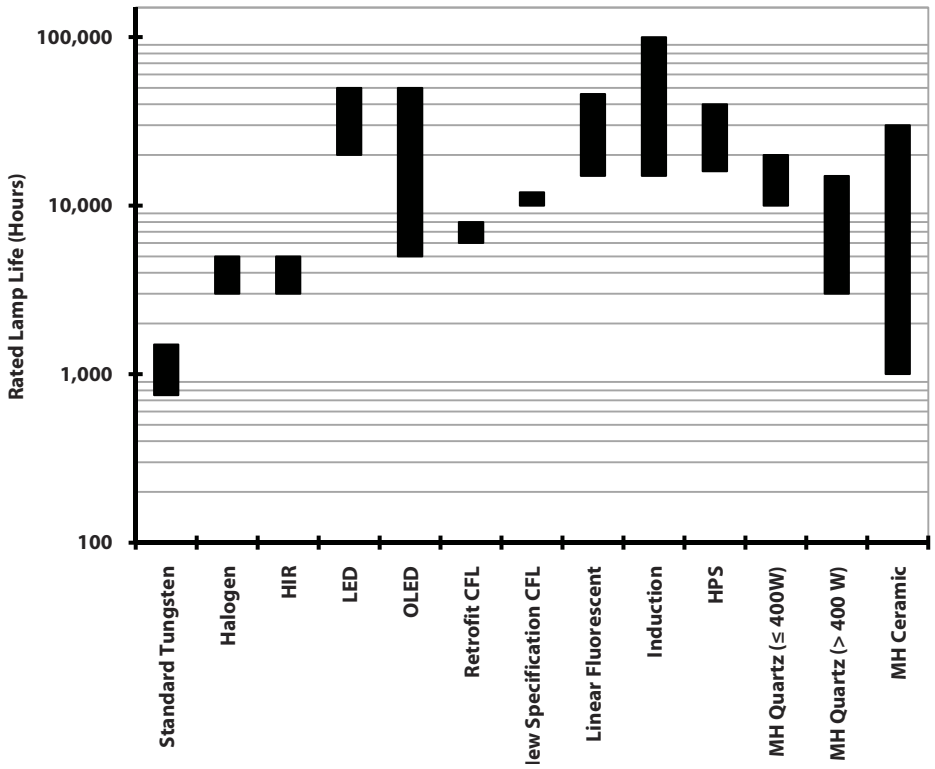


Figure 13.1 | Rated Lamp Life
Shown are the ranges for typical lamp life in hours for various electric light sources. All ranges are for full lumen output. Dimming may increase, decrease, or have no effect on lamp life; see Tables 13.1a and 13.1b for lamp life versus dimmming trends.

a particular percentage of initial lumens. Most common for LEDs, is to employ a time at which they are estimated to produce 70% of initial lumens, a time known as L_{70}. This method of defining LED lamp life assumes that LED lamps that fail catastrophically will be replaced (see 7.5.6.3 Failure Mechanism). Most common for Organic LEDs (OLEDs), is to employ a time at which they are estimated to produce 50% of initial lumens, a time known as L_{50}.

All light sources lose some ability to produce optical radiation over their operating lives. This loss varies with the type of light source and is known as lamp lumen depreciation (LLD). The ability of a light source to maintain its ability to produce optical radiation is the converse of LLD, and is known as lumen maintenance. For example, specification grade T8 linear fluorescent lamps generally have lumen maintenance greater than 90% at end of life, corresponding to an end-of-life loss of 10% of initial lumens. T5 and T5HO lamps generally have lumen maintenance greater than 95% at end of life, corresponding to an end-of-life loss of 5% of initial lumens. For LEDs, L_{70} corresponds to an end-of-life loss of 30% of initial lumens.

Depending upon the type of light source and manufacturer, lumen maintenance is specified in different ways. Commonly, initial and mean lumen values are provided. Initial lumens are measured after a period of lamp seasoning. Mean lumens are the expected number of lumens emitted at some percentage of rated life, typically taken to be 40% of rated life for fluorescent and metal halide lamps. With linear fluorescent lamps, the ballast choice (for example: instant, rapid, program start) and/or operating cycle (for example: 3 hours per start, 12 hours per start) may influence lamp life, and therefore the profile of LLD. For some tungsten-halogen and halogen-infrared lamps, lumen output at 40% of rated lamp life is approximately equivalent to the initial lumens. Mean lumen output is not reported for SSL products. Time to mean-lumens is taken as 50% of rated life for most other lamp types. [5] Refer to lamp specific data from the manufacturer.

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With all lamp families except SSL, LLD is commonly computed as a ratio of mean to initial lumens. The LLD factor is employed when performing calculations for maintained illuminance and/or other photometric quantities (see 10.7.1.2 Recoverable Light Loss Factors). This method should be expected to lead to installations that fail to deliver the design illuminance for the period beyond the percentage of rated life for which mean lumens is defined. For example, consider a 320W metal halide lamp with a rated life of 20,000 hrs, initial lumens of 31,000 and mean lumens of 18,000. LLD may be computed as 18,000 ÷ 31,000 = 0.58. Even when this value is employed as part of a design calculation, the illuminance should be expected to drop below the target illuminance after 40% of rated life has elapsed, which corresponds to 8,000 hrs (20,000 hrs × 0.40 = 8,000 hrs).

LM-80 was developed by IES to provide a standard method for lumen maintenance testing of SSL products [6]. It is one of a continuing series of IES approved methods, which are written to permit consistent results among laboratories by establishing uniform test methods. LM-80 codifies the measurement method for lumen maintenance of LED sources, which is defined to include *LED packages*, *LED arrays*, and *LED modules*.

LED Package An assembly of one or more LED dies that contains: wire bond connections; possibly an optical element; and thermal, mechanical, and electrical interfaces. The device does not include a power sources, does not include an ANSI standardized base, and is not connected directly to the branch circuit.

LED Array An assembly of LED packages on a printed circuit board or substrate, possibly with optical elements and additional thermal, mechanical, and electrical interfaces. The device does not contain a power source, does not include an ANSI standardized base, and is not connected directly to the branch circuit.

LED Module A component part of an LED light source that includes one or more LEDs connected to the load side of an LED power source or LED driver. Electrical, electronic, optical, and mechanical components may also be part of an LED module. The LED module does not contain a power source and is not connected directly to the branch circuit.

Direct View Application A lighting design application where the lamps and/or luminaires are intended to be viewed directly, as opposed to being employed for the general illumination of people or objects. Examples include sparkle effects, navigational markers, and media walls.

LM-80 defines "rated lumen maintenance life" (L_p) for LEDs as the elapsed operating time over which the LED light source will maintain the percentage, p, of its initial lumen output. For example, L_{70} is the time in hours to 70% lumen maintenance, and L_{50} is the time in hours to 50% lumen maintenance. The design application governs which value may be more appropriate for which application. L_{70} is appropriate for general illumination applications, whereas L_{50} may be appropriate for some decorative applications where the quantity of lumens is of minimal importance.

LM-80 is a standard method for actual measurement of rated lumen life. It does not provide guidance or make recommendations regarding predictive estimations or extrapolation. To place this in context, there are 8,760 hours in a year. A 50,000-hour lamp life corresponds to 11-years of operation at 12-hours-per-day. The rapid introduction of new LED products means that manufacturers employ modeling to make predictions about product characteristics that are dependent upon the hours of operation, including lumen maintenance, shift in dominant wavelength, and lamp life.

A LLD of not greater than 0.70 should be employed for SSL products in applications where the quantity of light is a key design criterion. A less conservative approach may be taken when the quantity of light is a less important design criterion, such as for a decorative or *direct view application*. This less conservative approach employs the traditional LLD model:

1. Choose the appropriate L_{xx} based on the application. Note that L_{xx} defines the lifetime at which the LEDs should be considered to have failed and require replacement.

2. Compute the life to mean lumens (LML) in hours, based on the appropriate L_{xx} determined in step (1) using the equation: LML= L_{xx} x 0.40

3. Attain the LLD curve for the LED product being considered. Such curves are available from manufacturers. An example is provided as Figure 7.53. Given the rapid pace of new product development, these curves will be based on predictions into the foreseeable future.

4. Draw a vertical line from the LML computed in step (2) to the intersection of the LLD curve attained in step (3). Read the vertical axis to find the appropriate LLD.

The above method should be expected to lead to installations that do not deliver the design illuminance for the final 60% of system life. Neither method (that is: selecting a LLD of 0.70, or using a ratio of mean to initial lumens) accounts for catastrophic failures, which require spot replacement. This method also does not account for parametric failure (see 7.5.6.3 Failure Mechanism) such as color shift.

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Lumen depreciation is accompanied by a decline in luminous efficacy for all lamp types. The rate of change depends upon the profile of LLD. See 13.2 Efficacy and Figures 7.24, 7.33, and 7.40.

Lamp life is not affected by the number of starts for filament and SSL lamps. Published life for fluorescent and HID lamps is based on the operating cycle. The standard operating cycles are 3 hours on / 20 minutes off for fluorescent lamps [7] [8] and 11 hours on / 1 hour off for HID lamps [9]. Manufacturers may report life based on different operating cycles, especially when lamps are intended for applications where these operating cycles would be atypical. For example, the rated life for many 1500 W metal halide lamps intended for sports lighting is based on five or more hours per start. Lamp life typically increases with operating time per start for fluorescent and HID lamps.

13.4 Auxiliary Equipment

With the exception of line-voltage tungsten filament lamps, all other light sources require auxiliary equipment: low-voltage filament lamps require a transformer; fluorescent and HID lamps require a ballast; induction lamps require a high frequency generator; and SSL lamps require a driver and some also require a transformer. These auxiliary components are discussed in the respective sections of 7 | LIGHT SOURCES: TECHNICAL CHARACTERISTICS. Control strategies include: on/off switching; dimming; digital scene control; daylight integration that may incorporate electric lighting control and shade control; occupancy sensing and control; time control; task tuning; lumen maintenance tuning; demand response; centralized network control; and distributed control. These control strategies are discussed in 19.2 Lighting Control Strategies. From the vantage point of the lamp all of these control strategies fall into one of two categories, switching or dimming, albeit with different cycle times. The auxiliary equipment and control strategy choices affect the performance and operating characteristics of different lamp types. Salient considerations include: dimming performance; lamp life; efficacy; lumen output; color; and noise.

Light sources have very different dimming performance, which depends strongly on the specific lamp type, auxiliary components (for example: ballast, driver), and control gear. Table 13.3 lists key performance considerations and rates lamps with green circles (typically good for most lamps in the family), orange diamonds (ranges from good to bad, exercise caution), or red exes (poor performance).

Filament lamps dim smoothly from 100 – 0% lumen output. Fluorescent lamps cannot be dimmed to zero lumen output. Some types, such as screw-based dimmable CFLs, extinguish when dimmed to 30 – 40% output. Screw-based dimmable CFLs also have very different chromaticity shifts as they dim, compared to the incandescent lamps they are intended to replace, as illustrated in Figure 13.2 [10]. Premium dimming equipment is available for the most common linear fluorescent lamps that permits dimming to as low as 0.5% of maximum lumen output. HID lamps cannot be dimmed below 50% without compromising life or creating considerable color shifts. Theoretically, LEDs can be dimmed from 100 – 0%, in steps that are impercetible, and without flicker. As of publication, few products have this capability. When making an LED specification decision, it is prudent to inquire about dimming performance and/or evaluate samples of all components, including the *LED luminaire*, driver, and end-use control device.

LED Luminaire A complete LED lighting unit consisting of a light source and driver together with parts to distribute light, to position and protect the light source, and to connect the light source to a branch circuit.

The life of most fluorescent lamps is affected by the ballast starting method. Some manufacturers provide figures or tables that summarize lamp life as a function of ballast starting method and operating cycle. One such example is provided as Figure 13.3, which illustrates that the lamp/ballast combination may affect T8 lamp life by greater than 50%. In applications that cycle fluorescent lamps frequently, as with occupancy sensors,

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Table 13.3 | Dimming Performance Ratings

Performance Consideration	Description	Filament	Screw-Based CFL[b]	Pin-Based CFL	Linear Fluorescent	HID	SSL
Dimming Range	Ability to reduce output to a very low level, often expressed as a percentage of full lumen output	●	✖	◆[f]	●	●[g]	◆
Smoothness	Lumen output changes should be smooth without flicker or pulsing, and all lamps on the control device should track together when output is adjusted	●	◆	●	●	●[g]	◆
Starting and Warm-Up	Ability of lamps to turn on at the minimum output setting, and also the ability to reach maximum output quickly	●	◆[c]	●	◆	◆[h]	◆
Stability of Lumen Output	Lumen output should not change without user intervention, and there should be no flicker or pulsing	●	◆	●	●	●[g]	◆
Integration with Controls	Ability of lamp and auxiliary gear to integrate with occupancy sensors, building automation systems, etc.	●	◆[d]	●	●	◆[i]	◆
Color Shift	Stability of CCT and CRI as a function of dimming	◆[a]	◆[e]	●	●	◆[g]	◆
Life	Lamp life not decrease as a result of dimming	●	◆	◆	●	●	●
Noise	The lamp and auxiliary gear should be nearly inaudible over the entire dimming range	◆	●	●	●	◆	●

a. Significant shift toward warm with dimming, which many find desirable.
b. Applicable only to the limited types that are capable of dimming.
c. Starting is nearly instant, warm-up is delayed by amalgam technology.
d. May not be compatible with all incandescent dimmers.
e. Color shift performance is very different than that of incandescent they are intended to replace.
f. Only 4-pin lamps are capable of dimming, performance depends on ballast and lamp.
g. Range, smoothness, stability, and color shift are not to the standards of linear fluorescent, but performance is adequate for most HID dimming applications.
h. Must be energized at full output and allowed to stabilize before dimming.
i. More complicated integration with building automation systems than fluorescent.

programmed start ballasts should be employed instead of instant start ballasts (see 7.3.6.5 Ballasts). For HID installations that employ occupancy sensors, lamps should be dimmed when the space is unoccupied, since extinguishing the lamps would require restrike and warm-up when the space is again occupied. HID lamps should be dimmed to not less than 50% of full output, which has no appreciable effect on their lamp life. Filament and LED lamp life is not affected by operating cycle. Dimming extends filament lamp life, but at the expense of efficacy. Dimming may extend LED lamp life, but only if the dimming is accompanied by a reduction in junction temperature, which is the principal determinant of LED lamp life.

Electronic ballasts and drivers are nearly inaudible at full output or when dimmed, and are unlikely to cause noise problems in typical commercial interiors. With magnetic ballasts, dimming may create vibrations in the plates of a transformer. The resulting hum is not typically problematic for applications that employ HID dimming, such as warehouses and parking garages, since these applications tend to have other background noise and dimming is often restricted to unoccupied times.

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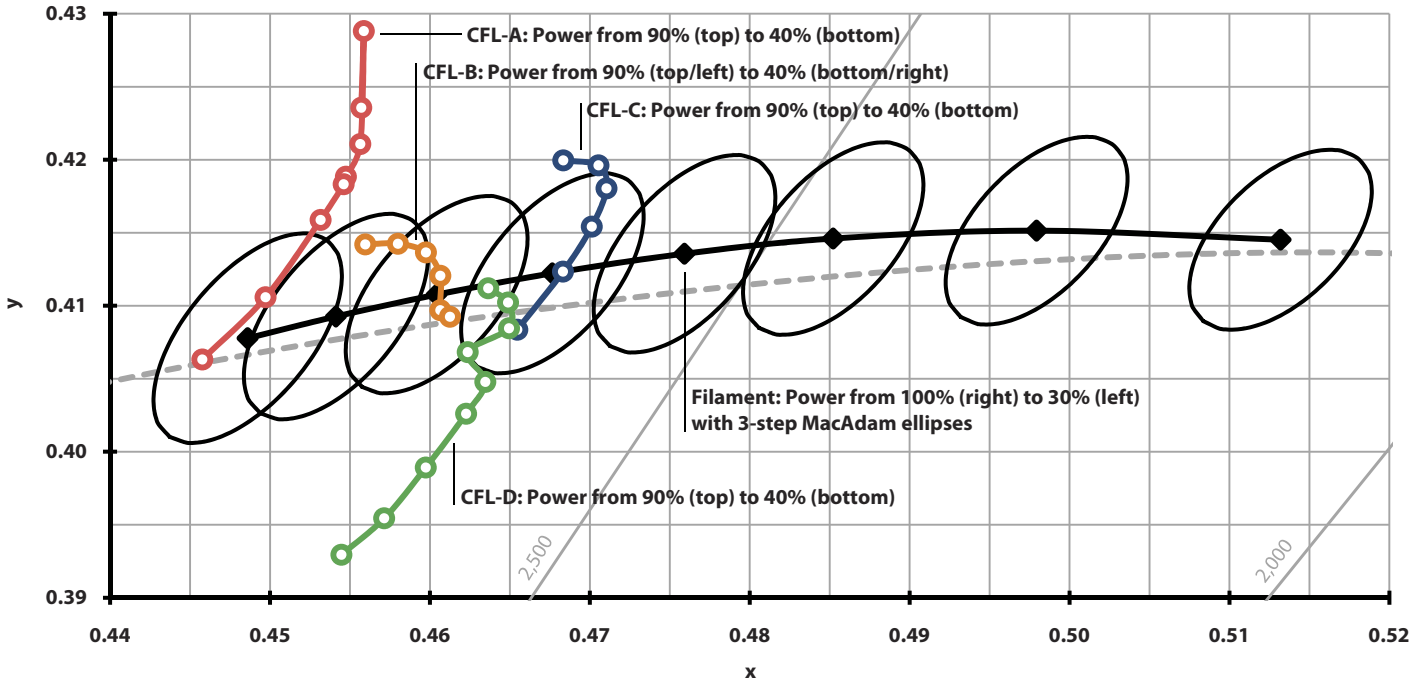


Figure 13.2 | Dimming and Chromaticity Shift of Filament and Screw-Based CFL Lamps
Three-step MacAdam ellipses for an incandescent lamp shown in 10% dimming increments from 100% to 30% power, along with the chromaticity shift for four different brands of screw-based dimmable CFL lamps [7].

Electronic dimming of filament lamps may cause filament vibration, which creates an audible buzz (see 7.2.5.2 Dimming). Some cooling strategies for LED heat sinks rely on forced air, either with fans or pulsing membranes. Some low-voltage power supplies, which may be used to power LEDs or low-voltage filament sources, also employ fans to cool internal parts. Even in products that employ quiet fans, the sound of moving air may be problematic in environments where it is desirable to minimize background noise. When considering these products for acoustically sensitive spaces it is prudent to evaluate product samples and coordinate with an acoustics consultant.

13.5 Starting and Restrike

LEDs and filament lamps are instant on and can be rapidly switched with no deleterious effect on performance. It is even possible to switch LEDs at such high frequencies that digital signals can be transmitted, unnoticed by human vision. Fluorescent lamps turn on instantly or within a few seconds, depending upon the ballast starting method. The warm-up time for all fluorescent lamps depends upon ambient temperature. Fluorescent lamps may require special ballasts for cold weather starting. Restrike for fluorescent lamps is nearly instant. HID lamps are insensitive to ambient temperature once they are started, but may need special ballasts for cold weather starting in severe climates. While starting occurs in a matter of seconds, HID lamps require from several to more than 10 minutes to reach greater than 90% of full lumen output. Once extinguished, HID lamps need to cool down before they can restrike and return to full output. The time to usable light output varies from several minutes for HPS lamps to greater than 20 minutes for some types of metal halide lamps.

When HID lamps are employed for general lighting the emergency lighting must have instant-on capabilities, and must remain active through restrike and warm-up rather than switching off when power is restored. See 16.4 Integration with Emergency Lighting.

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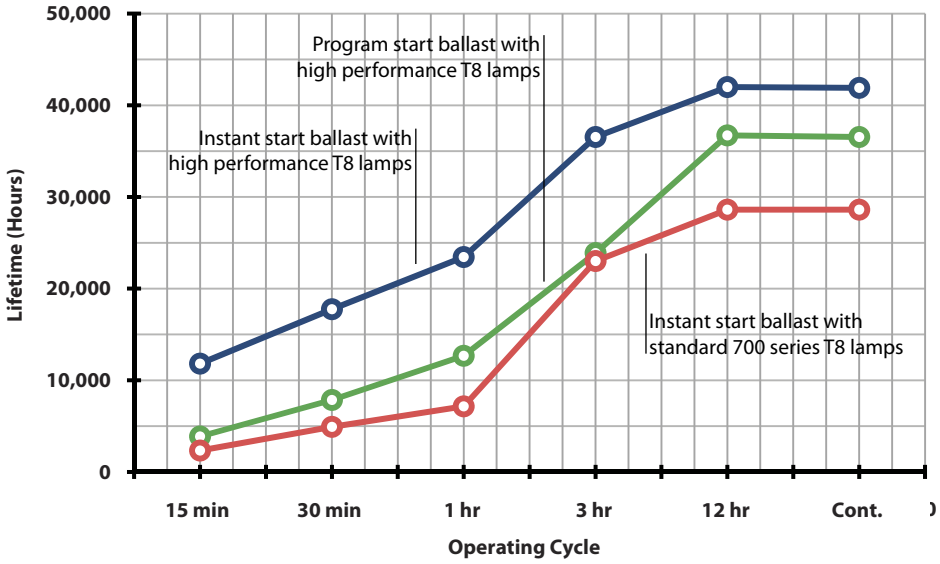


Figure 13.3 | T8 Linear Fluorescent Lamp Life versus Ballast Starting Method and Operating Cycle
While trends like these are likely to hold, these data should not be generalized for all linear fluorescent products. Verify data with lamp and ballast manufacturers.

13.6 Color

Salient specification considerations related to color include: color rendering (see 6.3 Color Rendition); color temperature (see 6.2.5 Color Temperature and Correlated Color Temperature); color uniformity and stability (see 6.2 Color Specification: CIE System and 7.4.8.4 Color Uniformity and Stability); and color saturation potential (see 6.2.4 Dominant Wavelength, Excitation Purity, and Complimentary Dominant Wavelength).

Tables 13.1a and 13.1b provide a summary of CCT, CRI, and qualitative rankings and commentary for color uniformity and stability. Additionally, Figure 13.4 provides the typical range of CCT for common lamps and Figure 13.5 provides the typical range of CRI. Additional details are provided in the relevant sections of 7 | LIGHT SOURCES: TECHNICAL CHARACTERISTICS.

13.7 Directional Intensity

Many light sources are *omnidirectional*. Examples include linear fluorescent, CFLs, and the ED and BT shaped HID lamps. These light sources do not incorporate integral optical components. They are intended to be employed in luminaires that redirect the lamp lumens toward the target to be illuminated.

Omnidirectional Emission of radiation in all directions. A special case of omnidirectional is isoradiant, which is the emission of the same quantity of radiation in all directions. A frosted GLS incandescent lamp is nearly isoradiant, except that radiation is less in the direction of the base.

Other light sources incorporate a reflector and/or refractive lens as integral components, including some halogen IR filament and ceramic metal halide lamps. Common bulbs include the PAR, MR, and AR shapes. While luminous flux is an important performance parameter for characterizing the optical radiation output of omnidirectional lamps, important parameters for reflector lamps are maximum center beam luminous intensity (commonly called candlepower) and beam angle, as diagrammed in Figure 7.22 | Beam Angle. Most LED packages have a refractive lens that purposely shapes the emission distribution of luminous flux, including side-emitting, diffuse-emitting, and various beam patterns from narrow to wide.

Directional light sources may outperform omnidirectional light sources even when their efficacy is lower. This is because when omnidirectional light sources are installed in luminaires, it is typical for a greater fraction of the lumens to be lost to absorption than with directional lamps. Consider, for example, two downlights with identical apertures

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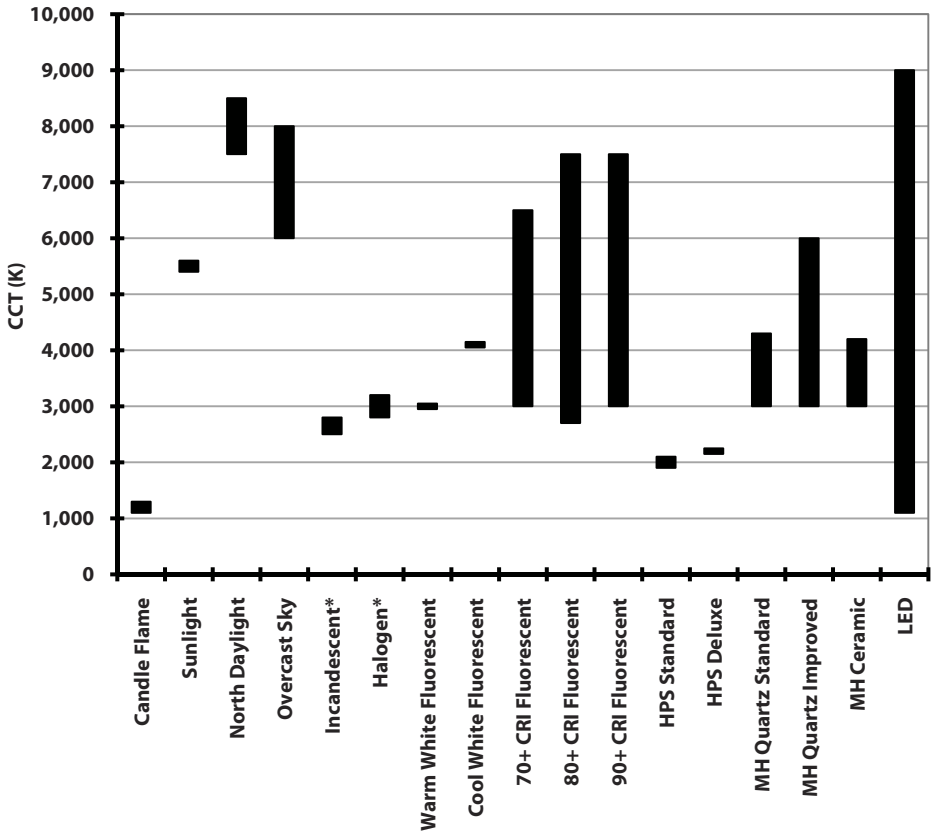


Figure 13.4 | Typical CCT Ranges
Shown are the range of typical CCT in kelvin for daylight and various electric light sources. *Incandescent and halogen values are at full output; dimming lowers CCT for filament lamps.

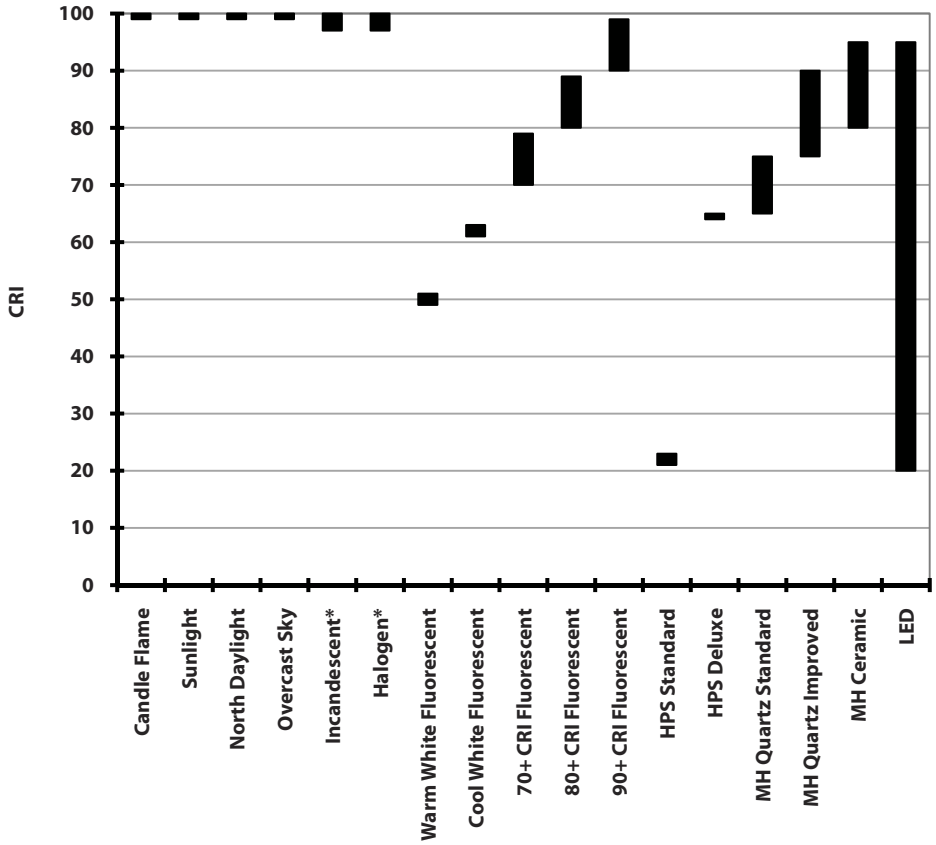


Figure 13.5 | Typical CRI Ranges
Shown are the range of typical CRI for daylight and various electric light sources. Incandescent and halogen values are for standard glass envelopes; colored or doped glass filament lamps have lower CRI.

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Table 13.4 | Types of Efficacy for CFL and SSL Downlights

Performance Characteristic	(2) 18W Quad Tube CFL[a]	(1) 32W Triple Tube CFL[a]	LED[a, b]
Cutoff	55°	55°	50°
CRI	82	82	78
CCT	2700 - 4100		3000
Spacing Criterion[c]	1.3/1.6	1.4	1.2
CBCP[d]	588	679	1000
Total Lamp Lumens	2500	2400	N/A
Total Lamp Watts	36	32	N/A
Lamp Efficacy	**69.4**	**75.0**	**N/A**
Input Watts to Ballast	39	36	N/A
Ballast factor	1.05	0.98	N/A
Input Watts to Driver	N/A	N/A	26.9
System Efficacy	**67.3**	**65.3**	**N/A**
Luminaire Efficiency	50.2%	62.2%	N/A
Lumens Exiting Luminaire	1316	1463	1426
Luminaire Efficacy (New Lamps)	**33.7**	**40.6**	**53.0**
Lumen Maintenance at End of Lamp Life	0.86[e]	0.86[e]	0.70
Luminaire Efficacy (End of Lamp Life)	**29.0**	**35.0**	**37.1**

a. 6″ aperture and specular Alzak® aluminum finish. Not representative of all CFL or LED products.
b. Current as of publication for remote phosphor technology. Not representative of all LED products.
c. The spacing criterion (SC) may govern the design when uniformity is desired. In this example, additional LED downlights may be required since it has a lower SC than the CFL downlights.
d. Center beam candlepower in units of candela.
e. Group relamping at 70% of rated lamp life is recommended for CFL lamps.

and reflector trims, one that employs a CFL lamp and the other LEDs. CFL lamps are omnidirectional and comparatively large; a large fraction of the lamp lumens is absorbed within the luminaire. LEDs are directional and small; a much smaller fraction of the lumens is lost to absorption. Even though, as of publication, the efficacy of CFL lamps is typically greater than that of LED lamps, luminaire efficacy can be lower. Table 13.4 provides quantitative details for one such example.

13.8 Physical Environment

Ambient temperature sensitivity is summarized in the last column of Tables 13.1a and 13.1b. Filament lamps are insensitive to ambient temperature, fluorescent lamps are optimized for a specific ambient temperature, HID lamps are essentially insensitive to ambient temperature once they are started, and LEDs are susceptible to early failure if the p-n junction temperature is allowed to exceed a specified level (typically 125° C).

T8 lamps are optimized for an ambient temperature surrounding the lamp of 25° C (77° F), whereas T5 and T5HO lamps are optimized for 35° C (95° F) operation. Higher or lower temperatures lead to a reduction in lumen output, as illustrated in Figure 13.6. Since linear fluorescent lamps consume the same power irrespective of temperature, these curves also illustrate the trend in efficacy as a function of ambient temperature. The higher temperature optimization for T5 lamps is intended to take advantage of heat buildup in enclosed or compact luminaires. In open luminaires, as with indirect and direct/indirect luminaires, the ambient temperature at the lamps may not reach 35° C and T8 lamps may perform better.

Fluorescent and HID lamps require special ballasts to start in cold weather. Fluorescent lamps may also need to be sleeved with a clear jacket in order to maintain suitable localized ambient conditions. With HID lamps, the outer bulb provides a stable thermal environment once the lamp is started. See also 13.5 Starting and Restrike.

Filament, fluorescent, and HID lamps dissipate their heat primarily through radiation, which in commercial building interiors either minimizes the space heating requirements, or more typically, adds to the cooling load. The split between radiation, convection and conduction is important when simultaneously optimizing lighting and mechanical system design [11]. LEDs dissipate their heat primarily through conduction, necessitating heat sinks to conduct heat away from the p-n junction; in some cases active cooling is also employed to provide forced convection.

When a lamp is to be employed in a damp location, brass bases should not be used; nickel or nickel-plated-brass offer better corrosion resistance.

13.9 Damage and Physical Harm

Short wavelength optical radiation has greater photon energy than long wavelength optical radiation, and greater potential to damage people and objects. Figure 13.7 illustrates the range of microwatts of UV per lumen for various light sources, where UV is considered to be optical radiation below 400 nm [12]. Because damage is also dependent upon the *action spectrum* of the receiving material—whether an art object, merchandise, or human skin—Figure 13.7 cannot be used alone to assess damage. A full assessment of damage potential requires knowledge of the optical radiation spectrum generated by the source (see 1.4.2 Spectral Power Data) and the spectrum absorbed by the material (see 6.1.3 Object Color). It may also be necessary to account for a luminaire lens or cover glass, which may have a spectrally selective transmittance, and will attenuate the optical radiation.

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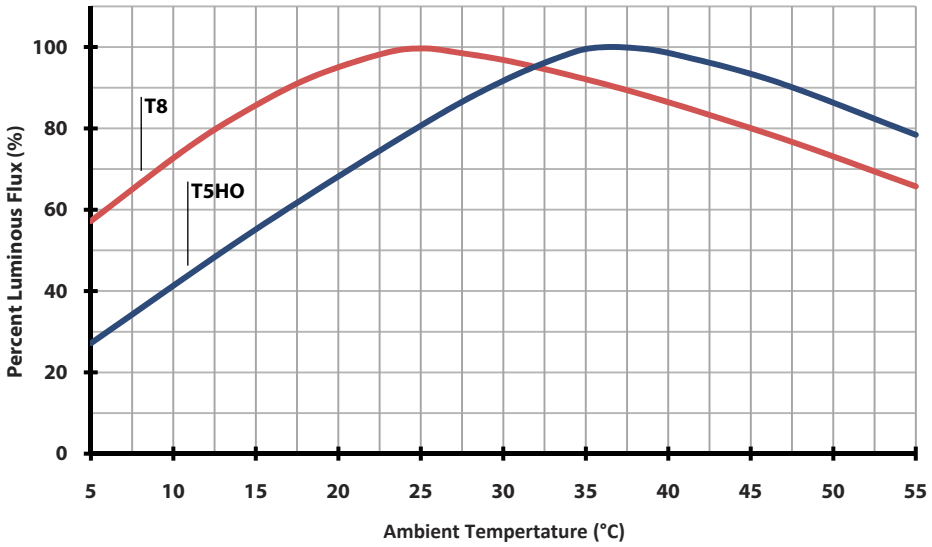


Figure 13.6 | T8 and T5HO Relative Output versus Ambient Temperature
Illustration of the different optimization as a function of ambient temperature for T8 and T5HO lamps

13.9.1 Potential Damage to Objects

Conservation considerations are especially relevant when sensitive objects are being illuminated, as with museum paintings, textiles, tapestries, furniture, rare books, scrolls, and other *organic* objects. Optical radiation may cause damage through photochemical action and radiant heating.

Action Spectrum The efficiency with which electromagnetic radiation produces a photochemical reaction as a function of the wavelength of the radiation.

Photochemical action is the process by which a molecule undergoes a chemical change as a result of absorbing a photon. Materials differ significantly in their response to optical radiation exposure. While photon absorption is independent of the surrounding environment, environmental factors such as temperature and humidity affect the chemical actions that occur after a photon has been absorbed. Possible effects of photochemical action include: color change, yellowing, fading, darkening, loss of strength, brittling, and surface cracking. Photochemical action is influenced by: quantity of irradiance; duration of exposure; SPD of the incident radiation; and action spectrum of the receiving material. [12]

Organic materials are partially made up of compounds of carbon, as with those derived from plants or animals. Nature has provided processes to dismantle organic materials in order to recycle the molecules that are building blocks of life on earth. Inorganic materials do not have hydrocarbons or their derivatives in their makeup, and do not have the structure or organization characteristic of living bodies. Breakdown of inorganic materials tends to occur more slowly than with organic materials.

Radiant heating is the increase in surface temperature caused by the absorption of radiant energy. Temperature elevation encourages chemical activity that may be damaging, such as dimensional changes, which may be particularly damaging where materials have different coefficients of thermal expansion. One example is a museum painting comprised of pigment on a substrate, and a varnish over the pigment. Partial shadowing of the painting, as may occur if the painting is inset into a frame, may cause differential heating effects in the shadowed area. On/off switching may cause cyclic expansion and contraction, and moisture migration, which leads to effects similar to that caused by photochemical action, including discoloration and cracking.

Color change may be characterized in the CIE LAB color space using color difference formula (see 6.2.3 Color Difference). Formulae for quantifying color shift as it relates to museum objects are provided in CIE publication 157, which also provides numerical procedures for assessing and quantifying potential damage from optical radiation [12]. Cuttle provides clear descriptions of the many considerations that must be balanced when designing the lighting for museum displays, including a discussion of potential damage caused by optical radiation [13].

13.9.2 Potential Damage to People

Optical radiation has the potential to damage the retina and skin if present in sufficient quantities. Damage to the retina may occur in one of three ways: mechanical damage

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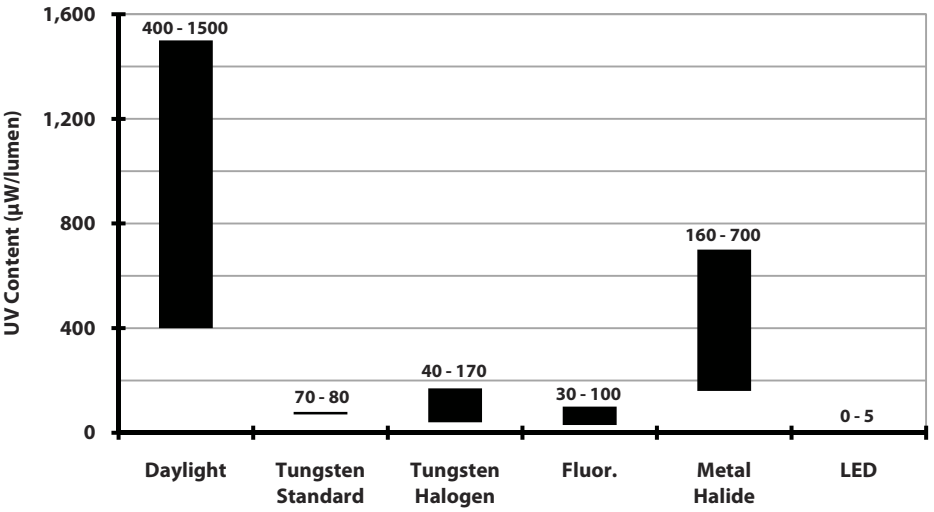


Figure 13.7 | UV Content
Shown are the range of typical UV content in units of µW/lumen for daylight and various electric light sources [8].

from intense rapidly pulsed lasers, radiating heat effect, and photochemical action [14]. Mechanical damage can only occur in the presence of specialized lasers; it is not generally relevant to architectural lighting. Radiating heat effect can cause damage by increasing the temperature of the retina as a result of absorption of radiation. It can be triggered by high wattage light sources focused directly on the retina, such as the beam from a xenon arc lamp or the sun. This is not generally a concern for architectural illumination, but may be relevant for anesthetized patients, or patients with artificially dilated pupils that are undergoing eye surgery [15]. The third mechanism, also known as photoretinitis [16] or the "blue light hazard", recognizes that optical radiation may be the catalyst for deleterious chemical reactions among retinal components.

The effective blue light hazard radiance of a source is calculated by weighting the source spectral radiance by the retinal blue light hazard function B(λ), which peaks between 435 and 440 nm [17]. In determining a permissible exposure there is a tradeoff between quantity of light and time. Higher quantities of light viewed for shorter periods of time are considered to pose the same hazard as lower quantities of light viewed for a longer time. Permissible exposure limits are based on a maximum value for the product of effective blue light hazard radiance and time. The limits are set through a consensus process and summarized in RP-27.1 [17] and RP-27.3 [18]. See also 3.3 Effects of Optical Radiation on the Eye.

Damage to human skin may be caused by excessive exposure to UV optical radiation. This type of skin damage is a form of *erythema* and is commonly called sunburn, though it can also be caused by UV radiation from welding arcs, tanning lamps, blacklights that emit UV-B, some metal halide lamps (especially those with broken outer bulbs), and germicidal radiators. The UV Index is an international standard of measurement that is used to characterize the strength of UV radiation from the sun at a particular place and time. An index of zero corresponds to zero UV radiation and an index of 10 roughly corresponds to sun exposure at midday under a clear sky. The index corresponds to risk levels that are low (0-2), medium (3-5), high (6-7), very high (8-10), and extreme (≥11). The UV index is primarily used in daily weather forecasts aimed at the general public, but can also be employed to characterize the UV exposure from electric light sources. The process employs the McKinlay-Diffey erythema action spectrum [19] to weight the SPD of UV radiation [20]. See also 3.4 Effects of Optical Radiation on the Skin.

Erythema Abnormal redness of the skin due to dilation and congestion of the capillaries, and often associated with inflammation or infection.

IEC 62471 Photobiological Safety of Lamps and Lamp Systems is an international standard that gives guidance for evaluating lamps and luminaires. It specifies exposure limits,

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measurement techniques, and a classification system for evaluating the photobiological hazard from sources of optical radiation (excluding lasers) between the wavelengths of 200 to 3000 nm. A second document in the series provides guidance on manufacturing requirements. [21] [22]

13.10 Lamp Geometry

Lamp geometry considerations include the physical size and shape of the outer bulb and/or light emitting element, and how the light emitting element is coupled to the optical components of the luminaire.

Some lamps, such as quartz metal halide, are available in the same physical size, but with different wattages and lumen outputs. For example, metal halide lamps with the ED28 outer bulb shape are available in 150, 175, 250, 320, 400 watts. With other lamp families greater lumen output is typically associated with larger lamps. For example, with fluorescent lamps, an increase in lumen output is typically achieved with an increase in the surface area of phosphor and thus greater lumen output is associated with larger lamps. There are exceptions: fluorescent lamp tubes may be bent to reduce the maximum overall length (for example: U-bent lamps, CFLs) or the phosphor loading may be increased to increase lumen output per unit area (for example, standard output T5 versus high output T5).

The most widely employed linear fluorescent lamps in new construction are T8, followed by T5. T2 lamps may be employed where a very small cross sectional diameter is advantageous. T12 lamp/ballast systems are not appropriate for new specifications; they have been superseded by T8 lamp/ballast systems. Other fluorescent lamp diameters are used in niche applications.

In applications such as projectors, fiber optic illuminators, and airport runway markers, it is especially important to ensure precise coupling between the light-emitting element (for example: filament, arc tube) and the luminaire reflector(s) and/or refractive lens(es). Lamps employed for these applications have a defined light center length (LCL), which is the distance from the center of the light-emitting element to a specified reference point on the lamp, which is usually a defined part of the base. Lamps with a defined LCL employ bases that dictate the position of the lamp within the luminaire, including the bayonet and prefocus bases. The physical dimension of a light source, extending to the tips of the electrical contact(s), is defined as the maximum overall length (MOL).

Smaller light sources tend to improve luminaire optical efficiency since there is less self absorption of optical radiation by the lamps themselves. For example, at the same physical size, a T5 luminaire will be more optically efficient than a T8 luminaire. Or, at equivalent optical efficiency, a T5 luminaire can be made smaller than a T8 luminaire. Smaller light sources and luminaires also require fewer raw materials, are often lighter, and tend to require less packaging and less fuel for shipping.

Consider clear and phosphor-coated metal halide lamps of the same wattage and bulb shape, installed in otherwise identical luminaires: optical efficiency will be worse in the luminaire with the phosphor-coated lamp. In general, the smaller the light emitting element—which may be a filament, phosphor coated bulb-wall, or arc tube—the better the optical efficiency of the luminaire. Small light emitting elements are also a requirement when a tight beam is required, as is necessary for long-distance projections and for creating defined spots of light.

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13.11 Sustainability

A full consideration of sustainability requires an analysis of at least: lamp components; materials consumed and discarded during manufacture; embodied energy associated with mining raw materials, manufacture, and transport; service life considerations such as efficacy, lumen maintenance, and life; and disposal considerations such as the ability to recycle spent lamps, and the potential for toxic components to leach out of municipal landfills. Figure 17.1 summarizes the primary inputs and outputs at each stage in a life cycle assessment.

At each stage from cradle-to-grave (or cradle-to-cradle), the full environmental impact includes such factors as: *global warming*; *acidification*; *eutrophication*; *photochemical ozone* creation; depletion of *abiotic materials*; and *human toxicity* [23]. There is no agreed upon method for assessing the full range of these tradeoffs, and some data (for example, embodied energy associated with manufacture) are proprietary and not available for publication. The balance of this section focuses on toxicity of lamp components, recycling, and cleanup of broken mercury-containing lamps. Chapter 17 | SUSTAINABILITY provides a broader discussion of sustainable lighting practices.

Global Warming The increase in the mean temperature of earth's atmosphere by the emission of greenhouse gasses that include carbon dioxide (CO_2) and methane (CH_4).

Acidification The loss of the nutrient base (for example: calcium, magnesium, potassium) in an ecosystem and its replacement with acidic elements. Acidification potential is dominated by nitrogen dioxide (NO2) and sulfur dioxide (SO2) emissions, which react with atmospheric water vapor to form "acid rain", causing ecosystem damage to flora, fauna, soil, and water.

Eutrophication Increase in the concentration of chemical nutrients in an ecosystem which leads to abnormal productivity for some species (for example, algae in rivers) that subsequently chokes out other species (for example, animal populations). It originates mainly from nitrogen and phosphorus in sewage outlets and fertilizers.

Photochemical Ozone Also known as smog, or ground-level ozone, it is formed by the reaction of volatile organic compounds and nitrogen oxides in the presence of heat and sunlight. It is toxic to humans in high concentrations.

Abiotic Materials Non-living chemical and physical components of the environment that underlie all biology, including optical radiation, temperature, water, atmospheric gases, and soil.

Human Toxicity Chemicals that pose a danger to humans through inhalation, ingestion, and contact, including mercury, arsenic, sodium dichromate, and hydrogen fluoride. These are caused primarily by fossil-fuel-based power consumption. The potential harm is based on the dose and the inherent toxicity of the compound.

Bioaccumulation The accumulation of a substance, such as a toxic chemical, in tissues of living organisms. It occurs when the rate of intake of a substance is greater than the rate of excretion or metabolic transformation of that substance.

13.11.1 Component Toxicity, the Universal Waste Rule, and Recycling

Most discharge lamps contain mercury, including all fluorescent and metal halide lamps, and most high pressure sodium lamps. Cadmium and lead are also present in some lamp types. Mercury and cadmium *bioaccumulate* in the environment. The mercury used in lamps may be in vapor, liquid or solid forms. It can enter the body through inhalation, ingestion, and skin absorption. Mercury that enters the body may be stored in the kidneys, or dispersed through the blood, spleen, brain, liver, bones, and fatty tissues. Low levels of exposure may cause irritability, excitability, shyness, and insomnia. Continued exposure can lead to violent muscular spasms. Acute exposure can cause profound effects on the nervous system, including psychotic reactions, suicidal tendencies, and delirium.

All mercury-containing lighting products are regulated by the U.S. EPA under the Universal Waste Rule (UWR), which is a subset of the Resource Conservation and Recovery Act (RCRA) Subtitle C hazardous waste regulations. The UWR streamlines the management of some common hazardous waste products, including batteries, some pesticides, thermostats, and lamps that contain mercury, cadmium, or lead. In general, the UWR prohibits the disposal of these products in municipal landfills.

Manufacturers have made significant mercury reductions since the 1990's and are continuing to make further reductions. Between 2001 and 2004 the total use of mercury in fluorescent lamps declined by 14% as a result of manufacturers' efforts to reduce the mercury content per lamp [24]. Recycling of mercury-containing lamps is strongly encouraged regardless of the mercury content. Good resources for information as of this writing include LampRecycle.org and the Association of Lighting and Mercury Recyclers (almr.org). Several states have adopted regulations that are more stringent than the UWR. As of publication, a state-by-state summary is provided at almr.org.

13.11.2 Cleanup of Mercury-containing Lamps

The US Environmental Protection Agency (EPA) provides guidelines for the clean-up of mercury from broken lamps. EPA suggests that the room first be aired out for at least 15 minutes, and for people and pets to avoid the area where the break occurred. All lamp parts should be handled without skin contact and placed in sealable plastic bags or glass jars. Cloth that has come in contact with the broken lamp parts should be discarded. Hard surfaces should be wiped. Vacuuming is generally not recommended since it will put mercury into the air, but vacuuming may be employed after all visible materials are removed.

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All clean up materials, including wiping cloths and the vacuum bag, should be placed in an outdoor trash receptacle. If recycling is mandated locally, the sealed jars or plastic bags with the broken lamp parts must be taken to the appropriate local facility. Recycling is always preferred, but if not mandated, the sealed jars or plastic bags with the broken lamp parts and clean up materials may be placed in an outdoor trash receptacle. EPA guidelines should be referenced for detailed procedures, which are periodically updated. [25]

13.12 Legislation

Legislation is enacted globally that will phase out low efficacy sources. Filament lamps are already used sparingly, if at all, in new commercial construction because of energy codes and sustainability initiatives. Since they are the least efficacious source for general illumination, legislation is expected to further restrict commercial application and greatly reduce residential application.

13.12.1 Luminous Efficacy Legislation

In the United States, the Energy Independence and Security Act of 2007 (EISA 2007) requires manufacturers to improve the efficacy and lamp-life ratings with progressively higher standards between 2012 and 2014. The performance requirements will effectively eliminate standard filament incandescent lamps beginning in 2012. EISA 2007 requires the US DOE to initiate two rulemakings, beginning in 2014, to consider whether the lamp standards should be made more stringent than the EISA 2007 levels. As of 2009, commercially available halogen-infrared lamps already met the 2014 requirements, though only in a fraction of the filament lamp categories summarized in Figure 7.26 | Taxonomy of Filament Lamps. Although halogen-infrared lamps are not yet widely employed, the legislation will likely drive a change in the market.

The EISA 2007 requirements apply to all general service lamps, including filament, compact fluorescent, LEDs, OLEDs, and "any other lamps that the Secretary determines are used to satisfy lighting applications traditionally served by general service incandescent lamps." If the 2014 rulemaking cannot produce savings that are greater than or equal to the savings from a minimum efficacy standard of 45 lumens per watt, effective January 1, 2020, then the sale of any general service lamp that does not meet a minimum efficacy standard of 45 lumens per watt will be banned. This is the only circumstance that may constitute a wholesale ban on a certain technology.

13.12.2 Legislation for 130V PAR Filament Lamps

In the past it was common to specify 130V lamps for 120V circuits in order to extend lamp life by operating the lamp in a continuously dimmed state. The US DOE rulemaking for 2012 standards may effectively eliminate this practice as it relates to PAR 20, 30, and 38 lamps. Table 13.5 illustrates that higher minimum efficacy standards will be required for 130V lamps than for 120V lamps.

13.13 Standards

Standards are especially relevant to light sources that require auxiliary equipment in order to ensure interoperability among components made by different manufacturers. Lamp standards in North America are developed primarily by: Illuminating Engineering Society (IES), National Electrical Manufacturers Association (NEMA), American National Standard Institute (ANSI), American National Standards Lighting Group (ANSLG), Next

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Table 13.5 | 2012 DOE Minimum Efficacy Rules for PAR Lamps

Lamp	Voltage	Spectrum	Minimum Efficacy Rule	Example: 100W LPW
PAR20	120	Standard	5.0 x (input power)$^{0.27}$	17.3
		Modified[a]	4.2 x (input power)$^{0.27}$	14.6
	130	Standard	5.7 x (input power)$^{0.27}$	19.8
		Modified[a]	4.9 x (input power)$^{0.27}$	17.0
PAR30, PAR38	120	Standard	5.9 x (input power)$^{0.27}$	20.5
		Modified[a]	5.0 x (input power)$^{0.27}$	17.3
	130	Standard	6.8 x (input power)$^{0.27}$	23.6
		Modified[a]	5.8 x (input power)$^{0.27}$	20.1

a. Modified is defined to mean the CIE 1931 (x, y) chromaticity coordinates lie at least 4 MacAdam steps (as referenced in IESNA LM-16) distant from the chromaticity coordinates of a clear lamp with the same filament and bulb shape, operated at the same rated voltage and wattage..

Generation Lighting Industry Alliance (NGLIA), Energy Star®, Federal Communications Commission (FCC), and other institutional entities. Standards related to electrical safety are developed primarily by: Underwriters Laboratory (UL), Canadian Standards Association (CSA), and the International Electrotechnical Commission (IEC).

Standards tend to lag behind product development. This should not be alarming; it is simply a consequence of new product development occurring prior to the standardization of those new products. It is not uncommon for novel light sources and auxiliary equipment to fall outside the parameters or scope of industry standards. In and of itself, this is neutral, and may occur because: 1) the product is innovative and there is not a standard with which to comply, 2) the product is innovative and operates in an acceptable manner, albeit different from the standard; 3) the product is deficient. In situations where standards are not met, it is prudent to validate performance claims and verify warranty information for all combinations of lamps and auxiliary gear under consideration.

In many locations it is necessary to employ equipment listed by either Underwriters Laboratory (UL) or the CSA International (CSA). Local requirements regarding UL or CSA listings may be especially problematic when retrofitting, since altering the interior components of a luminaire may void the original listing.

13.13.1 SSL

Because SSL products resemble both light sources and luminaires, existing standards for lamps and luminaires are not directly applicable to SSL products. New standards have been developed, or are in process of being developed, for many characteristics of SSL products,. Table 13.6 provides a summary that is current as of mid-2011.

13.13.2 High Performance T8 Lamps and Ballasts

A typical lamp catalog will list about 30 choices of F32T8 lamps that vary in wattage, lumen output, life, luminous efficacy, lumen maintenance, CRI, and CCT. These lamps can be combined with a similar number of ballasts that vary in starting method, ballast factor, dimming capabilities, number of lamps operated, size, and input voltage. The lamp/ballast combinations are nearly endless.

The Consortium for Energy Efficiency (CEE) launched an initiative for commercial lighting systems in 2004 with a focus on defining the characteristics of higher lumen, 4', 32W, T8 lighting systems. In 2007 CEE introduced a specification for reduced-wattage T8 sys-

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Table 13.6 | Industry Standards and Guides for SSL

Standard	Title	Description
IES LM-79	Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products	Describes the procedures to be followed and precautions to be observed in performing reproducible measurements of total luminous flux, electrical power, luminous intensity distribution, and chromaticity, of SSL lighting products for illumination purposes, under standard conditions.
IES LM-80	Approved Method: Measuring Lumen Maintenance of LED Light Sources	Provides the methods of measurement of lumen maintenance of sources including LED packages, arrays, and modules, under controlled conditions.
IES TM-16	IESNA Technical Memorandum on Light Emitting Diode (LED) Sources and Systems	A description of LED sources and systems, with answers to the most common questions that the lighting industry receives from the public.
ANSI/IES RP-16, Addendum a	Nomenclature and Definitions for Illuminating Engineering	Addendum a establishes definitions for SSL devices, their components, and performance characteristics.
ANSI/NEMA/ANSLG C78.377	Specifications for the Chromaticity of Solid-State Lighting (SSL) Products	Specifies the range of chromaticities recommended for general indoor lighting with SSL products that have control electronics and heat sinks incorporated. It is not intended to apply for outdoor products or for SSL products that produce colored light.
NEMA LSD 44-2009	Solid State Lighting—The Need for a New Generation of Sockets & Interconnects	A white paper that defines the need and opportunities for standardizing SSL sockets and interconnects to facilitite the transition of SSL to general illumination.
NEMA LSD 45-2009	Recommendations for Solid State Lighting Sub-Assembly Interfaces for Luminaires	A white paper focused on SSL sub-assembly interfaces for luminaires intended for use in general lighting. It is intended to lay the groundwork for a SSL interconnect standard by a standard development organization such as ANSI or IES.
NEMA LSD 49-2010	Solid State Lighting for Incandescent Replacement—Best Practices for Dimming	A white paper focused on integrated LED lamps intended for replacement of GLS incandescent lamps. Outlines characteristics of LED modules, power supplies, and controls that must be coordinated for satisfactory dimming performance.
NEMA SSL 3-2010	High-Power White LED Binning for General Illumination	Provides standardized categorization areas (bins) for colors of "white" LEDs for general illumination.
ANSI/UL 8750	Light Emitting Diode (LED) Equipment for Use in Lighting Products	Safety standard for testing UL products and related components.
IEC 62031	LED Modules for General Lighting—Safety Specifications	Specifies general safety requirements for LED modules with and without integral control gear.
IEC 62384	DC or AC Supplied Electronic Control Gear for LED Modules—Performance	Specifies performance requirements for electronic control gear for LED modules, to be used in conjuction with IEC 62031.
IEC/PAS 62612	Self Ballasted LED-Lamps for General Lighting Services—Performance Requirements	Specifies performance requirements for self-ballasted LED lamps together with the test methods for LED lamps that produce "white" light and are intended for domestic and general lighting purposes.
ENERGY STAR®	ENERGY STAR® Program Requirements for Solid State Lighting Luminaires	Criteria for the use of the ENERGY STAR® label for SSL products used for general illumination, including those with decorative functions. The labeling applies for residential and commercial products intended to be connected to the electric power grid.
NGLIA / DOE	LED Luminaire Lifetime: Recommendations for Testing and Reporting	Set of recommendations for reporting reliability of luminaire product lifetime, developed in part because the DOE Lighting Facts label does not provide lifetime information.
Zhaga	Consortium for the Standardization of LED Light Engines	Aims to standardize interfaces of many different light engines in the categories of: dimensional and mechanical, including "sockets"; power, insulation, and grounding; controls; photometry and colorimetry; and thermal. Finished standards will be offered to a standard development organization, such as IEC.

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tems. Specifications for both high performance and reduced wattage systems are available from the CEE website, along with product listings that meet the specifications [26].

The specifications are based on minimums for mean lamp/ballast system efficacy. Performance characteristics are defined for the lamp (that is: minimum values for CRI, initial lamp lumens, lamp life, lumen maintenance or mean lumens) and for the ballast (that is: minimum values for BEF, ballast frequency, power factor, and a maximum value for THD).

13.14 Cost of Light

Any consideration of costs must emphasize that the initial cost of the lamp is nearly always minor in comparison to the cost of energy to operate the lamps. In considering the life-cycle cost for general lighting after the initial installation, lamps typically represent less than 5%, with labor accounting for 5-10%, and the cost of energy accounting for the rest. When life-cycle costs drive decision making, and quantity of light is important, the efficacy of a lamp becomes more important than its replacement cost.

With filament lamps, dimming and under voltage operation are discouraged as energy saving strategies. The increased lamp life which accompanies reduced voltage does not begin to economically compensate for the loss in light output. With filament lamps it is better, in terms of cost per lumen-hour, to employ lower wattage lamps at full output than to dim higher wattage lamps.

In typical accounting, the concomitant costs on the environment are neither considered nor quantified. Some of these unaccounted costs include: the generation of greenhouse gasses associated with the manufacture, transportation, and operation of the product; the disposal of toxic byproducts employed during manufacture; and the extraction of raw materials from the earth used to construct the product.

13.15 References

[1] Tsao JY. Coltrin ME, Crawford MH, Simmons JA. 2010. Solid-state lighting: an integrated human factors, technology, and economic perspective. Proc. IEEE. 98(7):1162-1179.

[2] Bretschneider E. 2007. Efficacy limits for solid state white light sources, Photonics Spectra. 41(3):72-82.

[3] Stockwald K, Kaestle H, Weiss H. 2008. Significant efficacy enhancement of low wattage metal halide HID lamp systems by acoustically induced convection configuration. IEEE 35th International Conference on Plasma Science. Karlsruhe, Germany.

[4] NEMA LSD 54-2010. 2010. The strengths and potentials of metal halide lighting systems. Roslyn, VA: National Electrical Manufacturers Association. 8 p.

[5] IESNA DG-10-98. 1998. IESNA guide to choosing light sources for general lighting. New York: Illuminating Engineering Society. 16 p.

[6] IESNA LM-80-08. 2008. IES Approved method for measuring lumen maintenance of LED light sources. New York: Illuminating Engineering Society. 4 p.

[7] IESNA LM-40-01. 2001. IESNA approved method for life testing of fluorescent lamps. New York: Illuminating Engineering Society. 4 p.

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[8] IESNA LM-65-01. 2001. IESNA Approved method for life testing of compact fluorescent lamps. New York: Illuminating Engineering Society. 4 p.

[9] IESNA LM-47-01. 2001. IESNA approved method for life testing of high intensity discharge (HID) lamps. New York: Illuminating Engineering Society. 5 p.

[10] Hu X, Houser KW. 2003. Spectral and electrical performance of screw-based dimmable compact fluorescent lamps. Light. Res & Technol. 35(4); 331-342.

[11] Chantrasrisalai C, Fisher DE. 2007. Lighting heat gain parameters: experimental results. HVAC&R Research. 13(2);305-324.

[12] CIE. 2004. CIE 157:2004 control of damage to museum objects by optical radiation. Vienna, Austria: Commission Internationale de l'Éclairage. 29 p.

[13] Cuttle, C. 2007. Light for art's sake: lighting for artworks and museum displays. Oxford, UK: Butterworth-Heinemann. 304 p.

[14] Bullough JD. 2000. The blue light hazard: a review. J. Illum. Eng. Soc. 29(2); 6-14.

[15] Fisher KJ, Gehly J, Sliney DH. 1991. Surgical lighting: a review of ocular safety. J. Illum. Eng. Soc. 20(1); 28-31.

[16] Levin RE. 1998. Photobiological safety and risk–ANSI/IESNA RP-27 series. J. Illum. Eng. Soc. 27(1); 136-143.

[17] ANSI/IESNA RP-27.1-05. 2005. Recommended practice for photobiological safety for lamps and lamp systems–general recommendations. New York: Illuminating Engineering Society.

[18] ANSI/IESNA RP-27.3-96. 1996. Recommended practice for photobiological safety for lamps–risk group classification and labeling. New York: Illuminating Engineering Society.

[19] McKinlay AF, Diffey BL. 1987. A reference action spectrum for ultraviolet induced erythema in human skin. Human exposure to ultraviolet radiation: risks and regulations. Amsterdam, Netherlands: Elsevier. 83-87.

[20] ISO 17166:1999 (CIE S 007/E:1998). 1999. Erythema reference action spectrum and standard erythema dose. Geneva, Switzerland: International Standards Organization.

[21] IEC 62471 (CIE S 009:2002). 2006-07. Photobiological safety of lamps and lamp systems. Geneva, Switzerland: International Electrotechnical Commission.

[22] IEC/TR 62471-2. 2009-08. Photobiological safety of lamps and lamp systems-part 2: guidance on manufacturing requirements relating to non-laser optical radiation safety. Geneva, Switzerland: International Electrotechnical Commission.

[23] Osram Opto Semiconductors. 2009. Life cycle assessment of illuminants, a comparison of light bulbs, compact fluorescent lamps and LED lamps, executive summary. Berlin, Germany: Siemens Corporate Technology Center for Eco Innovations. 26 p.

[24] Mercury: Consumer and Commercial Products [Internet]. Washington (DC): Environmental Protection Agency (US); [updated 2010 Jun 21; cited 2010 Jun 24]. Available from: http://www.epa.gov/mercury/consumer.htm.

[25] Cleaning up a broken CFL [Internet]. Washington (DC): Environmental Protection Agency (US); [updated 2010 Jun 17; cited 2010 Jun 24]. Available from: http://www.epa.gov/cfl/cflcleanup.html.

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[26] CEE Commercial Programs: Commercial Lighting [Internet]. Boston (MA): Consortium for Energy Efficiency Inc.; [cited 2010 Jun 24]. Available from: http://www.cee1.org/com/com-lt/com-lt-main.php3.

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14 | DESIGNING DAYLIGHTING

Cheerfulness keeps up a kind of daylight in the mind, filling it with a steady and perpetual serenity.
Joseph Addison, 17th and 18th Century English Essayist and Poet

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Daylighting involves the delivery and distribution of light from the sun and sky to a building interior to provide ambient and/or task lighting to meet the visual and biological needs of the occupants. The design of a daylit building is a challenging task demanding an integrated design approach to simultaneously address occupant comfort, lighting quality, and energy efficiency across a wide range of daylight and weather conditions. This requires a thorough understanding of the sources of daylight and the role that architectural design, space planning, material selection, envelope loads, and systems integration play in daylight system performance and occupant comfort.

Daylight delivery systems include all elements that collect, transmit, reflect, control and distribute daylight to building interiors, which include the aperture, its glazing material, exterior and/or interior shading devices of all types, and any optical devices that help to direct or control daylight transmission or distribution to the interior while alleviating glare. The goal of most daylight delivery systems is to provide useful daylight to the visual tasks and room surfaces for a significant portion of the year, in an aesthetically pleasing, comfortable and energy efficient manner.

This chapter provides detailed discussions and guidelines on the design and performance of these systems. The content of this chapter and other sections of this handbook, including (7.2 Daylight (Light Sources), 19.3 Daylight Control and 19.4.6 Photosensors,) are of value to architects, electrical and mechanical engineers, interior designers, landscape architects, contractors, equipment and material manufacturers, as well as end-users such as building owners, developers, facility managers, and others. Each of these individuals plays a role in defining how a daylight system will perform.

14.1 Benefits of Daylighting

Daylighting, when designed correctly, can provide a wide range of benefits, including enhancements to the visual environment, the potential to improve worker occupant satisfaction and productivity, possible enhancement of circadian rhythm entrainment through exposure to higher luminances, and energy savings through a reduction of the electric lighting load [1].

14.1.1 The Visual Environment

Daylight can enhance an interior environment with luminance patterns that vary over time and space, creating visual interest that cannot be duplicated with electric sources. Daylight, with limited amounts of direct sunlight, is often used to enhance the appearance of large public spaces such as transportation concourses, lobbies and atria (see Figure 14.1). Daylighting makes a space more enjoyable for the occupants who may be waiting for a flight, transitioning between the exterior and the interior of a building, circulating within a building, or seeking a casual seating area. Direct sunlight generates interesting and dynamic shadow patterns across a space, while scattered light from the sky and reflected light from the ground provide highly beneficial diffuse daylighting.

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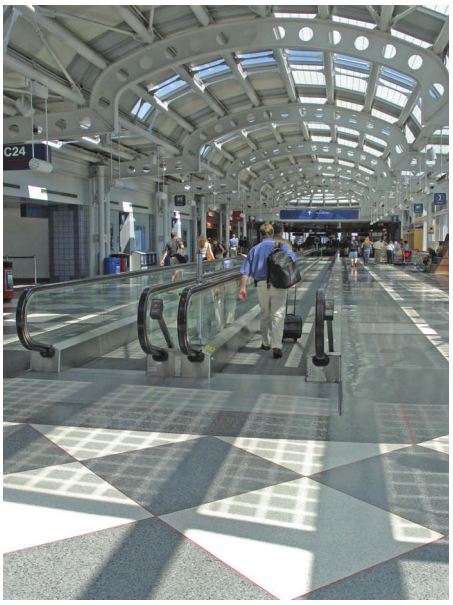


Figure 14.1 | Airport Concourse
Daylight enhances this space with a combination of diffusing fritted glass and transparent glazing. Note the rectangular frit pattern in the sunlight on the floor. The large diamonds are changes in floor material, while the small rectangles on the floor are created by frits on the glazing material. The frits reduce sunlight penetration and solar gain, and help to brighten the aperture at night. High reflectance finishes add to overall space brightness.
» Image © 2006 Ann Horn

Daylight enhances work environments with its continuous broadband spectrum that provides excellent color rendering, color matching and color discrimination under most sky conditions. Colors in a daylit space appear vibrant and true. Artists, museum designers, weavers, and others have historically relied on daylight for its color rendering qualities.

The general appeal of a daylit space includes an overall impression of brightness resulting from room surface luminances and illuminances that exceed those provided by an electric lighting system alone (See Figure 14.2). Daylight levels that reach many times what is required for space tasks, however, can create discomfort and increase the cooling energy required, and should be avoided.

Windows also help to connect people to the exterior world, adding visual interest, providing visual relief from demanding visual tasks, and extending the apparent boundaries of a space beyond its physical extents, further enhancing space quality.

14.1.2 Productivity and Worker Satisfaction

A view of the exterior provided through vertical windows located at or near eye height satisfies a major psychological need of most occupants. Research studies have shown higher performance in people whose work area is provided with a view [2]. The view out a hospital window has also been shown to affect patient recovery time [3] [4]. It is unclear exactly why view has these effects, although the view out a window is generally of much higher luminance than interior surfaces, and the connection to the exterior may help improve mood. In addition, the ability to focus vision on distant objects from time to time relaxes the eye's ciliary muscles. See Figure 14.3 for an example.

Since worker salaries are a much greater cost per unit of building floor area than energy or construction costs, even a small effect on productivity can be significant [5]. The higher levels of ambient lighting available through daylight can enhance visual performance for many tasks, provided that daylight control and work station layout achieve quality daylighting free of direct and reflected glare. As with any lighting design, daylighting must be tailored to the task or application. Lower room surface luminances and daylight levels may be required in spaces with significant computer use, for example.

A number of studies have investigated potential improvements in student learning in daylit schools as well as sales in retail environments with daylight (see Figure 14.4). The results of these studies have not been conclusive, given the difficulty of isolating the effect



Figure 14.2 | A Daylit Office
Daylight is available throughout this work space, entering via view windows. The narrow building plan and high reflectances permit the entire space to be illuminated with daylight. The south-facing windows on the left have operable exterior louvers that are adjustable and retractable to control direct sunlight and solar gain. Any direct sunlight admitted through these windows will be limited to the circulation area.
» Image ©Christopher Meek
» Courtesy of Weber+Thompson

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Figure 14.3 | Exterior Views
Providing workers with a view is a significant benefit of a daylit office space. This north-facing window in a southern U.S. location should receive little direct sunlight. Floor to ceiling windows are not required to achieve either daylighting or views and are likely to be energy inefficient in colder climates or when exposed to direct sunlight.
» Image ©Robbins Photography, Inc.



Figure 14.4 | A Daylit Store
Skylights uniformly illuminate this retail space, permitting the space to operate with little to no electric lighting during daylight hours.
» Image ©SunOptics

of daylight [6] [7] [8] [9] [10] [11]. Energy savings are likely if appropriate glazing material, aperture sizing, and an electric lighting control systems are applied.

A daylit work environment may provide additional benefits to building owners or corporate tenants. Workers are likely to enjoy working in such an environment, and therefore may be less likely to seek employment elsewhere. In addition, LEED-rated buildings, which often include daylighting, have been shown to command higher rental and sale prices, and to lease or sell faster [12] [13].

14.1.3 Circadian Rhythms

Early morning exposure to higher lighting levels plays an important role in the regulation of our body's circadian rhythms (see 3.2 Nonvisual Response to Optical Radiation). The receptors that regulate this cycle are most sensitive to the short wavelength region of the visible spectrum, and these wavelengths are abundant in daylight. A daylit interior space with spectrally-neutral light transmission characteristics should assist in regulating this cycle for the occupants, particularly those who occupy positions near the daylight apertures where daylight levels are highest. Elimination of morning blue light has been shown to delay evening melatonin production and sleep onset in students [14]. The maximum circadian benefit in school and work environments is likely to occur during winter at high

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latitudes, where people travel to work or school in the dark and lack morning exposure to daylight.

14.1.4 Energy Savings and Peak Load Reduction

When provided in sufficient quantity across an interior area, daylight can replace some or all of the electric light in these areas for a large portion of the day. With proper electric lighting control, daylighting can reduce lighting energy use between 30 and 60% in daylit areas [15], leading to cost savings and lower carbon emissions. A reduction in the electric lighting power during daylight hours can also reduce peak electricity demand and the cooling load in a space. A 100 W electric lighting load reduction may save as much as 30 additional watts of cooling load.

Daylight, which consists of broadband electromagnetic energy, does introduce heat to a space, but with spectrally selective glazing material that admits visible wavelengths while rejecting UV and ultraviolet wavelengths, a higher number of lumens per watt of heat is admitted than occurs with electric lighting. Interior daylight levels that exceed two to three times the electric lighting level will likely cancel out any cooling load savings.

Lighting energy savings may be similarly offset by higher solar gain or heat loss that occurs through daylight glazing material with poor thermal properties. To achieve a positive energy balance, daylight apertures must be properly sized and configured with efficient glazing material [16] [17]. Energy savings are best achieved through an integrated design process that simultaneously addresses architecture, lighting, and HVAC performance.

14.2 Daylighting Design Process

While each project is unique, daylighting solutions that have been proven to work can be applied across a wide range of projects. The solutions selected for a particular project should be based on the fundamental principles that guide the lighting design process. Daylighting design requires careful consideration of a variety of context issues, including site and weather conditions, space relationships, architectural style, user needs, and budget [18] [19]. The design process outlined here is specifically tailored to daylighting design. More details on design options, systems integration, and system performance are provided later in this chapter.

14.2.1 Daylighting Goals

The design of a daylighting system addresses a collection of project and space specific goals that are derived through a detailed programming exercise (see 14.2.3 Programming). However, in any daylighting design the following fundamental goals are critical to success:

- Provide usable interior daylight that responds to the needs of the occupants and tasks over a large area of the building. The needs of the occupants, tasks, and spaces are defined relative to both daylighting and electric lighting following the general approach outlined in 11.3.2 Programming.
- Use daylight to offset electric lighting energy with little or no penalty in both heating and cooling energy.
- Achieve an acceptable luminance balance across the daylit space to achieve comfortable viewing conditions.

Simultaneously, a daylighted space must avoid the two most common problems:

- Window or skylight glare
- Direct insolation that creates visual and thermal discomfort

Addressing each of the above requires teamwork and careful study of design decisions across a broad range of design disciplines throughout the building design process.

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14.2.2 Prerequisites

The design and operation of a daylit building requires a strong commitment on the part of the client/users and the entire design team. Without these commitments, daylighting is assigned a secondary or tertiary role in the overall design, and opportunities to maximize daylight-related benefits are lost. A commitment by the client/users will help focus priorities. A team commitment helps guide the overall design and ensures systems integration.

14.2.2.1 Owner Commitment

Today, many building owners seek a green or sustainable design, in some cases targeting a particular LEED rating. Daylighting is a logical focus in these buildings. Slightly higher costs may be associated with the design and construction of a daylighted building, although savings and benefits are realized by both the building owner and tenant over time. When only energy savings are considered, short payback periods for daylighting systems are somewhat rare, except with lower cost switching-based automatic lighting control systems. The low installed lighting power densities provided by today's efficient sources, luminaires, and lighting control techniques limit energy cost savings, while higher utility costs counter this effect. The added benefits of improved space quality, occupant satisfaction, and reduced carbon emissions are difficult to quantify, but are important benefits of daylit buildings. Still, without the owner's commitment to daylighting, important features or equipment that affect daylighting quality and efficiency, such as shading devices that improve lighting quality, or the automated control system that provides lighting energy savings, may be removed in a final cost-cutting phase (sometimes inappropriately referred to as value engineering).

14.2.2.2 Design Integration

Daylighting involves much more than simply punching openings in the exterior envelope of a building. In a daylit building, the building's form, siting, orientation, architecture, interior planning, and environmental systems must be carefully engineered to optimize both lighting and HVAC system performance. The most successful solutions evolve through a holistic approach to design, where daylighting is a prime, if not *the* major consideration throughout the process. Team members from all disciplines contribute to the design process from the initial programming stage through to construction and commissioning. The architect, together with the daylighting and/or energy consultant, must foster an integrated and collaborative design approach, and assemble a team that has both the commitment and knowledge to achieve a successful end product.

14.2.3 Programming

The design of a daylit building begins at the programming stage. The program for each space considers the desired space characteristics, functions, visual tasks, and the preferred lighting conditions for these tasks following the general approach outlined in 11.3.2 Programming. For daylighting, this often includes a space-by-space assessment of items such as the following (see 11 | LIGHTING DESIGN: IN THE BUILDING DESIGN PROCESS for more detailed coverage on these topics).

- target task illuminance values (illuminances may vary under nighttime and daytime conditions in transition and other spaces)
- luminance limits and/or luminance ratios,
- work plane or room surface daylight illuminance uniformity
- direct and/or reflected glare
- controls
- the importance of view
- the desire to admit or omit direct sunlight

The recommendations provided in the application chapters for electric lighting generally apply to daylighting. One exception is the luminance ratio between the task and distant

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surround, which for daylighting can often be greater than the 1:10 ratio recommended for electric lighting systems. Occupants are likely to tolerate somewhat higher luminance ratios for daylight, particularly when they are associated with a favorable exterior view.

At the programming stage, it is crucial that daylighting system design objectives are coordinated and understood by the entire design team, and become a focus for schematic design and further design development. Unfortunately, daylighting is often considered too late in the design process, after the building shape, layout and/or siting have been established. At that point, the application of daylight involves working within a set of established and limiting design conditions. Such an approach rarely achieves complete success as daylight coverage and realized energy savings are limited, and daylight quality is controlled through blinds and shades rather than through daylight-tuned architecture. To maximize performance and the opportunities for daylight across large areas of a building, daylighting must be assigned a high priority from the onset, preferably prior to final building siting, with daylight quality, energy savings, and occupant satisfaction achieved through collaboration across all design team disciplines that results in a well-conceived and integrated building design.

14.2.4 Schematic Design - Building Form and Siting

Solar angles and neighboring obstructions are important items to consider in siting a building. The orientation, geometry, and exterior shading of a daylight aperture affects daylight quantity and quality by establishing

- the times and angles at which sunlight strikes and penetrates the aperture
- the available daylight received from the sky and surround
- the interior daylight distribution [20].

At the schematic design stage, a preliminary building form expresses the initial concepts regarding daylight delivery approaches that best meet space and occupant needs. Preliminary daylight modeling at the space level can be applied to test daylight delivery concepts and assess performance. A design is fine-tuned or revised as feedback on energy and daylight quality is gathered through analysis of design performance. In configuring a daylighting system, an optimized design will minimize the need to engage operable interior shading, since these devices impede daylight and eliminate a view of the exterior. This can be accomplished through the application of exterior shading devices, and by selective orientation of daylight apertures. Note that proper building form and siting can simplify daylighting, while the reverse can make daylighting more complex, increasing the time when direct sunlight must be managed. More information on this topic is provided in 14.4 Building Orientation.

14.2.4.1 Initial Daylighting Analysis

As the building design and spaces begin to take shape with proposed aperture configurations and orientations, simplified daylight modeling can be employed to

- properly size and locate daylight apertures or shading elements
- confirm that design performance meets space and user needs
- suggest improvement or fine-tuning of the daylight delivery system or space architecture.

Graphical techniques, scale model studies, and computer simulations can be applied to size shading elements (such as light shelves, fins and overhangs) to limit sunlight penetration, while scale models or simple computer models can provide preliminary daylight illuminance values, uniformity measures, luminance ratios and performance measures that address system performance. In general, a relatively simplified space model is considered in preliminary daylight studies.

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14.2.4.2 Initial Energy Analysis

Energy modeling is valuable at the preliminary design stage for testing the energy performance of various designs. The fact that a building is daylit does not ensure it is energy efficient, even with a fully functioning lighting control system. Most building energy modeling software provides information on the lighting energy savings that might be achieved with automatic lighting control, as well as the heat gain and losses transmitted through daylight apertures that affect total building energy consumption. For example, the introduction of skylights with poor thermal performance (a high U-factor averaged across the glazing and frame) or high solar heat gain (low SHGC) can waste more heating and cooling energy than they save in lighting energy. With building energy modeling software, different systems, configurations and materials can be easily compared for energy performance, which will vary with site climate conditions. These studies should lead to the development of an energy-efficient design solution (considering both lighting and HVAC energy) and meet the needs of the space and occupants.

14.2.5 Design Development

This design phase includes the selection and layout of all equipment, and the establishment of lighting control zones to reduce electric lighting power within the daylit zones. Automatic lighting control is required to ensure that lighting energy is saved. This is often referred to as "daylight harvesting". See 14.14.2 Controls and 16.3.5 Photosensors.

In developing a final design solution, the results of further lighting and energy studies can help to finalize the general building form and layout, as well as the size and selection of daylight delivery system components, including glazing material and both interior and exterior shading devices. The focus of these studies should be to acquire information on spatial and temporal aspects of daylighting, direct sunlight penetration through apertures, and lighting and HVAC energy performance. Coordination across all disciplines is key—space layout and finishes must address task viewing conditions in relation to daylight apertures, minimize veiling reflections, shadowing, and task-to-surround luminance ratios. Similarly, exterior landscape design should enhance rather than limit daylight system performance. The goal of the design development phase is to meet the design targets and program goals established during the programming stage.

The electric lighting system should supplement the daylighting system at low daylight conditions, providing a comfortable and balanced luminous environment, and delivering the required lighting at all tasks in the absence of daylight.

14.2.6 Construction Documentation

It is very important for the design team to clearly document all components, equipment and materials that influence the quality and quantity of daylight delivered to a space, and properly integrate these with other building systems. Design documentation includes both construction drawings and the specifications (See 20 | CONTRACT DOCUMENTS). Specifications are critical because many of the details that affect the quality of an installation are defined in these written documents. In most situations, equipment and material performance specifications help ensure that system procurement, installation, commissioning and integration are performed properly to deliver the desired lighting quality, system efficiency, and energy savings.

14.2.7 Construction Administration

During the construction process, it is critical for the design team to review submittals for alternate equipment as well as shop drawings, ensuring that design intent and expected performance are met. It is advantageous to have the contractor involved with the design team throughout the design process, but regardless, should be aware of the importance of daylighting systems, related components, and the calibration of control systems to the final building performance.

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14.2.8 Commissioning

Following the construction process, automated lighting control systems must be calibrated to provide the desired performance. This involves configuring the control algorithm under a typical daylight condition. Performance at all other times of the year is based on this calibration setting. In cases where equipment is self-calibrating, the commissioning process should verify that established control settings are appropriate, and if not, the equipment should be manually calibrated or adjusted to override the system's self-calibration setting. Some self-calibrating systems recalibrate themselves over time to adapt to changes in space conditions, such as localized changes in reflectance that may occur as furniture is moved or interior conditions change.

14.3 Programming

14.3.1 Site and Climate

Site conditions establish the available daylight and building orientation options. The sky conditions at a particular location influence the design since available daylight varies with sky condition. In the northern hemisphere, which is assumed for the purpose of discussion throughout this chapter, a north-facing façade may experience a bright ground and low sky luminance under a clear sky, with conditions reversed under overcast skies, where the sky is relatively bright and the ground has a much lower luminance. Cloud cover may vary with the time of the year. In the Pacific Northwest, for example, the skies are generally overcast during the winter months and clear during the summer. Figure 14.5 shows cumulative daylight illuminance on unobstructed vertical facades facing the cardinal directions and on the flat roof of a building for a variety of different sites.

Site temperature conditions are also important, since they affect heat gain and loss through daylight apertures, and dictate whether a space must be heated or cooled. A design that performs efficiently in Los Angeles may lose energy in Toronto due to thermal losses. The design solutions in different climates must be tailored to the weather conditions.

Information on a building's neighboring environment must be gathered since obstructions can significantly limit the view of the sky and produce shadows and reflections that alter incident daylight on an aperture. Failure to consider these external factors can lead to poor or unexpected performance. For an office space in a large city, the lower floors may receive very limited daylight due to neighboring buildings. Sunlight reflecting off an adjacent building, however, can create an uncomfortable condition on the shaded portion of an adjacent building, and must be considered.

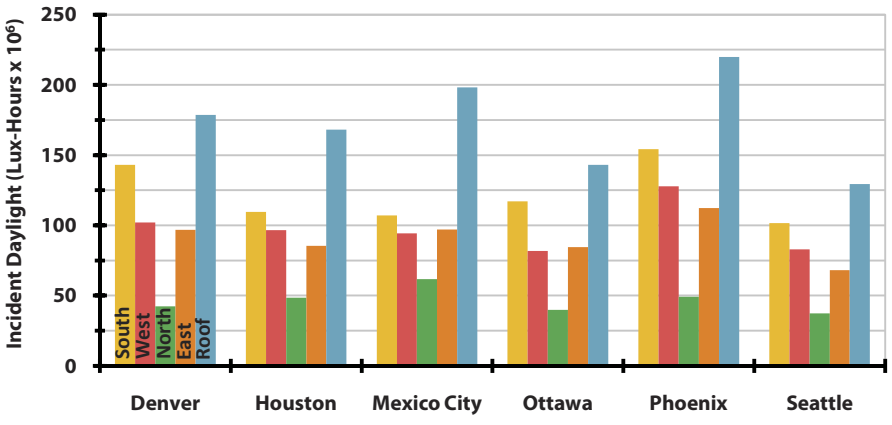


Figure 14.5 | Total Annual Incident Daylight
This graph illustrates how total incident daylight over the course of a year varies on different surfaces of a building, and across different site locations. These data were computed using Perez skies based on TMY weather data, considering how the sun, sky and an 18% reflective ground contribute daylight to these surfaces on an hourly basis.

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Other site conditions that affect daylight performance include vegetation and ground reflectance, as well as mountains and sloped terrain. Mountains can block low angle sunlight and reduce the sky contribution to a daylighting system. A forested site surrounding a building can reduce daylight availability, or offer shading opportunities at certain times of the year, while a parking lot or lake may provide undesirable sunlight reflections. Similarly, snow-covered ground will significantly increase incident daylight levels on a facade, but may provide uncomfortably high exterior luminances through view windows on a sunny winter day.

14.3.2 Occupant Needs

The design of a daylit building must consider the tasks that occur within its spaces and provide appropriate daylight conditions for these tasks. This is particularly true in environments with heavy computer use and for tasks and surfaces that are highly specular. Space layout and worker orientation are critical to avoid veiling reflections and high luminances in the field of view, such as when workers are seated facing windows. Blackout shades or other room darkening devices may be required in presentation spaces to accommodate video projection.

The nature of a space will also determine the applicability of certain control systems. Automated switching is better accepted in transition spaces, while dimming, which is generally not detected, is preferred in living and work spaces. The concept of daylighting and integrated electric lighting control for the purpose of saving energy may be a new concept for many building inhabitants. For this reason, occupants must be informed of the operation and benefits provided by special daylighting system components, such as shading devices and automatic controls. Proper operation, the willingness to recalibrate systems for occupants who demand higher or lower lighting levels, and the ability for occupants to temporarily override the system, will help to increase occupant acceptance of these systems.

14.3.3 Budget

A daylit building will often incur higher design and construction costs. While some costs may increase, others may decrease. A more efficient design may require smaller mechanical equipment that provides cost savings that help offset any higher costs related to daylighting. An automated control system is one of the added costs in a daylit building, but this equipment is essential to realize energy savings. Increased costs can be justified through lower energy costs along with extended in-service lamp life when lighting equipment will be switched off during daylight hours. Similarly, the cost of exterior shading devices can be recovered through savings in cooling energy or smaller building mechanical equipment. Since windows are included in most buildings, regardless of whether or not the building is daylit, much of the cost to daylight a building is already included in the basic building envelope. In a daylit building, these apertures are arranged and engineered to meet daylight design and energy performance goals.

14.3.4 Operations and Maintenance

The design team should investigate the capabilities of the building's maintenance staff, who may require training to properly manage the systems that contribute to successful daylighting. For example, following occupancy or at some future date, a control system may need to be recalibrated. Either the maintenance staff possesses the knowledge and equipment (such as an illuminance meter) to carry out this function, or a manufacturer or third-party must be called upon to conduct this task. The project design team and equipment manufacturers must provide operations manuals to the facility's staff with recommended maintenance and adjustment procedures. Some routine maintenance may include periodic cleaning of the daylight apertures.

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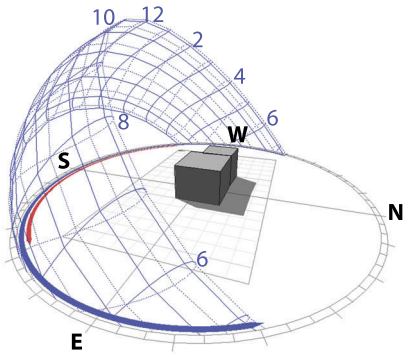


Figure 14.6 | Solar Path Diagram for 40N Latitude
Solar positions should be considered when orienting a building, laying out spaces, and configuring daylight apertures and shading devices. 40 N latitude includes cities such as Denver, CO, Indianapolis, IN and Philadelphia, PA.

14.4 Building Orientation

The preferred configuration of a daylight delivery system will vary with orientation, primarily due to changes in solar position. Site latitude and aperture orientation determine the incident daylight illuminance and the potential for sunlight penetration (Figure 14.6).

14.4.1 Profile Angle

Figures 14.7 and 14.8 illustrate the number of hours per year that different solar profile angle ranges are present on different façade orientations for site latitudes ranging from 0 through 50 degrees. At latitudes near the equator, the north and south facades become similar, with mainly high solar profile angles on each. At very high latitude, beyond that conveyed in these figures, sun angles are much lower, and more sunlight strikes a north façade in the summertime. Beyond the Arctic Circle the sun is above the horizon all day near the summer solstice and its path completely encircles a building over a 24-hour cycle, with the highest solar altitude occurring as solar noon when the sun is in the south sky.

14.4.2 Generalized Sun Positions

The typical sunlight conditions provided on orientations facing the standard compass directions (within about 15 degrees of north, east, south, and west) for a northern hemisphere, mid-latitude site (20-60 North latitude) are outlined below and are summarized in Table 14.1. Performance for other directions can be deduced from these general observations and an analysis of profile angle and solar position (see 7.1.5 Solar Position, 7.1.5.4 Solar Angles Relative to a Vertical Surface, and 14.10 Assessing Sunlight Penetration).

Table 14.1 | Daylight Conditions by Orientation
Daylight quality characteristics for facades facing the standard compass directions at mid-latitudes (23.5-60 N).

Facade Orientation	Daylight Characteristics
North	• Most stable and easiest to control • Provides high quality diffuse daylight • At higher latitudes, some sunlight penetration is possible early and late on a summer day, otherwise the facade is free of direct sunlight • Lowest available incident daylight , but reduced need for shading could result in more daylight delivered to the building interior over the year
South	• High angle summer sunlight is relatively easy to control with an overhang • Deep penetration of low angle winter sunlight can be controlled with adjustable blinds or operable shades to avoid discomfort glare • High latitudes have lower sun angles • High solar loads occur during the coldest time of year
East	• Low-angle morning sunlight requires operable blinds or shades in work areas • Afternoon conditions are similar to North since facade is in shade • Vertical shading devices can block morning solar angles in winter at higher latitudes
West	• Low-angle afternoon sunlight requires operable blinds or shades in work areas • Late afternoon solar gain corresponds with peak exterior temperatures, creating high space cooling loads • Morning conditions are similar to North since facade is in shade • Vertical shading devices can block afternoon solar angles in winter at higher latitudes

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14.4.2.1 North-facing

The north side of a building is relatively free of direct sunlight, which minimizes the need to apply shades and maximizes the opportunity for view. At mid-latitudes, direct sunlight will strike a north façade from a high azimuth angle near the summer solstice only very early and late in the day (see the solar path diagrams in 7.1.5 Solar Position for times when the solar azimuth angle exceeds ±90°). For this reason, the conditions on a north facade are more consistent and controllable than for any other orientation, with diffuse daylight provided from both the sky and ground for most of the year. The incident illuminance on a north window, however, is the lowest of all possible orientations, and has the lowest solar gain. The net heat loss is also likely to be highest of any exposure. Due to lower incident daylight, it may be advantageous to apply larger glazing areas or higher glazing transmittance on the north side of a building. A façade that faces to the west of north is likely to receive late-day, low-angle sunlight near the summer solstice, and may require some interior or exterior shading to block this sunlight. At the equator, north and south facade orientations are very similar, and will receive high angle sunlight for half the year and will be in shade for the other half.

14.4.2.2 East- and West-facing

On an east-facing facade, a window will receive low angle sunlight in the morning along with its associated glare and solar gain. During the afternoon, the daylight conditions approach those of a north-facing façade since the sun is on the opposite side of the building. The situation for a west-facing façade is similar, but mirrored about solar noon, with direct sunlight occurring during afternoon hours. One difference, however, is that afternoon sun on a west façade presents a worst-case scenario for the cooling load, since high solar gain coincides with peak exterior temperatures and peak building cooling loads. West-facing glazing should therefore be minimized or avoided in climates with large afternoon cooling loads. In certain circumstances and climates it may be beneficial to have direct sunlight entering an east or west-facing space.

14.4.2.3 South-facing

For a south-facing aperture in the northern hemisphere, a window may require little or no shading control during the summer months, since the sun will be relatively high in the sky. A south-facing façade is in shade at sunrise and sunset between March 21 and September 21, with sunlight penetration being deepest at solar noon, when the solar profile angle is lowest. On the solar equinox dates, the solar profile angle (see 7.1.5.3 Solar Angles) on a south façade is the same throughout the day, meaning sunlight will penetrate the same distance perpendicular to the window at all hours when not otherwise obstructed. Between September 21 and March 21, sunlight will strike the façade from sunrise to sunset, with interior shading likely required at many of these times. The sun rises south of east and sets south of west, and is at its highest profile angle with its shortest penetration distance at solar noon. Table 14.2 provides simple equations for solar profile angles that will be present at solar noon for the solstice and equinox dates based on a site's latitude, while Figure 14.9 illustrates the solar profile angles across the year for a 40 N latitude south-facing orientation.

Table 14.2 | South-facing Noontime Solar Profile Angles

Equations for solar profile angle at noon on a South-facing facade for the solstice and equinox dates, and relative magnitude of the profile angle at other times of the day based on season.

Date	Noontime South-facing Solar Profile Angle (degrees)	Solar Profile Angle at Other Times of the Day
Winter Solstice	90 - L - 23.5	Lower than at solar noon
Equinox	90 - L	Unchanged
Summer Solstice	90 - L + 23.5	Higher than at solar noon

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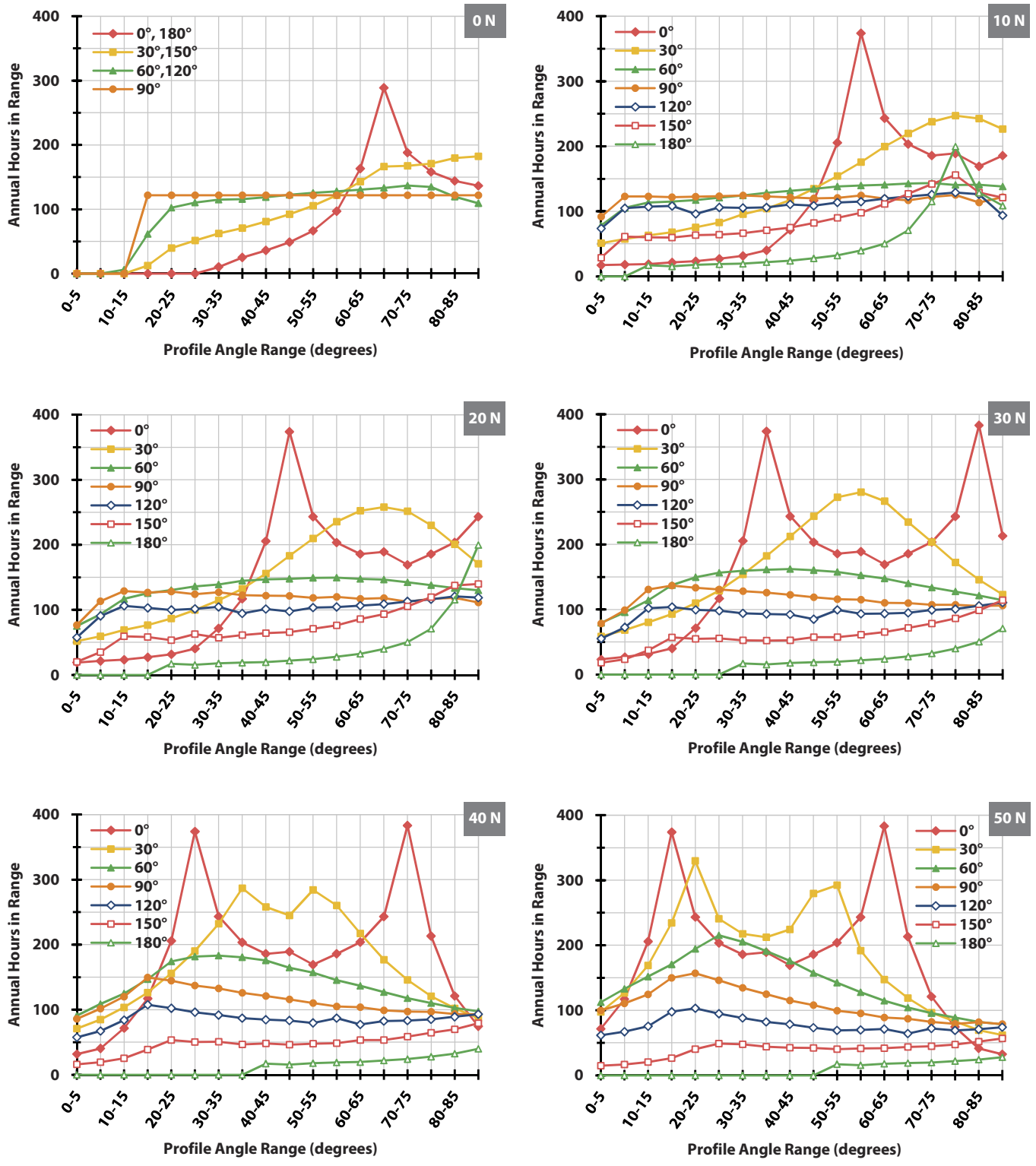


Figure 14.7 | Annual Solar Profile Angle Distribution by Latitude and Elevation Azimuth
Number of annual hours that the solar profile angle falls within 5-degree angular intervals between 7 a.m. and 7 p.m. solar time at the elevation azimuth angles shown in the legend (South = 0° elevation azimuth, East/West = 90°, North = 180°).

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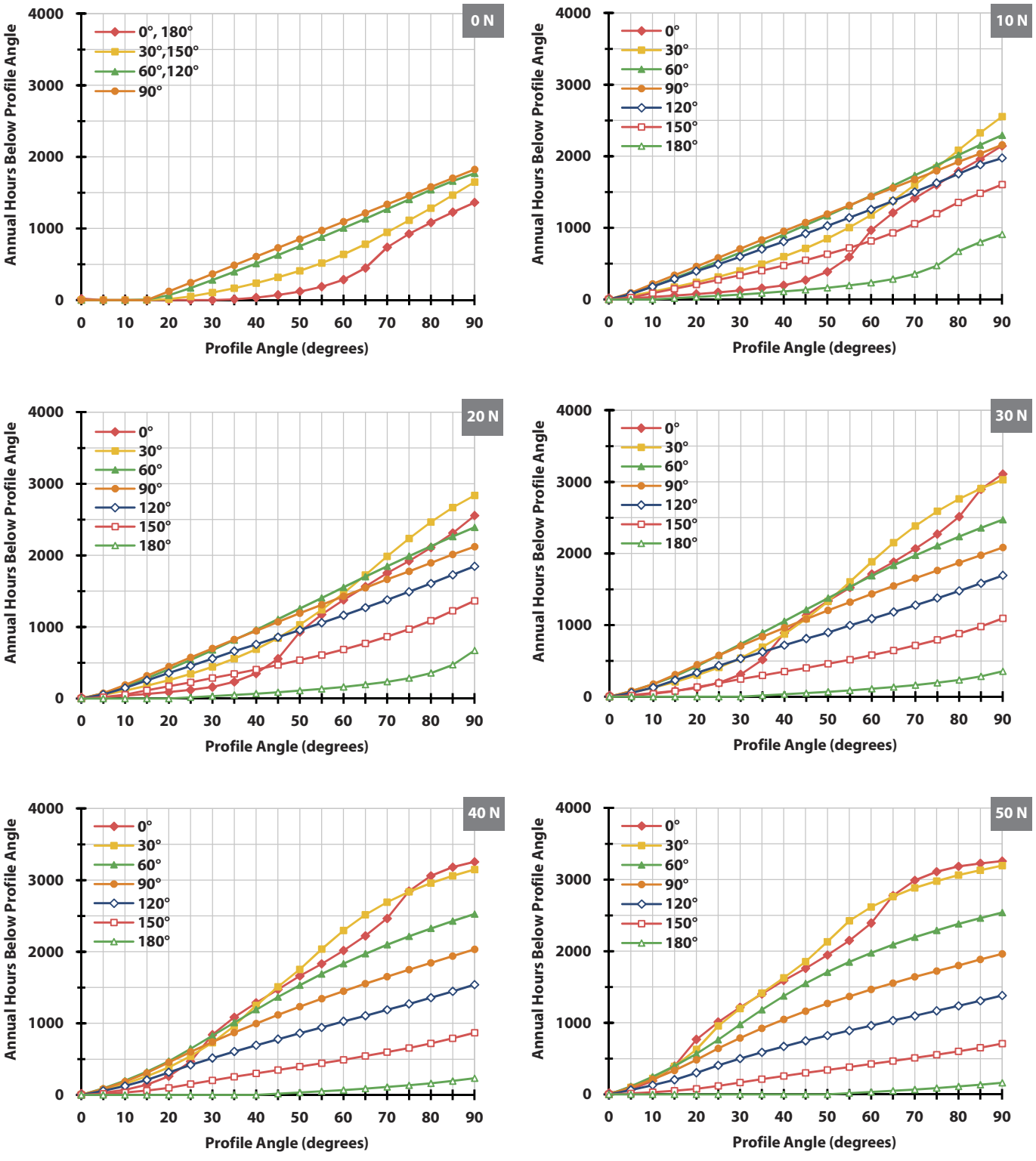


Figure 14.8 | Cumulative Solar Profile Angle Hours
Number of cumulative hours across the year that the solar profile angle is below a given angle between 7 a.m. and 7 p.m. solar time for the elevation azimuth angles listed in the legend (South = 0°, East/West = 90°. North = 180°).

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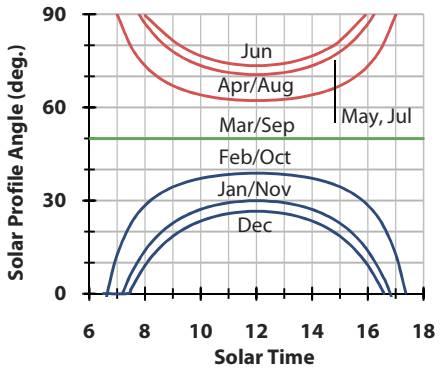


Figure 14.9 | Solar Profile Angles for 40 N Latitude

These angles are for the 21st day of each month and are for a South-facing facade at 40N latitude. High late spring and summer angles are easily blocked by an overhang. For more than two months either side of the winter solstice, the profile angle never exceeds 40 degrees.

14.4.2.4 Horizontal Elements

Horizontal skylights receive direct sunlight, in addition to daylight from the sky, whenever the sun is above the horizon, with the magnitude of both increasing at higher solar altitude angles. As a result, significantly more daylight is delivered through skylights during the summer, and skylights, on both a daily and annual basis, receive significantly more incident daylight than vertical windows. More available daylight means that skylight apertures can generally be smaller, which improves energy efficiency. During overcast conditions, horizontal glazing still receives a significant amount of daylight since the sky is brightest at zenith (straight up). Figures 7.11 and 7.12 provide details on the incident illuminance provided on both horizontal and vertical surfaces from both the sun and the sky from standard clear, partly cloudy and overcast skies (see 7.1.6 Daylight Availability). Domed skylights help to capture more sunlight when the sun is located at lower altitude angles. The fact that skylights are located above most tasks is another advantage, since daylight is more efficiently delivered to a horizontal work surface from overhead.

14.4.3 Orientation Relative to Polar North

In orienting a building on a site, it is important to understand that the north arrow on a compass does not correspond to a true north direction for the path of the sun. This occurs because the earth's magnetic pole is not aligned with its axis of rotation, which determines solar position. Local anomalies, such as iron ore deposits, can create additional variations. Across North America, the approximate difference between magnet north and polar north (not accounting for local variations) is shown in Figure 14.10. This graph provides the angular adjustment necessary to convert an azimuth orientation referenced from magnetic north to one referenced from polar north (see Figure 7.10 | Azimuth Angles). In applying this adjustment, the apparent position of magnetic north for most locations is in Northern Canada. When studying a daylighting system's performance in software or using a scale model, the building must be oriented properly with respect to polar north. For example, for a building in Vancouver, BC with a façade facing 30 degrees west of magnetic north (a_e=150°) is actually facing only about 14 degrees west of polar north (a_e=150°+16°=167°) since the correction from Figure 14.10 is approximately 16 degrees.

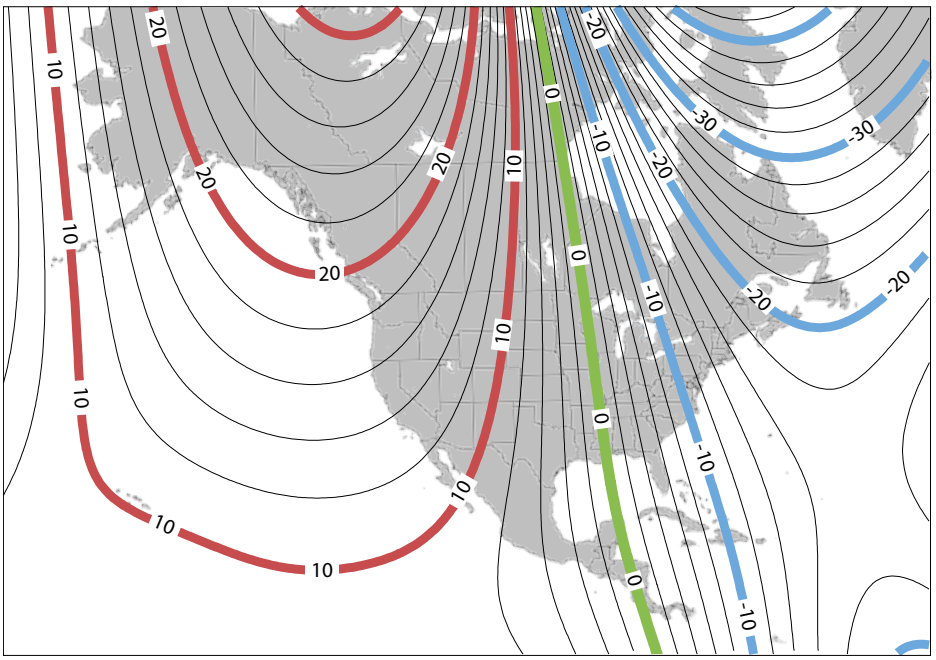


Figure 14.10 | Magnetic to Polar North Angle Correction

The North compass direction for daylighting calculations must be corrected from the magnetic North direction by the values shown since magnetic North is located in Northern Canada and not aligned with the Earth's rotational axis.

» Image created with NOAA's World Magnetic Model Software.

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14.5 The Building Design

Daylighting design is facilitated through careful space planning and design in relation to a building's configuration and orientation, daylight apertures, interior space geometry, and the exterior space surrounding the building. The building geometry and form evolves from the daylight delivery methods applied.

14.5.1 Layout of Interior Spaces

Given the daylight conditions on different façade orientations, daylit buildings are often elongated in the east-west direction to provide greater north and south exposure where direct sunlight is either infrequently encountered (north) or relatively easy to control (south). To daylight a large percentage of the building interior, the building must also be relatively thin, placing more interior area near the perimeter. See Figure 14.11 for an example. Circulation and service spaces may be best located in a central core, or on the west and east facades.

Proper building space layout should locate spaces on facades for which they are best suited. For example, in a school art spaces are best located on the north side, where daylight is diffuse and relatively consistent in distribution and quality. More glare tolerant spaces can be placed on the other exposures. Spaces that best accommodate light shelves should be positioned on a south-facing façade where they are most effective. Classrooms that are vacated at the end of the school day at 2:30 p.m. may be more accepting of a western exposure since for most of the occupied day the sun will not strike that façade (note that daylight savings time places solar noon closer to 1 p.m. than to 12 p.m., further limiting exposure to afternoon sunlight conditions). Spaces that can benefit from winter solar gain in colder climates should be located on a southern exposure.

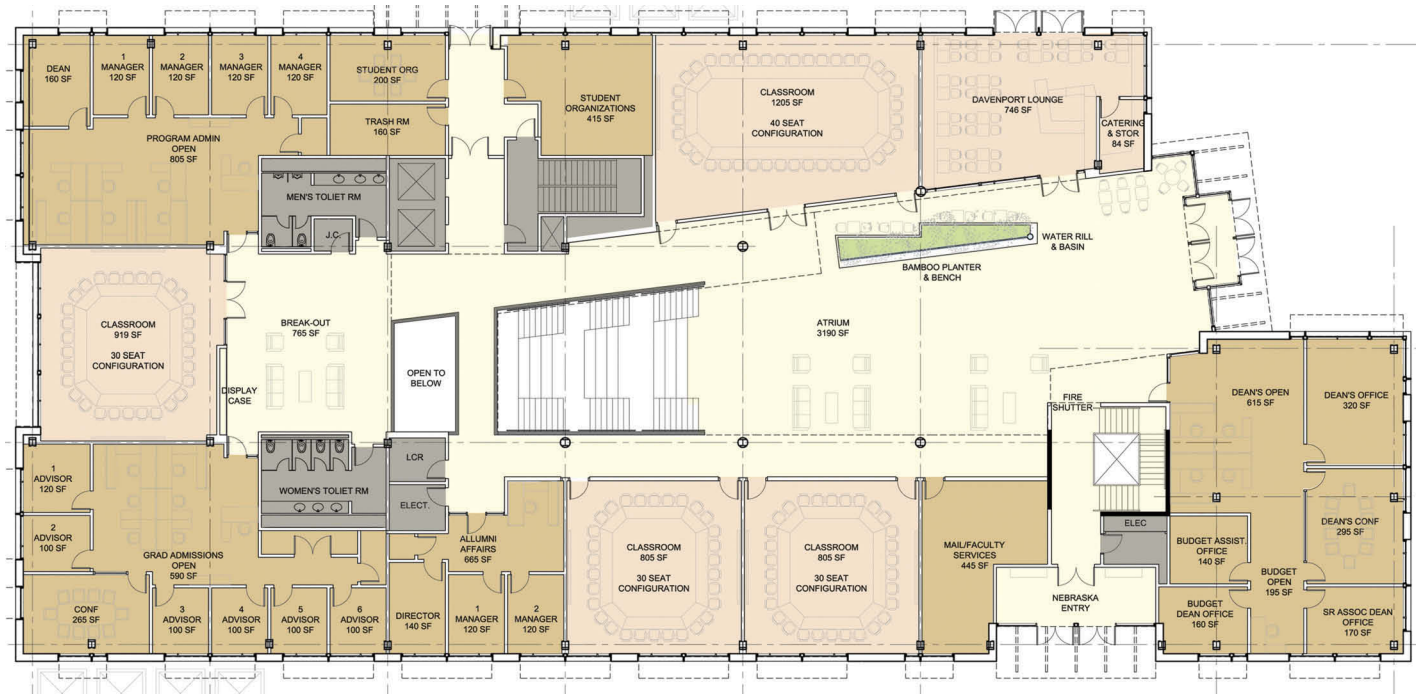


Figure 14.11 | A Daylit Building
This elongated floor plan in a universisty building permits daylight to be delivered to most spaces through either windows or a central skylit atrium. Brown colored spaces are office and work areas, coral colored spaces are classrooms and meeting spaces, and cream colored areas include circulation and the atrium. Atrium delivers more daylight to surrounding spaces on the upper floors. Service areas and lavatories are concentrated in interior locations where no little or no daylighting is possible.
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Many buildings are not oriented along a principal compass direction. With knowledge of the sun's position and the assistance of modeling tools, sunlight penetration and the available daylight can be determined for any aperture orientation (see 14.10 Assessing Sunlight Penetration).

In some cases, parts of a building may be designed to shade other building sections or daylight apertures from direct sunlight. An example may be a lobby with a large expanse of glass that is shaded by a taller section of a building during the afternoon hours. This can improve visual comfort, reduce cooling loads and decrease energy consumption.

14.5.2 Exterior Landscape and Hardscape

The amount of light striking a daylight aperture depends on the luminance, size and relative position of the sun, sky, ground, and other objects that contribute daylight to an aperture. Objects that can shade the sun or sky, including vegetation and other structures, can significantly alter direct daylight, as well as the luminance of the ground and other surfaces that reflect daylight onto an aperture. Since sunlight may provide five or more times the illuminance generated by the sky when striking either a vertical or horizontal aperture, shadowing objects can significantly reduce incident and reflected daylight. Some building designs have employed deciduous vegetation as a means of controlling solar gain, which also lowers the daylight provided. Landscape design must be coordinated with building siting and architectural design to achieve the desired daylighting performance, keeping in mind that trees grow and will cast significantly larger shadows in the future.

14.5.3 Facade Design

A façade's exterior can be configured to control sunlight, admit diffuse daylight, and maintain a view of the exterior through the application of overhangs, light shelves, and other architectural features. The design of these features should be tailored to the façade's orientation, the site latitude, and to the needs of a space. An exterior shading system can reduce cooling loads and minimize the time that interior shading devices may be required. The solutions for protecting windows from direct sunlight vary by orientation and latitude, with horizontal elements providing maximum benefit on a south-facing façade at mid-latitudes, and both horizontal and vertical elements providing benefit on east- and west-facing facades, depending on the time of day and season.

In the design of exterior shading devices, other issues that may need to be considered include the following.

- treatment of snow and ice, which may build up and subsequently fall from louvered and other elements
- birds, which gather or may nest in covered areas
- cleaning and maintenance of the windows and shading system.

14.5.4 Daylight Apertures

The placement of daylight apertures determines the distribution of interior daylight more than any other feature. With windows, the majority of the daylight reaching the work plane near a window arrives directly from the daylight aperture. As the distance from the window increases, the fraction from interreflected light increases (See Figure 14.12).

Higher windows provide deeper daylight penetration. Placing windows close to surfaces with relatively high reflectances, such as near the side walls within a space, helps to reduce the contrast between the window and adjacent interior surfaces. In addition, splaying the opening to a daylight aperture both widens the interior daylight distribution and brightens neighboring wall and ceiling areas. This decreases the contrast between the aperture and its surround which improves visual comfort. The size and spacing between windows or skylights determine the overall uniformity of daylight that will be achieved across a

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work plane or room surface and can be assessed through daylight analysis software or physical models. Skylight spacing for uniform illuminance is discussed in 14.6.2.1 Skylights. In some cases, non-uniform daylight distributions may be desired to create a focal point or to add drama to a space.

14.5.5 Reflective Properties of Surfaces

Daylighting systems perform best with relatively high room surface reflectances that

- increase the amount of daylight delivered
- increase daylight penetration
- provide more daylight to surfaces facing away from a daylight aperture, thus reducing shadows
- reduce the contrast between the daylight aperture and adjacent interior surfaces, making aperture viewing conditions more comfortable

Recommended reflectances are shown below, with higher values preferred.

- Ceiling: 90% or greater
- Walls: 60% or greater
- Floor: 20% or greater
- Partition: 40% or greater

Glossy or specular architectural surfaces can be problematic, particularly when a daylight aperture is positioned at the mirror angle to the surface for a common viewing position. Examples include video information displays, glass showcases and even highly specular room surface materials such as polished granite. Anti-glare coatings may provide benefit on video displays and glass, but the best solution is space planning that considers the interaction between these surfaces and daylight apertures.

Semi-specular reflections can improve daylight distribution by reflecting daylight deeper into a space from a surface such as a light shelf, which is out of view of the occupants.

14.6 Glazing Materials

This section describes the various metrics used for quantifying the properties of glazing materials, and provides an overview of many of the available glazing options.

14.6.1 Performance Parameters

Today, there are a wide variety of glazing materials available. Their light transmitting characteristics vary in the amount of light transmitted, its spectral content, and the directional characteristics of the transmitted light. Materials differ in other important characteristics like thermal properties, solar transmission, cost, thickness, and appearance. In designing daylight delivery systems for buildings, selection of the glazing material must consider daylight quality and distribution, energy performance, cost, constructability, durability, code requirements, and aesthetics. Energy codes may set minimum performance standards

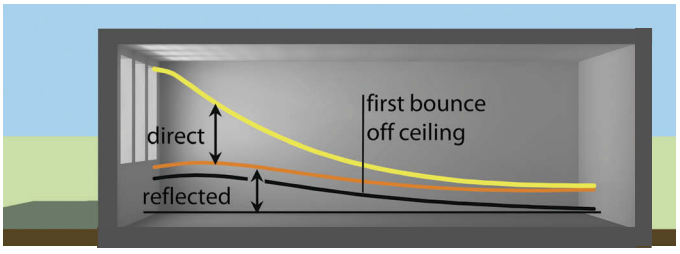


Figure 14.12 | Direct and Reflected Daylight Illuminance
This graph illustrates the direct and reflected contributions (including the first bounce from the ceiling) along the center line of a room with sidelighting provided by a clear sky. The room size is 12.2 x 12.2 x 3.0 m and reflectances are 90/60/20. The top line shows total illuminance, middle line is all interior reflected light, and bottom line is the first bounce from the ceiling. Reflected light is more than half of the total illuminance beyond about one window height into the space.

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for glazing materials based on a site's climate zone [21]. Energy modeling to validate code compliance through a performance rather than a prescriptive compliance path provides greater design flexibility for aperture sizing and glazing materials.

14.6.1.1 Visible Transmittance (VT or T_{vis})

Visible transmittance is expressed as either a percentage (0-100%) or as a decimal (0-1.0). This value represents the fraction of the incident flux arriving at a normal angle of incidence (straight onto a surface) that passes through a material. In daylighting design, higher VT requires smaller glazing areas to achieve a particular target illuminance. Higher VT can lead to greater energy efficiency, since fenestration is typically the weak link in the exterior envelope for thermal gains and losses; however, higher transmittances and smaller glazing areas may reduce daylight uniformity and increase glare due to higher contrast with surrounding surfaces. Conversely, low glazing transmittances (below about 25-35%) may not provide an energy efficient design and may be rated as too dark by occupants [22] [23]. However, in environments with extended periods of clear bright skies, some projects have achieved success with lower transmittances [24].

Standard clear insulated glazing (two layers of glass separated by an air space) with a low emittance coating has a transmittance of roughly 75%. For view windows, slightly lower transmittances are often selected to increase visual comfort. The optimum transmittance involves a balance between energy (heating, cooling, and electric lighting) and occupant comfort. Triple-pane windows may be required by code in very cold climates.

Although VT is measured for light striking normal to a surface, transmittance is a function of incident light angle. Figure 14.13 shows the reduction in transmittance that a single flat sheet of clear glass and an insulated glazing unit comprised of two clear glass layers will experience for different incident light angles. At incident light angles above 60-70 degrees to the surface normal, transmittance drops off significantly.

14.6.1.2 Solar Heat Gain Coefficient (SHGC)

The SHGC, which ranges from 0 to 1.0, represents the fraction of incident solar radiation transmitted through a glazing material into a space, either through direct transmission, or through absorption and subsequent radiation, conduction, or convection. SHGC considers the transmission of UV, visible, and infrared radiation. Outdoors, the fraction of visible radiation in direct sunlight is only about 46% of the total radiation (measured in watts). The remainder lies primarily in the ultraviolet (7%) and infrared (47%) portions of the spectrum, all of which contributes to heat gain within a space. When a space must be cooled, a glazing material that transmits visible wavelengths but rejects the non-visible wavelengths is preferred. Conversely, when heating is required, the non-visible wavelengths contribute beneficial solar gain that reduces heating energy. For this reason, higher SHGC's can save energy in cold climates.

14.6.1.3 U-factor

The U-factor is a measure of the conduction of heat through a material, typically measured in W/h/m^2/K or Btu/h/ft^2/F. U-factor is the inverse of the thermal resistance (R-value) for a material or assembly, with lower U-factors signifying better insulation properties. The heat transferred through a material via conduction, Q, in watts or BTU's, is the product of the temperature difference (ΔT) across the material, the U-factor, and the area (A) of the material.

$$Q = U \times A \times \Delta T \qquad (14.1)$$

Properties that affect the U-factor include the glazing material, its thickness, the number of layers, the spacing between the layers, the fill gas within this space, and any special coatings that are applied to the glass, such as low-Emittance (low-E) coatings. Low-E coatings limit the radiation of heat across the air space, improving a window's thermal performance.

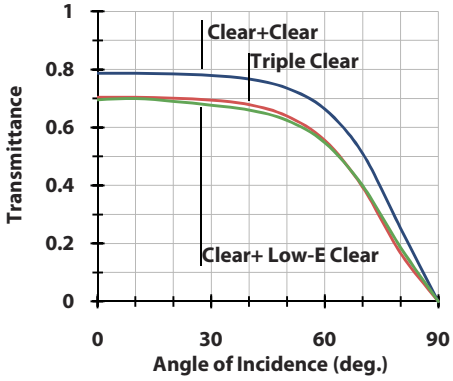


Figure 14.13 | Glass Transmittance versus Angle of Incidence
Glass transmittance varies with the angle at which light strikes the surface, particularly at high angles.

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While the above parameters affect heat transmission through the center of the glass, the weak link on most windows is the frame, particularly when solid material extends from the exterior to the interior. Window frames are typically made of aluminum, wood, vinyl or fiberglass. Thermal breaks (non-conductive layers) within the frame, particularly frames made of conducting material such as metal, help to reduce frame heat transfer, lowering the U-factor for the entire assembly and improving its energy efficiency. In building energy analysis, it is important to consider the average U-factor of an entire window assembly, which considers both the glass and the frame. Most glazing U-factors are center of glass values, so windows with large frame and mullion areas will have significantly higher U-factors when averaged across the assembly.

14.6.1.4 Light-to-Solar-Gain Ratio (LSG)

The ratio of VT to SHGC, which is often referred to as the Light-to Solar Gain ratio, serves as a metric by which to compare materials for suitability in hot climates, where spaces must be cooled most of the year. High LSG ratios help to minimize the cooling load associated with daylight, and improve energy efficiency in hot climates and in spaces that must be cooled. Materials with a high LSG ratio are not generally good choices for cold climates where passive solar gain is beneficial.

14.6.1.5 Transparency (Diffuse versus Image-Preserving)

The transparency of a glazing material determines the directionality of the light transmitted through it. An image-preserving material (which can be either clear or tinted) provides a view of the exterior and does not redirect transmitted light. On the other hand, translucent materials distribute transmitted daylight in all directions regardless of the incident direction. Many translucent materials provide a distribution that is close to a perfectly diffuse reflector (see 1.5.1.1 Reflection). Light from the sun, sky and ground will produce similar distributions when transmitted through a diffuse glazing material. Translucent glazings are best applied above eye height since a view of the exterior is generally desired. Some materials provide only partial diffusion of the direct beam, retaining some of its directionality. A few materials, such as fritted glazing and most fabric shade materials, provide a combination of specular and diffuse transmittance. Sunlight can pass through the clear glazing areas in fritted glass (see 14.6.2.7 Fritted Glass), or through holes in a fabric shade, but is otherwise reflected, diffusely transmitted, reflected or absorbed.

Many skylight materials are translucent or prismatic to disperse sunlight over a wide range of angles, illuminating large areas while eliminating the negative thermal and visual discomfort associated with the sunlight beam. This is essential in work spaces to maintain comfortable viewing conditions. For non-Lambertian materials, it may be possible to obtain directional transmittance distribution functions, or BTDFs (see 1.5.1.2 Transmission and 14.18 Formulary), to analyze their system performance within advanced software tools. A haze measurement is used to assess the degree of diffusion of plastics, with a value of 90% or greater recommended for most diffuse daylighting purposes. Haze is the percentage of transmitted light at normal incidence that is scattered more than 4 degrees by the material [25].

14.6.2 Architectural Glass

Architectural glass is typically image-preserving, with variations in the number of layers, fill gasses, additives and coatings. These coatings and additives change the appearance of the glass, making it more reflective, less transparent, and altering or changing the spectral makeup of the filtered and reflected daylight. Architectural glass can be obtained in a variety of different forms and options as described below, and must be distinguished from spandrel glass, which has opaque elements behind it and is often used to sheath portions of a building to retain the look of a full-glass exterior facade. Architectural glass can be obtained in a variety of different forms and options as described below.

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14.6.2.1 Insulated Glazing Units

Insulated glazing units (IGUs) consist of multiple layers of glass separated by an air space or an insulating and light transmitting material. The most common fill gas is air, which must be coupled with a desiccant material to remove moisture within the space to prevent condensation. More advanced windows contain an inert gas such as argon or krypton, or sometimes a vacuum, to limit conduction and convection and further improve the U-factor. Solid materials that are used for fill include fibers, cellular layers, and aerogel material. These materials increase U-value and diffuse transmitted daylight.

14.6.2.2 Low-E

Low-E glazing contains a low emissivity coating, typically on one of the inside faces of an insulating glass unit. This coating is a microscopically thin layer of a metal or metal-oxide that inhibits thermal radiation from one pane of glass to the next, leading to lower U-factors and SHGCs. In an insulating glass unit, the low-E coating is typically placed on one of the inside surfaces. Placing it on the inside of the outer glass layer (surface #2, the second surface from the exterior) will generally result in the best option for low SHGC, while placing it on the outside surface of the inner pane (surface #3) will generally result in better U-factor performance.

14.6.2.3 Spectrally Selective

To deliver a low SHGC, but high VT, spectrally selective coatings are often applied to glass. These coatings, often microscopic layers of silver, reflect the non-visible wavelengths while admitting the visible energy, resulting in highly efficient daylight in spaces that require cooling. Figure 14.14 illustrates the differences in spectral transmittance across a variety of different glass types. Outdoors, daylight contains approximately 93 lumens per watt of radiation, but daylight transmitted through the best spectrally selective glazings may be as high as 250-300 lumens per watt. By nature, spectrally selective coatings are also low-E coatings.

14.6.2.4 Low Iron

Glass manufactured with a low iron content has very high transparency, and is colorless, whereas standard soda lime glass has a slight green tint. Low-iron glass also has a lower reflectance and is therefore popular in storefront windows and other applications where high clarity and transmittance are desired.

14.6.2.5 Tinted Glazing

Some windows and skylight materials contain tints to modify glass appearance, which also affects the spectral content of the transmitted daylight. Available tints consists of gray, blue-gray, aqua-blue, aqua-green, deep blue and bronze. It is important to assess the color of the

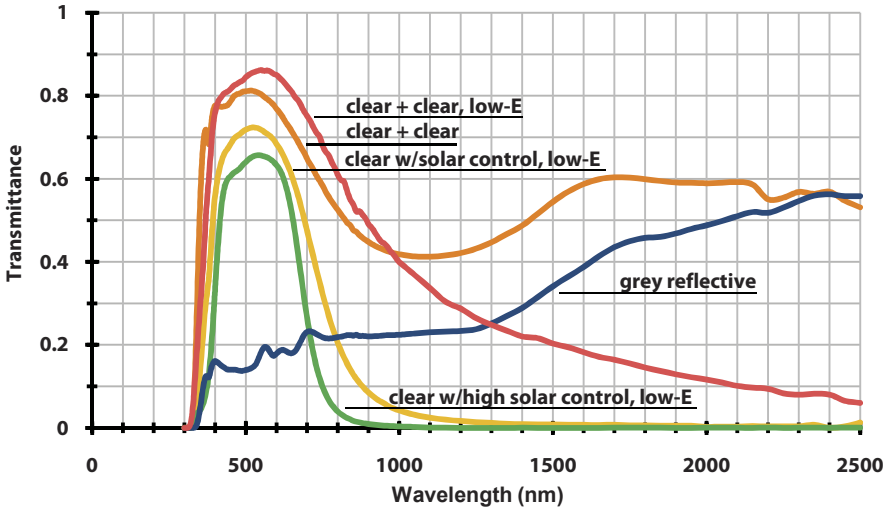


Figure 14.14 | Spectral Transmittance Curves for Glass
These spectral curves were generated from the Window 6 library [27] for a range of different glazing configurations. Those with higher transmittances above the visible range have higher SHGC values and lower LSG ratios. High solar control glazing transmits radiation primarily in the visible wavelengths and has a LSG ratio over 2.7.

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delivered daylight and its effect on color rendering as well as on exterior view when considering tinted glazing. Actual installations or glass samples should be evaluated when selecting a tinted glazing. The LSG ratio is also worth reviewing, since some tints absorb more visible radiation than non-visible. Absorption increases glass temperature, and some of this heat will be convected or radiated into a space. Manufacturer catalogs or the Window software [26] should be consulted to determine the optical properties of the glazing material.

14.6.2.6 Reflective Glazing

Reflective glazing has a mirror-like exterior appearance. These coatings help to reduce the overall solar transmittance, resulting in a lower SHGC. For many years, reflective glass was considered to be an energy saving glazing material for use in hot climates. Most of these reflective coatings, however, provide low VT's (often less than 10-20%) with a relatively poor LSG ratio (less than 1.0) and are not appropriate for a daylit building. High reflectance glazing will have a mirror-like appearance when viewed from the brighter side — on the outside by day, and on the inside by night.

14.6.2.7 Fritted Glass

Fritted glass is image preserving glass with a screened ceramic material fired onto the glass in a pattern of dots, lines, or other shapes (see Figure 14.15). The frit can absorb or transmit light in a diffuse manner, depending on the frit color and thickness, while the unfritted glass area is clear and permits a view through the material. The quality of the view depends on the frit size, coverage area and color, with darker and opaque frits providing a clearer exterior view. Fritted glass is often used to mediate direct sunlight penetration, although even with a high frit coverage fraction, sunlight that passes through the transparent areas will still be glaring, and will not provide sufficient protection for work tasks. Light-colored, diffusely transmitting frits can also become uncomfortably bright when illuminated by direct sunlight. In selecting fritted glazing, daylight transmission, interior surface luminance, view, and the material's exterior and interior appearance are important performance considerations.

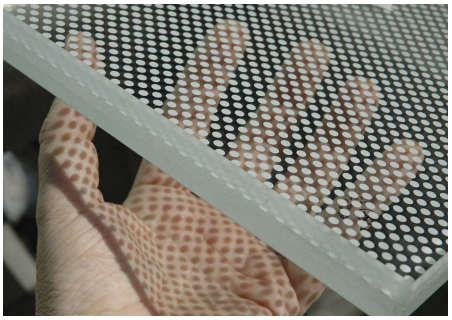


Figure 14.15 | Fritted Glass
Fritted glass as a ceramic coating, typically lines or a pattern applied to the glass surface. At greater distances from the glass, the shadows of this small frit pattern will disappear due to the large angular size of the sun in relation to that of the dots. View clarity also improves with distance from the glass and when darker frit material is used.
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14.6.2.8 Chromogenic Glazings

Chromogenic glazing materials are often referred to as "smart windows", since their transmittance can be tuned to the daylight conditions present. Varying the transmittance of these windows simultaneously controls light transmittance (VT) and solar gain (SHGC). In electrochromic glazing, which is the most common of these materials and now commercially available, a voltage is applied to the electrochromic layer to alter the glazing's transmittance, which then remains at the set condition after the voltage is removed. The time required to change the glazing transmittance is on the order of a few minutes and varies with temperature. At very low transmittance settings, the windows take on a somewhat bluish appearance. Multiple studies have analyzed the energy savings and lighting quality provided by these materials [27] [28] [29] [30]. The energy savings provided by electrochromic glazings are greatest in hot climates, but their darkened state is not low enough to eliminate the need for interior shading devices to block the sun's rays when used in work spaces such as offices.

Photochromic glass, which automatically darkens when exposed to ultraviolet radiation, has been available in eyeglass lenses and is now under development for use in buildings, but is not yet commercially available. A similar technology is thermochromic glass, which consists of a coating or gel that undergoes a chemical change upon reaching a particular temperature, causing it to either reflect infrared radiation or become opaque. This technology can be used to reduce solar gain during warmer times of the year, and is better suited to skylights than vertical glazing since the view out is lost when the material is activated by heat.

14.6.2.9 Self-cleaning Glass

Self-cleaning glass has been developed to assist nature in removing dirt from the glass surface. A titanium dioxide coating on the outside glass surface helps the sun break down

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organic material that adheres to the glass, and then, because the coating is hydrophilic, helps rain wash away the residue from the glass surface [31] [32].

14.6.2.10 Solar Films

A number of different films are available that can be professionally applied to existing building glazing to alter its performance. Sun control films reject UV and infrared radiation to provide additional protection against fading or to reduce solar gain.

14.6.2.11 Laminated Glass

Laminated glass incorporates a clear vinyl layer sandwiched between two layers of glass. The vinyl holds the glass together in the event of breakage and also reduces sound transmission through the glass. Laminated glass can be found in glass skylights, storefront windows, hurricane areas and other locations where impact resistance is desired, and in windows subject to high levels of noise such as in airports.

14.6.2.12 Glass Strength

Standard float glass, which is used in most installations, is annealed, as opposed to heat-strengthened or tempered glass where the glass is cooled quickly to place material near the outer surface of the glass in compression and strengthen the glass. Annealed glass is cooled slowly to eliminate these stresses. Tempered glass is commonly used in doors and in some laminated skylights. When broken, it shatters into very small pieces. Heat-strengthened glass is also used in laminated skylights and in areas where stronger glass performance is desired. One example is a façade where the glass may be partially shaded, which induces thermal stress in the glass along the shadow line. This is particularly true for glass that absorbs higher amounts of solar energy. Heat strengthened glass will break into larger pieces than tempered glass. Glass can also be chemically strengthened.

Some security and safety glass products are designed with a film applied to the glass to prevent easy breakage. Fire-rated glass is available in a variety of different configurations. This type of glass is rated for a given period of time, and may include tempered glass, gel-filled units, glass ceramics and wire glass, among others. Some reflect heat to provide added safety to occupant's on the opposite side on the glass.

Table 14.3 | Examples of Glass Properties

A variety of different types of glazing material and their performance properties. Quantities are center-of-glass values. All configurations are insulating, double-layer unless indicated. High LSG values are beneficial in spaces where cooling is frequently required since it indicates more light transmission (lumens) per watt of energy transmitted into a space. Reflective glazing, in addition to having low LSG, often also has low VT.

Glass Type	Color	VT (%)	SHGC (%)	LSG	U-Factor (Winter)
Standard Low-E	• Clear	79	70	1.13	2.74
	• Grey Tint	40	45	0.89	2.74
	• Bronze Tint	48	50	0.96	2.74
	• Blue-Green Tint	60	39	1.54	2.74
Reflective Low-E	• Reflective Grey	15	27	0.56	2.74
	• Reflective Bronze	19	30	0.63	2.74
Spectrally Selective Low-E	• Low Iron Clear	64	27	2.37	1.60
	• Green	49	28	1.75	1.60
Skylight, Low-E, Double w/Argon Fill	• Clear	53	32	1.66	2.85
	• White	38	30	1.27	2.74
Skylight, Triple	• White	45	58	0.78	1.71

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14.6.3 Performance Properties of Common Glazing Materials

The various options in coatings, fill gasses and the number of glass layers provide differences in the visible transmittance and thermal performance properties for architectural glazing and skylight materials. A brief sampling of different glazing materials and their characteristics are provided in Table 14.3. LSG values in this table vary significantly across the different types of glass. The High LSG values possible with spectrally selective coatings provide daylight with less solar gain and are very beneficial in warm and hot climates. The reflective glass types listed have low solar gain, but even lower visible transmittances, and are not good choices for daylighting applications. The low LSG on the triple-layer skylight is designed to provide beneficial solar gain to help offset heat loss in a colder environment. Manufacturer catalogs or the Window software [26] should be consulted to determine the performance properties of glazing material.

14.6.4 Acrylic and Polycarbonate

Most unit skylights for commercial buildings are constructed of either acrylic or polycarbonate material. These higher performance plastics can be either clear or diffusing, and are often domed, vaulted or pyramidal to accept daylight from lower angles and increase the skylight's structural rigidity. Like windows, skylights can be created with one, two, or three layers of glazing material to achieve different thermal performance. Most modern acrylic and plastic glazing materials are UV-stabilized and will not yellow over time when exposed to UV radiation. Acrylic and polycarbonate glazing are commonly found in both residential and commercial curb-type skylight products.

14.6.5 Prismatic Materials

Prismatic materials offer another approach for diffusing sunlight in skylight applications. Prisms, facets and ridges on the glazing surface can be used to disperse the sunlight beam as it is transmitted through the material. The advantage of prismatic skylight materials is higher VT than is possible with a white pigmented material (by minimizing material reflection and absorption). Higher VTs help to minimize the glazing area required, which can improve energy efficiency by minimizing heat gain and loss.



Figure 14.16 | Clerestories Applied in a Worship Space
Diffusing fiberglass sandwich panels are applied in clerestories on all four walls of this space to provide daylight from all directions and help to brighten the ceiling, eliminating the need to apply uplight luminaires that are mounted on the large steel trusses during daytime services. The floor-level windows are clear to provide a limited view to the exterior and help balance luminances across the vertical extent of the walls.
» Image ©Richard Mistrick

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14.6.6 Sandwich and Cellular Panels

Sandwich panels are multi-layer, flat diffusing fiberglass panels which can have insulation between the panels to improve their thermal resistance [33]. The transmitted light is diffuse. While these products do not have very high VT values, the higher additional thermal resistance provided by the insulating layers helps to counter the need for greater surface area. Sandwich panels can be used in skylights, sloped, or vertical glazing where a diffusing material is desired over a large area (see Figure 14.16). The material should be UV stable to prevent yellowing. High performance versions of these materials incorporate a silica aerogel for the insulation, with some products provide a U-factor that approaches the performance of an opaque wall, but with a relatively low 20% transmittance [34].

Cellular polycarbonate panels are another option for translucent glazing. These panels are constructed of rectangular cells with either air or an insulating material like silica aerogel within the cavities. The panels are translucent, lightweight and are good insulators.

14.6.7 Embedded Systems

Some glazing systems have optical features embedded within the glazing material. Multi-layer window configurations may contain blinds or a reflector system between the layers of glass. If specular, they can redirect daylight to the ceiling or reject sunlight and heat by reflecting a portion of the sun's rays back out through the window [35]. A sample of such a product is shown in Figure 14.17. Another optical system involves an acrylic panel with laser cuts embedded in the panel to redirect sunlight using total internal reflection. Light that strikes these cuts above the critical angle (see 1.5.1.1 Reflection) is reflected upward toward the ceiling.



Figure 14.17 | Specular Reflectors within a Glazing System
This fixed system is designed to reject high angle summer sunlight while redirecting lower angle sunlight inward to the ceiling.
» Image ©OKALUX GmbH/Germany.

Static specular systems will redirect daylight at different angles at different times of the day and year. Some systems utilize curved reflectors where different sections of the reflector are tuned to different incoming solar angles. Static reflector and single axis systems do not alter a sun ray's azimuth direction, with the result that morning light is directed to one side of a room and afternoon light to the other side. Daylight distributions that change significantly with season or time of day make electric lighting system integration more challenging.

The solar heat gain provided by embedded systems that contain specular reflectors will depend on the incident sunlight direction and where the sun's rays are reflected. Advanced computer models that apply BSDF data or full optical modeling of these systems are necessary to evaluate the sunlight contribution through these glazing systems.

14.7 Daylight Delivery Systems

A daylight delivery system is a collection of architectural elements, including an arrangements of windows or skylights along with accompanying shading, glare control, and light redirection devices. These collectively admit, control and distribute daylight to a building's interior. The shape of a space also plays an important role in the delivery and control of daylight, as does the placement of the daylight aperture within the space, with higher apertures spreading daylight across larger areas.

Daylight delivery systems include a variety of sidelighting and toplighting systems (see Tables 14.4 and 14.5). A daylight delivery system is designed to admit and/or redirect daylight from the sun, sky, and ground, all of which may provide light onto a daylight aperture (see 7.1 Daylight). A single space may also be daylit using more than one delivery system, such as a combination of windows and skylights, to increase daylight coverage.

A daylight delivery system must perform over a wide range of sky conditions, and must address occupant comfort by limiting the luminance within the field of view while dis-

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Table 14.4 | Sidelighting Systems

Sidelighting System	Comments
View Window	• Provides a visual connection to the exterior • Provides non-uniform daylighting to spaces along a building's perimeter, to a depth of 1.5 to 2 times window height • Requires operable shading devices in work spaces, except for some north-facing exposures • Luminance of shading devices when illuminated by direct sunlight is an important design consideration
Window w/Overhang	• Overhang blocks sunlight at high profile angles before it enters the building • Improves lighting quality by limiting occupant exposure to influences of direct sunlight • Preserves view at many hours when shades would otherwise need to be applied • Helps reduce building cooling load • Overhang may be solid, translucent or louvered. Translucent and louvered will transmit diffuse daylight to the window • Overhang must be wider than the window to be effective across a wide range of solar elevation azimuth angles
Window w/Fins or Recess	• Fins block or filter sunlight (depending on material) at higher lateral angles, reducing the need to apply operable shading devices and preserving the view • Shading of window reduces building cooling load • Luminance of light colored fins illuminated by direct sunlight can become a glare source
Clerestory (Window above Eye Height)	• Provides deeper penetration of daylight due to the height of the glazing • Requires evaluation of direct sunlight potential, which can be remedied with translucent glazing and fixed or operable shading elements, where necessary
Light Shelves	• Provide a more uniform daylight distribution by reducing high levels adjacent to the window • Vision glass may be slightly lower in transmittance; High VT for upper window helps increase daylight penetration • Shelf should be wider than window to block sunlight at higher elevation azimuth angles.
Exterior Shelf	• Shelf serves as overhang for lower window, eliminating the need for interior shading devices much of the time. • Shelf reflects daylight onto ceiling through upper window • Shelf may be opaque or translucent • Upper window will require shading if no interior shelf is present
Interior Shelf	• Shelf blocks transmitted sunlight from striking work plane directly, increasing daylight levels by allowing the upper window to operate without interior shading devices in most designs • Shelf reflects daylight to the ceiling; a semi-specular reflectance increases daylight penetration

tributing daylight to interior surfaces. Interior and exterior control, redirection and shading elements are generally required. There is no single solution that works in all spaces and orientations. Daylighting systems are discussed in more detail in the sections that follow.

14.7.1 Sidelighting Systems

Sidelighting involves daylighting through vertical walls along the perimeter of a space. If the windows are at or near eye height, they function as both daylight and view apertures. One of the challenges of sidelighting systems is that the daylight distribution provided by these systems is inherently non-uniform. The amount of daylight delivered to a horizontal work plane drops off significantly with distance from a window.

Figures 14.18 to 14.21 provide graphic performance data for a number of the systems described in this section. Note that sky, aperture, glazing, shading and room characteristics affect daylight distributions, and the performance shown is for the listed space and aperture conditions. Distributions will vary as sky and solar positions change. It is important to understand how these systems perform to best tailor a design to a space and to its visual tasks. In some cases, an overcast sky provides higher interior values than does a clear sky. Other sky conditions, such as some form of partly cloudy sky, may provide even higher values.

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Table 14.5 | Toplighting Systems

Toplighting System	Comment
Skylights	• Take advantage of high daylight levels provided by direct sunlight on the roof • Can provide a relatively uniform distribution of daylight across a space • Provides daylight from above - the best direction for lighting most tasks • Interior levels vary linearly with exterior horizontal values, peaking with summer clear skies • Consider splaying wells for wider interior daylight distribution and improved efficiency • Skylights over work spaces must be diffusing, or must contain baffles or louvers to block direct sunlight • Apply high performance materials and appropriate aperture area to control heat loss and solar gain • Energy savings can only be achieved if electric lighting is dimmed or switched off • Requires coordination with structural, mechanical and electric lighting systems.
Clerestories and Roof Monitors (Includes Sawtooth Roof)	• Can provide daylight across a large area • Best to apply clear glazing facing north and address sunlight penetration on other orientations using diffuse glazing, baffles or other shading devices where direct sunlight would be objectionable, such as in most work spaces • High roof reflectance increases daylight levels • High ceiling reflectance increases daylight levels. • Proper sizing and layout is required to achieve uniformity of daylight across a space
Sunlight Pipe	• High daylight delivery efficiencies are possible for the direct sunlight beam • Require direct sunlight, so best in climates with a large fraction of clear skies • Interior appearance is that of a luminaire when used with a finished or dropped ceiling Requires coordination with other systems to avoid interference problems in attics and ceiling plenums • Sunlight pipes can be as long as 15m, with bends permitted in the pipes

14.7.1.1 View Windows

The view provided by a window is very important to the occupants, but at the same time provides daylight to the perimeter of a building. As a rule of thumb, daylight penetration into a space from windows for the purpose of achieving energy savings through automatic lighting control is only practical to a horizontal distance of approximately 1.5 to 2 times the window head height when windows have moderate to high VT. In some building/energy codes, the area within one window height of the exterior wall is considered as a primary daylight zone, while the area between one and two window heights is referred to as the secondary daylit zone, and may need to be controlled separately from the primary daylit zone. North-facing spaces, where windows can provide clear views of the exterior with little to no sunlight penetration, may provide deeper daylight penetration than other spaces where interior blinds or shades are likely to be applied. Overcast skies are likely to provide less penetration since the ground luminance is rather low and the sky is brightest at zenith. Higher or taller windows will provide deeper penetration through direct illumination of the work plane. The fraction of total work plane light that is reflected from interior surfaces increases with distance from the window as shown in Figure14.7. The distribution of daylight on the ceiling is also a function of window position. The closer the top of the window is to the ceiling, the bright the ceiling will be at the exterior wall. Lower portions of a window direct daylight deeper into the space onto the ceiling.

A number of studies have analyzed the minimum preferred window size, and have shown dependence on the nature of the view provided [36] [37] [38]. Most of these studies were performed in open plan offices. The results indicated that larger windows are required when the view contains objects that are closer to the window, since occupants prefer that the view be framed within the window. At larger occupant distances from a window, the view becomes more restricted for a given window size, and wider windows are preferred. The minimum acceptable window size listed in these studies was in the 25-30% range for the interior window-to-wall ratio, with ratios less than about 15-20% perceived as unacceptable. Subjects also prefer larger and more regular window patterns with thinner mullions; windows with a VT of at least 35 to 40%, and transmission that is spectrally

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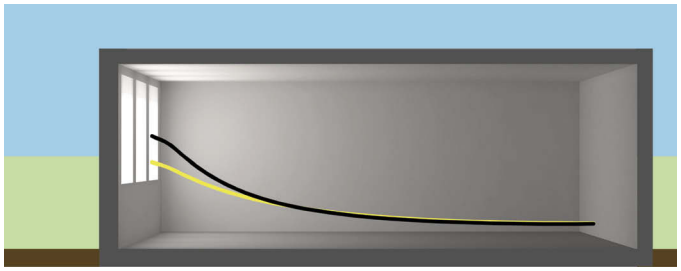
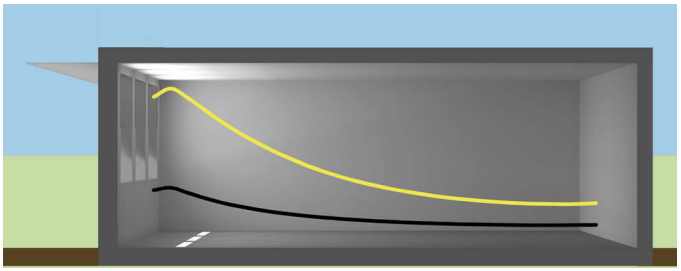
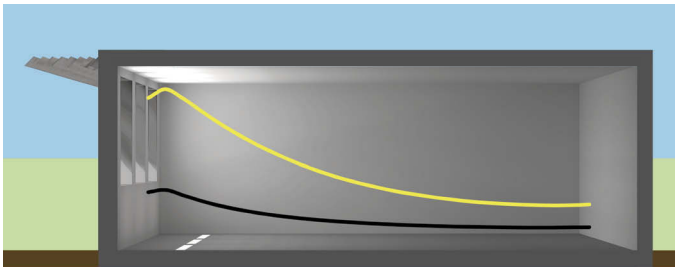


Figure 14.18 | Sidelighting: South-facing Window Studies

Clear Sky: T_{vis}=0.035 Diffuse; Overcast: T_{vis}=0.50
Glazing is clear-vision glass with a low-transmission diffusing overlay to approximate fabric shading when direct sunlight glare is problematic. In all examples, clear-sky (yellow) and overcast sky (black) illuminance distributions are shown for March 21 at solar noon. Room reflectances are 90/60/20 (ceiling/walls/floor).



Clear Sky: T_{vis}=0.50; Overcast: T_{vis}=0.50
Glazing is clear-vision glass. An opaque overhang helps to avoid direct sunlight glare at higher solar profile angles and the need to apply shading during many daylight hours. The March 21st clear sky condition with no shade (only a sliver of sunlight can be seen on the floor) produces significantly higher daylight levels than the condition above, which requires shading. Under overcast skies, however, daylight levels are reduced due to the limited view of the sky.



Clear Sky: T_{vis}=0.50; Overcast: T_{vis}=0.50
Glazing is clear-vision glass. A louvered overhang is introduced to address direct sunlight glare. Performance with these louvers is very similar to that of a solid overhang

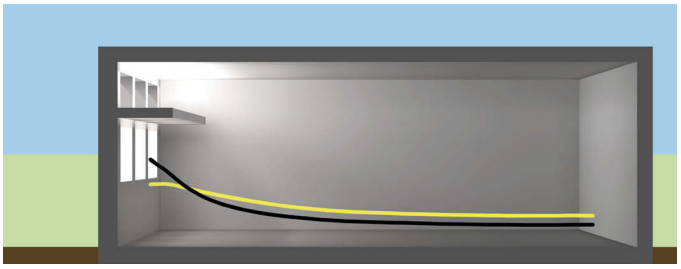
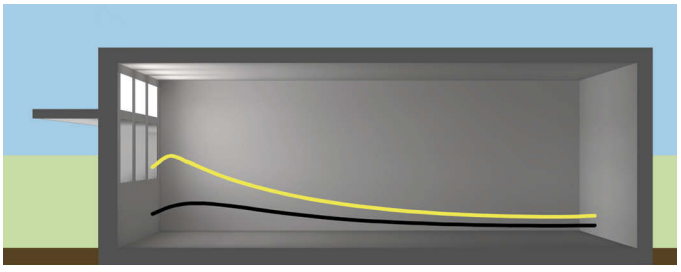
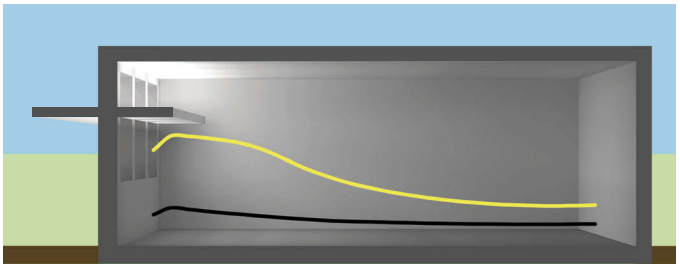


Figure 14.19 | Sidelighting: South-facing Light Shelf Studies

Interior Shelf, Clear: T_{vis}=0.65/0.04 (upper/lower window); Overcast: T_{vis}=0.65/0.50; ρ_{shelf} = 0.80
Glazing is clear-vision glass. Under clear sky conditions, a translucent (diffusing) shade covers the lower window to block direct sunlight. Both a clear sky (yellow) and overcast sky (black) illuminance distribution are show for March 21 at noon. Room reflectances are 90/60/20 (ceiling/walls/floor).



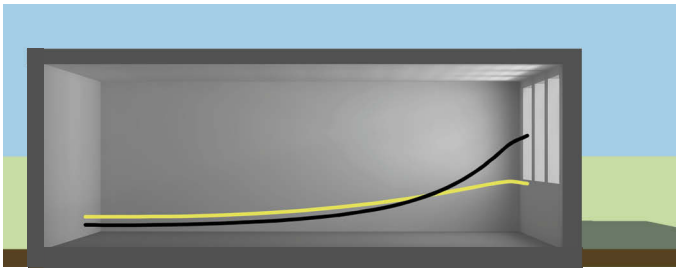
Exterior Shelf. Clear Sky: T_{vis}=0.08/0.50; Overcast: T_{vis}=0.65/0.50; ρ_{shelf} = 0.60
Glazing is clear-vision glass. An opaque overhang is introduced to address direct sunlight glare. Translucent shades are applied to the upper window under clear skies.

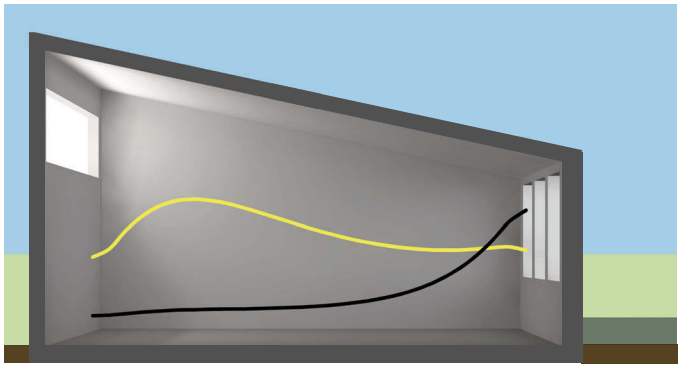


Exterior and Interior Shelf, Clear Sky: T_{vis}=0.65/0.50; Overcast: T_{vis}=0.65/0.50; ρ_{shelf} = 0.60/0.80 (exterior/interior)
Glazing is clear-vision glass. An opaque overhang is introduced on both sides of the window to address direct sunlight glare. Interior illuminance under clear skies is significantly improved under clear skies, but is reduced under overcast skies due to sky obstruction.

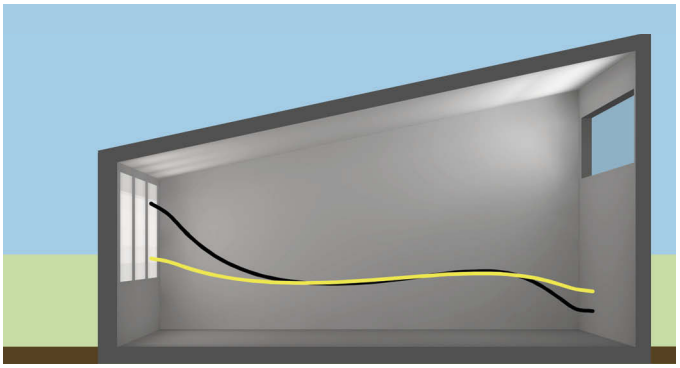
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Figure 14.20 | Sidelighting: North-facing Window Study
Clear Sky: T_{vis}=0.65 Diffuse; Overcast: T_{vis}=0.65
Glazing is clear-vision glass with no fabric shading or overhangs. Clear-sky (yellow) and overcast sky (black) illuminance distributions are shown for March 21 at solar noon. Room reflectances are 90/60/20 (ceiling/walls/floor). Overcast sky values are slightly higher than south due to higher transmittances. Clear sky values are slightly higher than south-facing with translucent shades. View can be maintained under most daylight conditions.





(a) Both Skies: Clerestory, T_{vis} = 0.20, Diffuse; View Glazing, T_{vis} = 0.65



(b) Clear Sky: View Glazing, T_{vis} = 0.035; Clerestory, T_{vis}=0.65
Overcast: View Glazing, T_{vis} = 0.50; Clerestory, T_{vis}=0.65

Figure 14.21 | Sidelighting: Bilateral Daylighting Studies
Typical daylight distributions provided through bilateral daylighting using a clerestory and view glazing. (a) South-facing diffuse clerestory with a clear north view window, (b) South-facing view window with diffuse shading under clear skies and clear north-facing clerestory. Both a clear sky (yellow) and overcast sky (black) illuminance distribution are show for March 21 at noon. Room reflectances are 90/60/20. Overcast sky performance is lower for the lower transmittance, diffusing south-facing clerestory configuration.

neutral. In one study, people preferred some sunlight entering the windows, particularly when they were seated farther from the window. In interior zones, an atrium can provide a connection to the exterior through sunlight patterns, changing levels of daylight, and possibly even a view if the atrium is on the building's perimeter and has vertical glazing.

View windows in work spaces that are exposed to low angle sunlight must be fitted with operable interior or exterior shading devices to block direct sunlight at these times. Overhangs or light shelves can shade interior work surfaces from high angle sunlight, which permits the occupants to retain an unobstructed exterior view over more sky conditions. Still, under certain conditions, view windows can become objectionably bright. Space layouts should orient workers so windows are to their side, to keep bright windows out of the direct field of view and avoid reflections in computer displays. The orientation of computer displays is important in many different space types, such as offices, schools, airports, and stores. Likewise, the orientation of chalkboards and white boards in schools should avoid reflections from daylight apertures.

14.7.1.2 Clerestories

Another effective daylighting approach involves the use of clerestories, which are windows positioned above eye height, or above an adjacent roof. Their added height provides greater daylight penetration, but offers little benefit in terms of view. Smaller view windows can be added to provide a visual connection to the exterior. Sunlight penetration may require the application of overhangs, diffuse glazing or adjustable shades in spaces with important visual tasks. Figure 14.22 illustrates a few clerestory applications. Some clerestory configurations are a cross between toplighting and sidelighting, locating a clerestory element within the ceiling. Clerestory windows can be configured to provide

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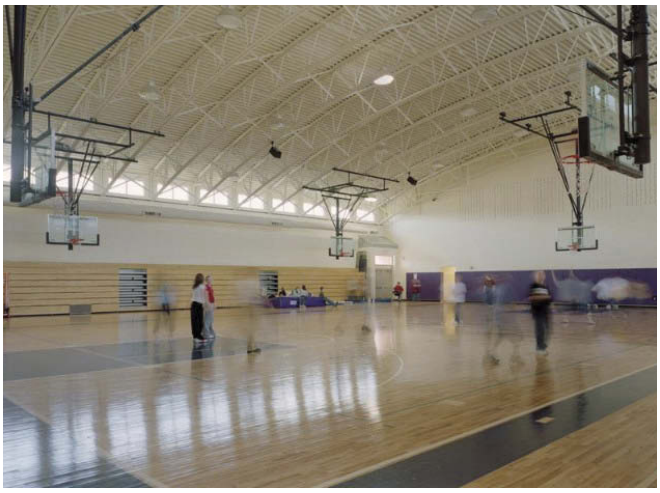
relatively uniform daylight levels over large areas, with ceiling-reflected daylight illuminating the space directly below the clerestory window.

14.7.1.3 Light Shelf Systems

Light shelves are horizontal shading and light reflecting elements along a window that intercept and redirect sunlight and sky light upward into a space. They can be located on the exterior, interior or on both sides of a window. They are most effective on a south-facing facade and work best in sunny climates. An interior light shelf intercepts and reflects sunlight penetrating through a window directly above it, permitting this window to remain unshaded most of the year. Only at very low sun angles is sunlight likely to pass through the upper window without striking the shelf. On a southern exposure, this will likely occur during the winter at mid-latitudes. The number of hours of sunlight penetration should be assessed to determine if shading devices are needed on any upper glazing.

An exterior shelf or brise soleil shades the lower window and reflects sunlight through the upper window (mostly in a diffuse manner, but this depends on the shelf material). Since interior shading would not be required except at low sun angles, the view out through the lower window is retained for a large fraction of the daylight hours. An additional and important benefit is that a shelf partially blocks the view of the sky at locations near the window. This reduces the illuminance near the window and creates a more uniform daylight distribution across a space since points near a window would otherwise receive excessive amounts of daylight. In addition, the view of the bright sky is limited, providing a more comfortable viewing condition for occupants in this area.

It is often stated that the purpose of a light shelf is to increase daylight penetration by redirecting sunlight onto the ceiling deep within a space, but this is not generally true.





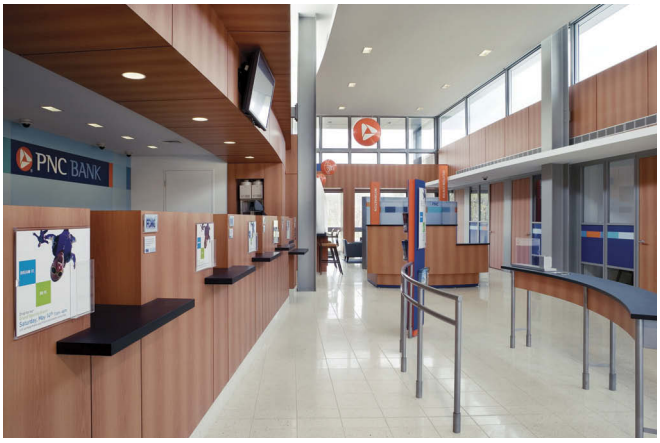


Figure 14.22 | Clerestory Examples
From bottom left clockwise, clerestories deliver daylight to the lobby/teller area of a small branch bank, to a gymnasium, and to a library.
» Left Image © PNC Financial Services Group
» Top Left Image ©Perkins & Will
» Top Right Image ©Jon Zachary

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Most light shelves are nearly Lambertian (diffuse reflectors), so the shelf primarily illuminates the ceiling directly above it, which then reflects the light into the space in a diffuse manner with only a fraction of this daylight penetrating deep into the space. If both the shelf and ceiling are diffuse reflectors, upon each reflection, half of the light leaving those surfaces is directed back toward the window. For a light shelf to direct a significant amount of light deeper onto the ceiling, it must be constructed of a material that is at least semi-specular. A material that is too specular will image a sunlight beam pattern onto the ceiling with streaks or hot spots.

Light shelves are less effective under an overcast sky or when a façade is in shade. Under these conditions, light shelves reduce interior daylight levels at all points compared to an unshaded window, since from any point on the work plane the view of the sky is partially obstructed by a shelf. The top surface of a shelf receives significantly less daylight when it is illuminated only by light from the sky. Annual daylight metrics permit the evaluation of light shelf performance under sky conditions likely to be present at a building site, and are strongly recommended for evaluating performance across the sky conditions expected at a site. Figure 14.19 provides a comparison of the daylight distribution across a space provided by different light shelf configurations for an overcast and single clear sky. Diffusing shades are necessary for conditions when sunlight penetration would produce objectionable interior conditions.

An important and often overlooked concern with light shelves is the amount of time that low angle sunlight entering the window above the shelf will penetrate beyond an interior shelf, illuminating room surfaces, work plane tasks, and occupants with direct sunlight. This is likely to occur in virtually any light shelf design, with shorter shelves increasing the amount of time that sunlight penetration will occur. A deeper shelf will block sunlight more times of the year, but also reduces the amount of daylight delivered to the space since the shelf obstructs more of the sky and intercepts more daylight.

In the design of light shelves, the width of both interior and exterior shelves is also important - a shelf must be wider than the window opening to block low altitude sunlight at non-zero azimuth angles relative to the façade (higher solar elevation azimuth angles). See 14.10 Assessing Sunlight Penetration for sunlight penetration assessment techniques.

Light shelves do not need to be opaque. Figure 14.23 illustrates a novel variation of a light shelf that applies a translucent material to redirect daylight from a clerestory both upward and downward. Without this translucent material, the floor and wall directly below the clerestory would receive significantly less daylight than the remainder of the room since an opaque shelf limits the view of the bright ceiling area.

14.7.1.4 Reflector Systems

Reflector systems have been developed for the upper portion of a window to redirect daylight deep into a space onto the ceiling. While an interior light shelf is a single reflecting element, these systems are comprised of multiple elements, on a smaller scale, that redirect daylight in a specular manner. In these systems, the angle of reflection must be carefully controlled to direct sunlight upward onto the ceiling, and not downward into occupants' eyes. Dynamic systems consist of specular horizontal blinds that can be adjusted to redirect sunlight to the ceiling deep within a space. In some products, an upper section of blinds is combined with a lower section that is configured to block direct sunlight and admit diffuse daylight. The challenge of any reflector system is that it requires precise beam control to illuminate a ceiling deep within a space at a near grazing angle. A small change in the reflected light ray direction results in a significant change in where the reflected ray will strike a room surface. Some specular reflector systems are small enough to be located within the air space of insulated glazing units, which eliminates the need for cleaning of the mirrorlike surfaces.

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Figure 14.23 | Translucent Light Shelf
This clerestory design applies a translucent arching light shelf with integrated electric lighting. The structure transmits daylight to the wall and floor directly below the shelf, increasing daylight levels under the shelf, illuminance uniformity and helping to balance room surface luminances across this classroom.
» Image ©Innovative Design



Figure 14.24 | Specular Reflectors
A specular reflector system is applied to the interior of the upper portion of a window to redirect daylight to the ceiling of an office space. Mullion and column shadows are visible across the ceiling and an exterior light shelf shades the lower window (supports are visible outside the window).
» Image ©LightLouver, LLC

A static reflector systems is shown in Figure 14.24. The challenge for a static system is that sunlight angles vary across the year, by 47 degrees in altitude angle at noontime alone. A 5-10 degree change in output direction will significantly change the distribution of daylight on the ceiling, so different sections of this fixed, curved reflector direct sunlight different distances onto the ceiling, and the redirected sunlight angle for any single point on the reflector varies significantly throughout the year (by 47 degrees).

During the summer, when the sun is high in the sky, significantly fewer lumens are incident on a window, and the hours during which a south-facing window receives sunlight is reduced given the sun's path across the sky - a southern exposure is in shade except for a few hours around solar noon when it receives sunlight at very high angles. In applying these systems, reflectors must be mounted as close as possible to the exterior façade to avoid being shadowed by the window frame or due to the thickness of the exterior wall.

When considering reflector systems, it is important to investigate the patterns and distribution of light provided on the ceiling (from the upward directed light) and the luminance of the reflector system when viewed from typical occupant positions within the space. Both will vary with solar position and with sky conditions. Off-axis solar azimuth positions result in similarly angled reflections onto the ceiling. See Figures 14.7 and 14.8 for solar azimuth and altitude angles across the year. BTDFs are beginning to become available for these systems to permit detailed modeling studies to be performed [39].

14.7.1.5 Sunlight Tracking Systems

Direct sunlight, with its collimated beam, lends itself well to redirection using specular reflectors or to focusing into optical fibers. Some advanced reflector systems incorporate a sun-tracking system and redirect sunlight along a predetermined path, such as into an atrium or vertical light chase, or horizontally through a ceiling plenum or across the upper portion of a room. The redirected light rays then either strike an architectural surface, or are distributed by another optical device. Fiber optic daylight distribution systems apply lenses or reflectors to focus the sunlight into optical fibers which transfer the daylight to interior spaces. The fibers terminate within a device that resembles a luminaire mounted at the ceiling. Any optical system that must focus or redirect sunlight in a consistent direction must track the sun's position, which adds to system costs as well as to maintenance costs. These systems are most effective in locations where sunlight is plentiful.

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Figure 14.25 | Toplighting Examples
Top: A skylight with a shallow well provides highly efficient and uniform daylighting in an industrial space. The high reflectance ceiling and floor increase illuminance and overall space brightness.

Middle: Splayed skylight wells improve system efficiency and daylight distribution in a classroom. Placing the edge of the splayed well close to the wall eliminates shadowing on the upper wall.

Bottom: North-facing clerestories in a sawtooth roof deliver diffuse daylight into pre-kindergarten classrooms.

» Top Image ©SunOptics
» Middle Image ©SunOptics
» Bottom Image ©Prakash Patel/VMDO







14.7.2 Toplighting

Toplighting involves daylight systems that primarily deliver light to interior spaces from the roof. Glazing may be horizontal, sloped or vertical (as in the case of a sawtooth roof monitor). Figure 14.25 provides a number of examples. The orientation of the daylight aperture and the nature of the tasks in the space beneath skylights dictate whether clear or translucent glazing is preferred. In most of these systems, a uniform layout of daylight elements across the ceiling produces a uniform distribution of daylight across the space. In some cases, toplighting may be applied in a non-uniform manner to wash a wall, or to accent a portion of a space (see Figure 14.26).

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Figure 14.26 | Skylight Wall Wash
A narrow skylight and well are used to wash the front wall in this small chapel. Electric lighting for the wall is also located within the well for nighttime use.
» Image ©Richard Mistrick

14.7.2.1 Skylights

Skylights are the most common toplighting approach and can vary from small unit skylights to large structural glazing systems [40] [41] [42] [43] [44]. Some specialized forms apply advanced optical devices. In spaces with a dropped ceiling, attic, or concealed roof structure, daylight is transmitted from the glazing to the space below through a skylight well, which affects the amount and distribution of the daylight entering the space. Skylights offer a number of distinct advantages as a daylighting system. First, where sunlight is abundant, the available daylight on the roof of a building is significant, permitting smaller aperture areas than would be required with vertical glazing to achieve similar daylight illuminances. This helps to minimize heat loss and solar gain. Second, providing daylight from above provides light of high quality and uniformity.

Clear vs Translucent

Skylights are usually made of glass, acrylic, polycarbonate or fiberglass. If clear glazing is desired, the skylight is made of tempered or laminated glass or an acrylic material to prevent breakage. Translucent glazings are acrylic or polycarbonate and may be flat, domed, pyramidal, vaulted, or some other shape. Pyramidal and domed skylights that project upward from their base help to collect daylight from the sun at low altitude angles.

For skylights over work areas in offices or industrial situations, translucent glazing is usually necessary to diffuse direct sunlight and broaden the interior daylight distribution to cover a larger area, preventing bright sunlight patterns from striking tasks or neighboring surfaces. In public spaces, both clear and translucent glazing are acceptable. Very large areas of translucent glazing alone, however, may cause a space to take on the unwanted appearance of a cloudy day in the absence of strong shadows and directional highlights. Large areas can also be exceedingly bright when illuminated by sunlight. Dynamic sunlight patterns provided by transparent glazing are often desirable in these spaces, providing a connection to the exterior and adding visual interest. The sparkle and drama provided by direct sunlight is possible with only a small fraction of the total skylight area (such as 10%) being transparent. Atria, lobbies, shopping malls, airports and other large spaces often include tinted transparent glazing in skylights which has a reduced transmittance and lower SHGC to improve visual comfort and energy efficiency. When transparent skylights are applied, careful layout or special treatment may be necessary to shade work areas such as counter areas, information desks, and reception desks from direct sunlight to create comfortable working conditions.

Clear and translucent skylights differ in their thermal impacts. Heat gain associated with clear glazing is likely to occur in areas illuminated by the sunlight beam, which can cause thermal discomfort. Translucent glazing disperses the daylight and other radiation over a much wider area so that little to no thermal impact can be felt by the occupants.

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Well Shape and Size

In spaces with a ceiling plenum, well shape and size along with the glazing material determine both the system efficiency and the distribution of daylight within a space. Tall, vertical wells focus daylight downward rather than at wider angles, requiring shorter spacing between skylights to achieve work plane uniformity. More daylight is also lost within the well due to absorption. Splaying the sides of a well can significantly improve a skylight well's efficiency and also widen the daylight distribution as shown in Figure 14.27 and 14.28. Splayed wells should be considered when a skylight well must traverse a relatively deep ceiling plenum. Well efficiencies can be determined using Figure F14.1 for vertical wells, and the equations in 14.18.1.13 Splayed Well Efficiency for splayed wells [45].

Spacing of Skylights

The spacing of skylights should be selected to provide the desired uniformity of illuminance or luminance within a space or across a surface. Special situations such as warehouses with tall aisles may require detailed analysis to determine optimal spacing conditions for a skylighting system. In large open spaces, the maximum spacing for skylights ranges from 1.0 to more than 1.5 times the ceiling height above the work plane, depending on the well geometry. Splayed wells and shallow wells permit greater spacing distances

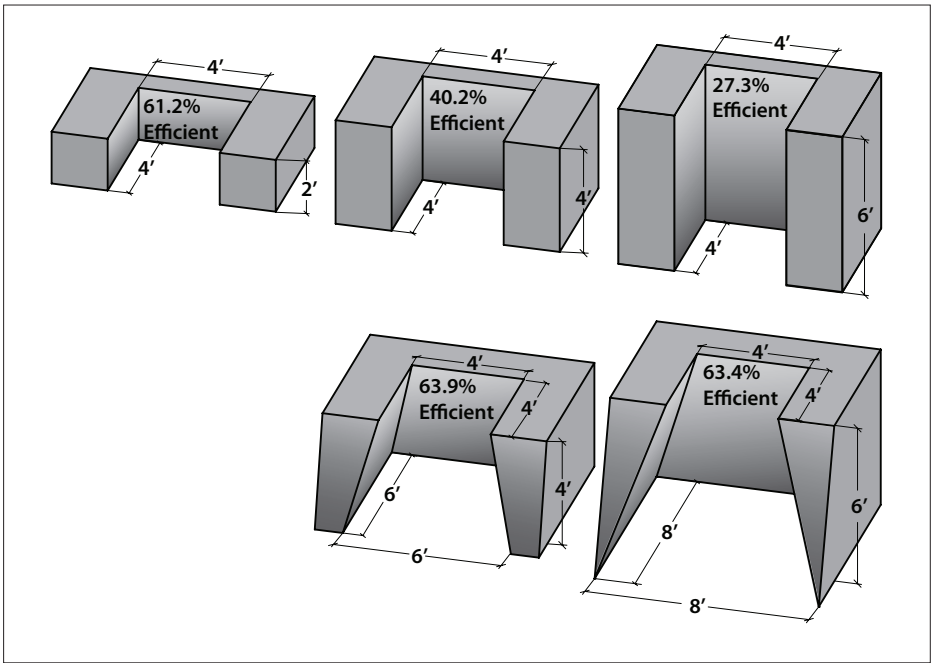


Figure 14.27 | Splayed Skylight Wells
Splaying a skylight well can significantly increase the well efficiency, the amount of light that passes through the well.

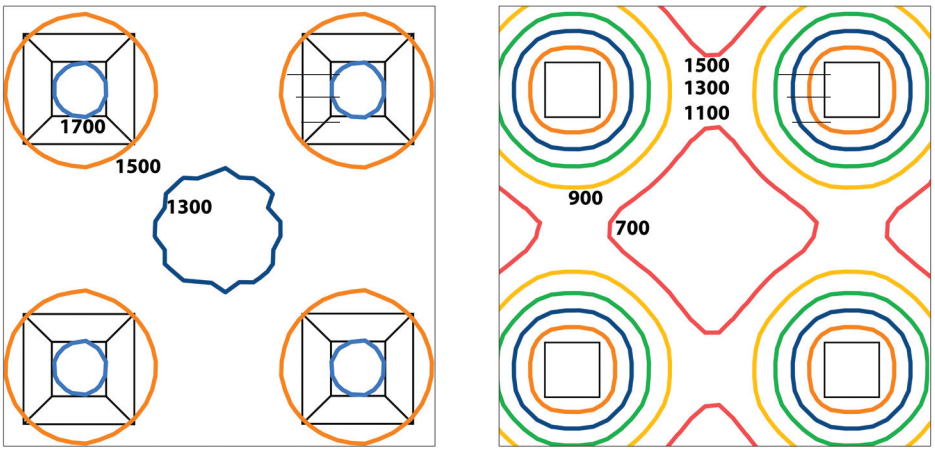


Figure 14.28 | Well Performance
Work plane illuminance uniformity improves significantly when a well is splayed, as shown in these two contour images. The skylight area is the same for both the splayed and vertical well layouts. Skylight spacing is twice the height to the bottom of the well. The height of the well is equal to the skylight width. The bottom edge of the splayed well is twice as wide as the skylight opening.

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than are possible with deep vertical wells. Simple computer models can be used to assess proper spacing for a given well geometry.

Advanced Optical Systems for Skylights

Sunlight tracking reflectors and shading devices either redirect more daylight onto the skylight opening, particularly when the sun is low in the sky, or shade the skylight opening from direct sunlight to avoid overlighting of the building interior at high solar altitude angles. At higher latitudes, the sun is relatively low in the sky (less than 30-40 degrees) for a large portion of the year. A reflector that extends above the roof line can capture more daylight than would occur with a flat or simple domed skylight. The daylight delivered across different hours of the day, as well as through different seasons of the year is more consistent with light redirecting devices. See Figure 14.29 for an example of a skylight with integrated reflectors that rotate within the skylight as it tracks the sun.



Figure 14.29 | A Skylight with Sunlight Tracking Reflectors
The angled reflectors in this solar tracking skylight rotate to redirect sunlight onto a diffusing lens material, increasing the amount of daylight delivered at low solar angles.
» Image ©Solar Tracking Skylights, Inc.

14.7.2.2 Tubular Skylights

Tubular skylights, sometimes referred to as tubular daylight devices or sunlight pipes, involve high reflectance specular metal tubes that act as optical pipes to transfer sunlight from a rooftop collector to a space below as shown in Figure 14.30. The optical sections of pipe are round and fitted with a lens at the bottom, taking on the appearance of a luminaire within the space. The lensed aperture at the ceiling plane broadens the daylight distribution and seals the pipe's interior. The rooftop device consists of a reflector and/or refractor that collects sunlight, and to a lesser degree light from the sky. Since these pipes primarily rely on sunlight, these systems are more effective in climates where clear skies are abundant and present for extended periods of time, since the sudden obstruction of the sun by a cloud will result in an abrupt reduction in the amount of daylight delivered. Some systems provide an option to place an electric light source within the tube, but these do not provide highly efficient electric lighting and obstruct a portion of the daylight within the tube. Tubular skylights are often used in residences, but have also been applied in schools, warehouses, retail, and office applications.

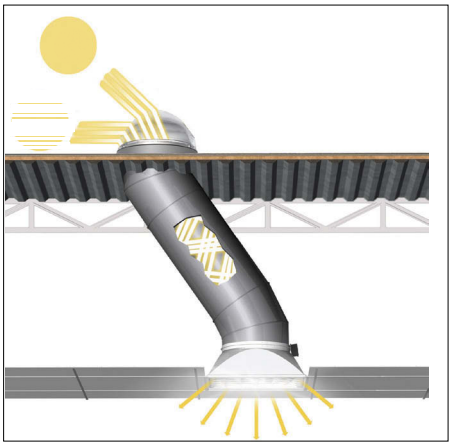


Figure 14.30 | A Tubular Skylighting System
The sunlight collector applies prisms or a reflector to redirect sunlight into a high reflectance specular pipe which terminates at a lens or other optical device.
» Image ©Solatube International

14.7.2.3 Roof Monitors

Roof monitors consist of raised ceiling sections with sloped or vertical daylight apertures along the line where the ceiling is raised (see Figure 14.31). The glazing may be translucent or clear, with clear glazing commonly used on a north-facing exposure to maximize daylight transmission. Translucent glazing is preferred for south-facing monitors. A series of clerestories, with a sloped ceiling/roof between these sections of vertical glazing is referred to as a sawtooth configuration, and was a common daylighting system in factories in the early 1900s. Another option for south-facing roof monitors is to apply clear glass with vertical baffles spaced within the well to prevent direct sunlight penetration to the space below (Figure 14.32).

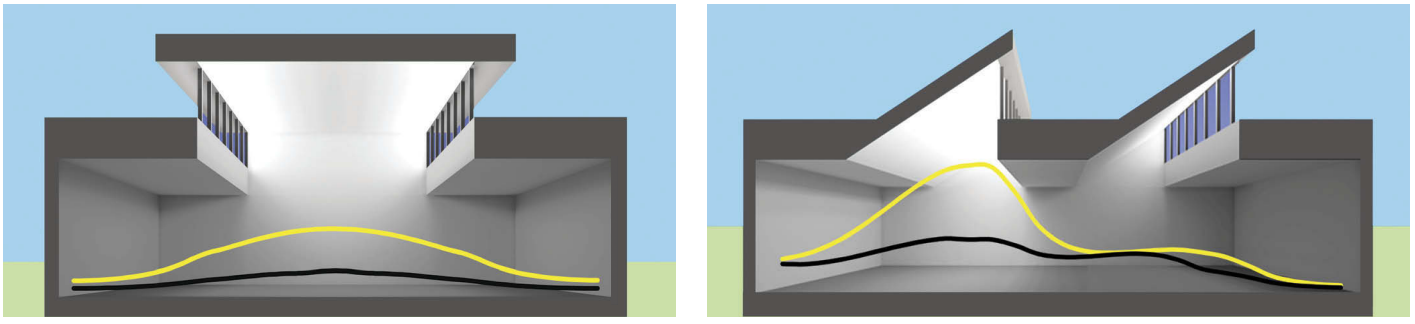


Figure 14.31 | Roof Monitor Study
A standard raised roof monitor (left) and a north facing sawtooth arrangement (right). The illuminance distriubution under both a clear (yellow) and overcast sky (black) are shown for March 21 at noon. The 60% reflective roof in this example adds to the daylight contribution, particularly under clear skies. In the sawtooth design, the left monitor produces higher work plane illuminance due to the added reflection from the sloped roof of the adjacent monitor, which faces the sun.

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Figure 14.32 | Sunlight Blocking Baffles
Fixed baffles in a large centrally located south-facing clerestory within a classroom block any direct sunlight that penetrates the clear glazing, providing diffuse daylighting for the spaces below.
» Image ©Innovative Design

14.8 Exterior Shading Devices

In commercial buildings such as offices and schools, spaces must be cooled many days of the year. To minimize the cooling load, it is essential to control the solar gain through daylight apertures (windows and skylights). This is best accomplished by preventing direct sunlight from striking the glazing surface. The difference in incident radiation between a sunlit and a shaded facade may be as high as 80%. Additional benefits of exterior shading include improved visual comfort by eliminating sunlight penetration and extending the time when the view out is not obstructed by interior shading devices.



Figure 14.33 | Exterior Shading Devices
Exterior shading devices can take many different forms. The image on the left shows vertical elements that shade a facade at higher solar elevation azimuth angles. The open louver in the center image transmits daylight while also blocking direct sunlight. The awning type system on the right blends with the architecture and is effective at shading the windows as seen in the shadows on the building.
» Left and Center Images © Construction Specialties, Inc.; Right Image ©Christopher Beland

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Approaches for shading windows to prevent sunlight penetration include:

- recessing the window
- applying an overhang, which may be solid or translucent
- applying an exterior light shelf, which serves as an overhang for the window below it and redirects daylight to the window above it
- incorporating a brise soleil (louvered overhang or screen) to shade a window.
- applying other screening elements to block sunlight at key angles

Some examples of exterior shading elements are provided in Figure 14.33.

In sizing an overhang, sunlight penetration can be evaluated as shown in 14.9 Assessing Sunlight Penetration. Both the solar profile angle, a_p, and the solar elevation azimuth angle, a_z (the angle of the sun relative to the facade's horizontal orientation) must be evaluated in assessing daylight penetration, as shown in Figure 14.34. See 7.1.5.3 Solar Angles and 7.1.5.4 Solar Angles Relative to a Vertical Surface for a more detailed description of these angles.

The distance that an overhang extends out from a building determines the solar profile angle above which it will completely eliminate sunlight rays. The width of the overhang along a building is also important, particularly when the overhang is for a single window. In many cases, overhangs are designed to be only as wide as the window and therefore shade the window completely only when the sun's azimuth position is perpendicular to the façade. As the solar elevation azimuth angle (solar azimuth relative to the façade) increases in either direction, sunlight passes beneath the overhang and enters the window (see Figure 14.35). Depending on the location of interior tasks, this may cause occupants to apply interior shading devices more frequently. A similar issue can occur with interior light shelves for light entering the window above the shelf. Vertical elements can be added to extend the range of azimuth angles that are adequately blocked, with recessed windows performing a similar function.

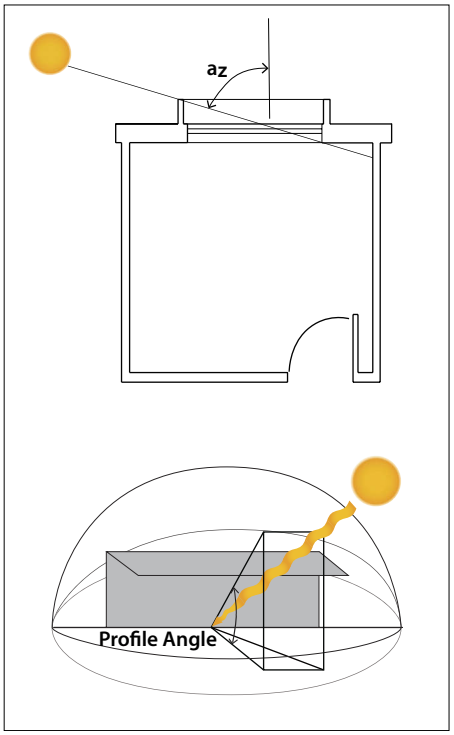


Figure 14.34 | Sunlight Angles and Daylight Penetration
Top: plan view illustrates cutoff of high solar elevation azimuth angles due to window geometry. Bottom: The solar profile angle determines penetration distance in a vertical plane perpendicular to the facade.

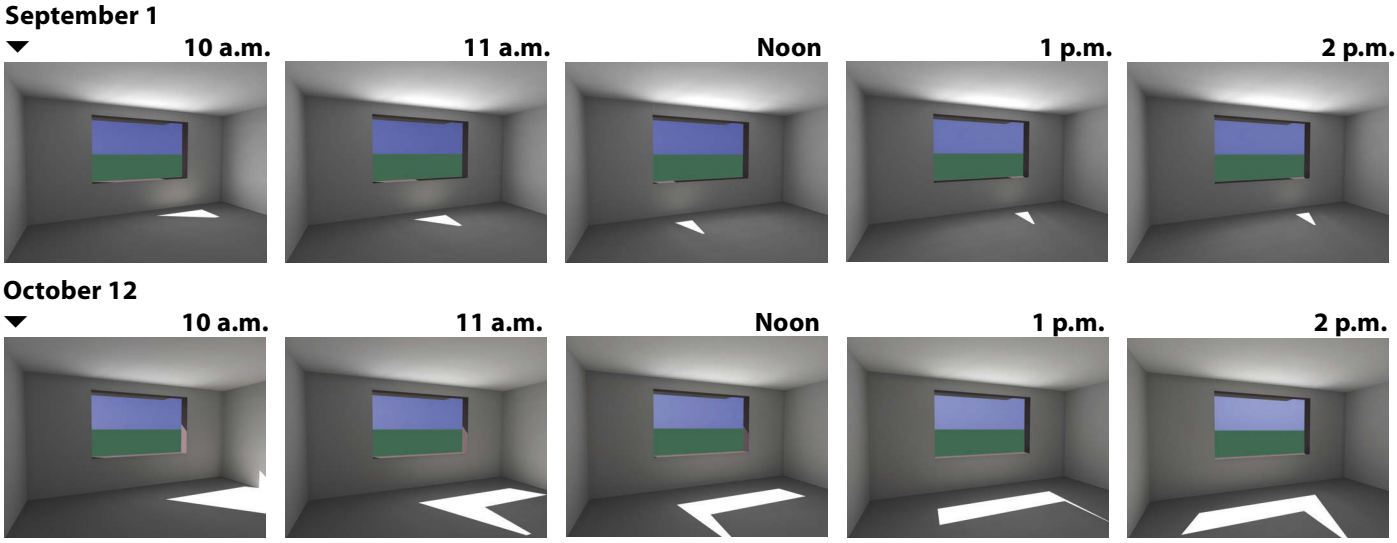


Figure 14.35 | Sunlight Penetration Under an Overhang
These examples show sunlight penetration under an overhang that is only as wide as the window. The overhang extends four feet from a one-foot thick exterior wall. Sunlight passes under the side of the overhang on September 1 where a continuous overhang would allow no sunight to enter the space. At the later October 12 date, sunlight penetration under the side of the overhang permits sunlight to penetrate further than it would with a wider or continuous overhang. The 1 p.m. time is approximately solar noon due to daylight savings time. The site position is 40N and the window faces due south.

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Table 14.6 | Shading Angles for Blinds

The shading angle blocked by blinds with a 15% slat overlap. The solar angle listed in this table is the profile angle, a_p, for horizontal blinds and the elevation azimuth angle, a_z, for vertical blinds.

Blind Angle (Degrees)	Solar Angle Blocked (Degrees)
0	41
10	35
20	29
30	23
40	16
50	9
60	0

14.9 Interior Shading Devices

Shading devices such as horizontal or vertical slatted blinds, translucent shades, or curtains are applied on most windows in work spaces such as offices or classrooms. Occupants operate these devices in response to daylight to block direct sunlight from entering a space and alleviate glare, or to reduce daylight levels that are excessive or uncomfortable. Other uses are for fashion, privacy, and security. Automatic shading systems are now commercially available to optimize interior daylight illuminance, visual comfort and energy savings [46].

Some interior shading devices are fixed, such as a light shelf (see 14.7.1.2 Light Shelf Systems). Even a window system with exterior shading, such as an overhang, will have direct sunlight enter at low solar altitude angles and requires interior shading. This is true on east exposures early in the day, western exposures late in the day, and on a southern exposure during the wintertime at mid to higher latitudes.

Where significant room darkening is required, windows are often fitted with a pair of shades – one for darkening and the other for daylight control. Similar shades can also be added to skylights.

14.9.1 Blinds

Slatted blinds offer angle adjustment to accommodate different daylight conditions and solar positions, while maintaining a limited view out through the space between the blinds. Horizontal blinds are more common than vertical blinds, with vertical blinds better suited to the east and west exposures of a building to address low angle sunlight striking a window from high elevation azimuth angles (the sun's azimuth relative to the façade). The overlap for most blinds is on the order of 15%, allowing horizontal blinds to block out profile angles above 41 degrees when set to a horizontal position. Table 14.6 lists the solar angles that are blocked by a range of different blind angles. For horizontal blinds, the blocking angle applies to the solar profile angle while for horizontal blinds it is the solar elevation azimuth angle. Daylight can pass through blinds with only minor attenuation at incoming angles that run parallel to the blind slats, and is admitted through interreflection, and with greater attenuation, at other angles. Changing the blind angle to a more closed position reduces daylight transmission and the interior luminance of the blinds, providing both daylight and glare control. Blind color affects daylight transmittance, blind luminance, and the color of the daylight reflected into a space. Perforated blinds are available to maintain some of the exterior view even when the blinds are closed. One of the disadvantages of blinds is the appearance across a space or facade with blinds set to different positions and orientations. Specialty products are also available, such as a split set of horizontal blinds with those above eye height configured to reflect daylight to the ceiling while those below are separately adjusted and may have different surface properties.

Horizontal louvers or blinds on a building's exterior shade windows from direct sunlight. Some models can be raised and lowered, while others are permanently mounted in front of the window and may simply rotate. These systems are most popular in hot climates where cooling loads are high.

14.9.2 Fabric Shades

Fabric shades have become increasingly popular in recent years (see Figure 14.36). Characteristics to consider in their selection include the color and weave of the fabric. Most woven shades contain holes covering 1 to 10% of the fabric. This percentage is referred to as the openness factor. For straight-on viewing, direct sunlight is transmitted unobstructed through these holes, but is angular dependent based on the weave of the fabric. Openness factors and transmittance values are for straight-on viewing. In addition to transmitting daylight in a specular manner through the holes, the fabric material itself

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Figure 14.36 | Fabric Roller Shades
Two layers of fabric shades are applied in this conference room – a light colored fabric with open weave and a blackout shade. The light color selected for the blackout shade helps to reduce contrast with neighboring surfaces.
» Image ©MechoShade

transmits and reflects daylight with a distribution that is close to Lambertian (diffuse). Lighter colors and thinner weaves produce higher interior luminances on the fabrics that may cause visual discomfort. The diffuse contribution to transmittance can be approximated by subtracting the openness factor from the total visible light transmittance provided by the manufacturer.

Photosensors can also be configured to lower shading devices when the illuminance on a window exceeds a certain value. When direct sunlight is not present, a photosensor aimed out a window will receive a reading that roughly corresponds to the average luminance of the exterior environment. Luminances beyond a particular ratio, such as the 1:10 ratio for task to far surround luminance used for electric lighting, can be used to assess the need for glare control [47] [48]. With daylighting, however, occupants are likely to be more tolerant of higher exterior luminances when they are associated with a favorable view. Automatic shade control is sometimes employed to achieve a consistent and orderly appearance across a façade.

Fabric roller shades can also be configured to vary the fraction of the window covered, typically operating from the top of the window downward. Note that for a window with an overhang, roller shades that operate upward from the bottom are more effective at maximizing daylight penetration, since the shaded portion of a window can remain unobstructed. Unlike blinds, the interior luminance presented by a closed fabric shade is not adjustable by the occupants, making proper selection of fabric weave and color critical.

One potentially important aesthetic consideration with interior shades is their effect on view. For fabric shades, lighter colors will minimize the quality of the view available through the holes. Dark colored fabric improves the view out through the fabric, but absorbs both solar energy and daylight, increasing solar gain and limiting daylight transmission. Light colored fabrics provide greater proportional reductions in heat gain when applied with high SHGC glazing materials, and less with high performance, spectrally selective glazing.

The exterior appearance of fabric shades may also play a role in the selection of shade color and their operation, with a lighter color shade or blind being more noticeable than a darker one. Some products are available with different interior and exterior colors to offer a preferred appearance on both sides of the fabric.

Blackout shades may be required on windows for audio/visual presentations. These come in a wide variety of colors, and for maximum effectiveness employ side tracks to eliminate

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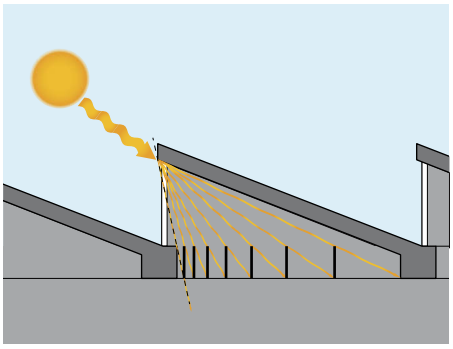


Figure 14.37 | Clerestory Baffles
The layout of baffles in a south-facing clerestory well with clear glazing to just block direct sunlight results in variable baffle spacing [52]. The controlling point for this design is the shadowing edge of the overhang.

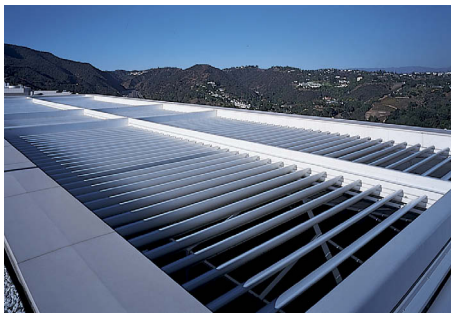


Figure 14.38 | Motorized Louvers at a Museum
Automated louvers maintain stable interior daylight illuminance levels.
Image ©Construction Specialties, Inc.

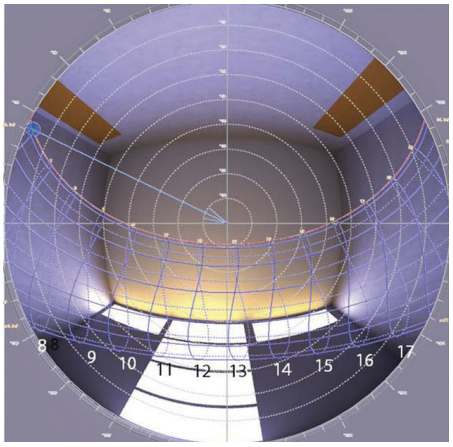


Figure 14.39 | Fisheye View with Sun Path Overlay
This format can be used to determine the direct sunlight exposure that a point will receive across the year. When constructed from two different images, the same projection mode must be used for both the room image and the solar angles.

daylight penetration along the outside edge of the shades. Both fabric shades and adjustable louvers are also available for controlling daylight from skylights.

14.9.3 Occupant Control of Shading Devices

Most interior shading devices are controlled by the occupants, with control provided by either a cord or motorized system. Studies have shown that occupants commonly set blinds at a position that requires no readjustment throughout the day, and leave them in this position for extended time periods [49] [50]. Other studies have shown that occupants are more likely to object to their blinds or shades being closed than opened. One study found that occupants accept automatic closure of their blinds if direct sunlight striking the work plane exceeds 50 W/m^2 or the incident solar illuminance exceeds 50 klx [51]. Below these levels, occupants would often override an automatic blind control system that closed their blinds.

14.9.4 Static Shading Systems

Some shading systems consist of static architectural elements. Light shelves are one such example. Another is the application of baffles in a skylight or clerestory well to block direct sunlight transmitted through clear glazing. These baffles can be opaque or translucent to reflect and diffuse entering sunlight. Their presence will reduce daylight levels under more diffuse sky conditions. With vertical glazing, a non-uniform spacing of the baffles optimizes performance, as shown in Figure 14.37.

14.9.5 Automated Shading Systems

Automated adjustable baffles, louvers or other devices are commonly employed on skylights in museums, where careful control of daylight is necessary to maintain constant, low illuminance levels on display artifacts (see Figure 14.38). Automated shade and blind control is also available for window applications. Most of these systems control fabric shades, while others control interior or exterior blinds or louvers. Sensors can act to close blinds or shades when the average luminance viewed out through a window exceeds a prescribed value, or when direct sunlight striking a façade is below a given angle. Computer models of the building and site can assess solar position and shadow pattern on a building, and then control shading devices accordingly.

The advantage of automatic control is that shades are retracted more often than would occur with occupant control (see 14.9.3 Occupant Control of Shading Devices). Automatic shading control is best suited to the east and west façade where sunlight is likely to strike the façade for half of the day, and shading devices would are not required for the other half.

14.10 Assessing Sunlight Penetration

A critical step in the design of most daylit buildings is the development of a solar and daylight control strategy for the various spaces and apertures. In work spaces and elsewhere where important visual tasks are performed, direct sunlight should not penetrate more than a short distance into a space and sunlight patterns should be eliminated from the occupant's general field of view to provide comfortable viewing and work conditions. Office lighting guidelines recommend a task to distant background luminance ratio of 1:10, which is easily exceeded by sunlit surfaces. Daylight apertures should fall within a 1:20 ratio for the view to the exterior.

Sunlight penetration can be assessed using a CAD tool (with many such tools now available), a physical scale model (see 14.16.4.1 Massing Models) or through simple hand calculations. Figure 14.39 illustrates an approach that superimposes the sun path on a fisheye view from a task location of importance. With such a diagram, it is easy to

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evaluate when and for how long sunlight will penetrate and illuminate a the point if no window shading is applied.

The example in Figure 14.40 illustrates a hand-based graphical approach for assessing the times of the year when the solar profile angle is below that provided by a particular shading device, such as an overhang. This approach similarly provides information for every day of the year on a single graph, and does not require an expensive CAD tool. To perform a study of this type, complete the following steps:

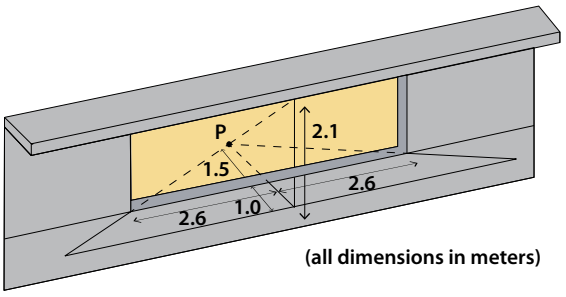
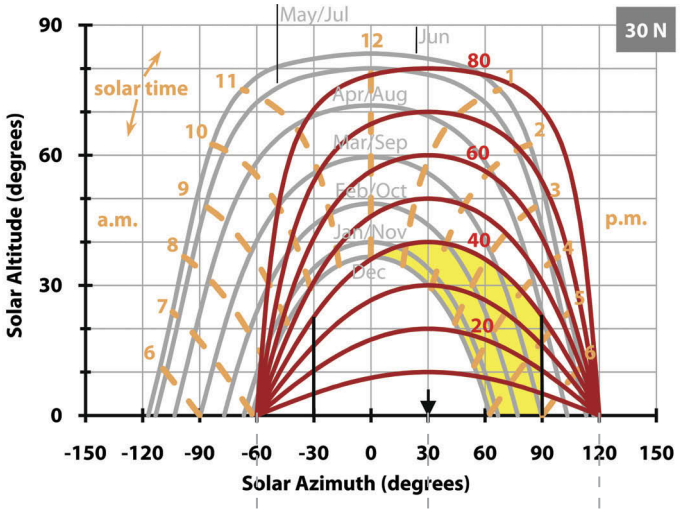


Figure 14.40 | Evaluating Sunlight Penetration to a Point Through a Daylight Aperture
Consider point P in the sketch at right with the façade oriented 30 degrees west of south at 30 N latitude. To determine the solar positions that will are within the bounds presented by the window extents and the overhang, compute the profile angle to the outside edge of the overhang and the solar elevation azimuth angle to the outside vertical edge of the window.

The height to the overhang divided by the perpendicular distance to the shadowing edge from point P is equal to 0.84 (2.1/2.5). Using Figure 14.42 or Equation 7.10, sunlight with a profile angle of 40 degrees or less can strike that point.

Similarly, since the distance to either side of the window divided by the perpendicular distance to the outside window edge is 1.73 (2.6/1.5), the azimuth cutoff angle is 60 degrees to either side of the facade orientation. Since the facade's elevation azimuth is 30 degrees, the solar azimuth limits for penetration to point P are -30 and 90 degrees.

Overlaying Figure 14.41 onto Figure 7.8, and using these angles as boundaries for solar positions that are visible from point P, the yellow shaded area in the graph below right highlights those solar positions and times of the year when point P will be illuminated by direct sunlight.



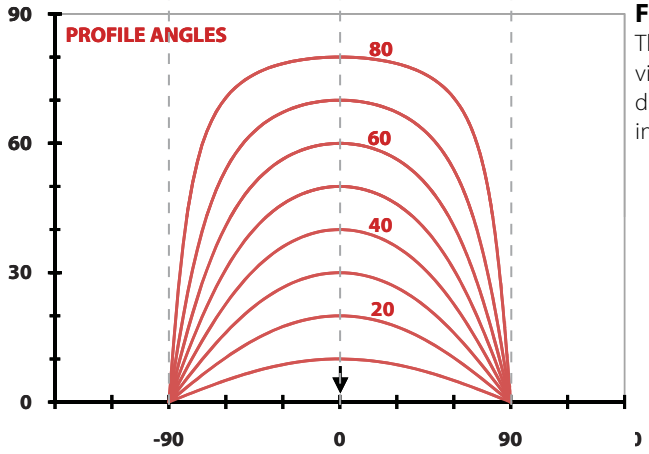


Figure 14.41 | Solar Profile Overlay
This graph can be overlayed onto one of the solar path diagrams provided in Figure 7.8, with the arrow aligned to the elevation's azimuth direction to determine the solar profile angle of any sun position during the year relative to that facade.

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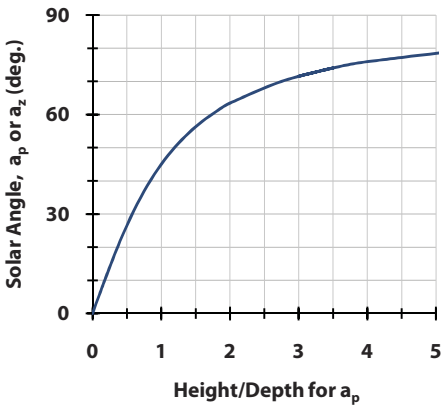


Figure 14.42 | Solar Angles to Obstructions
Profile angle or elevation azimuth angle corresponding to a given height or width-to-depth ratio to an obstruction (see example in Figure 14.40).

1. Copy Figure 14.41 onto a clear slide transparency

2. Determine the profile angle and solar elevation azimuth angles below which sunlight penetration will occur in both the vertical and horizontal directions using Figure 14.42 based on the aperture and shading system geometry.

3. Overlay the transparency onto the appropriate solar path chart (Figure 7.8 | Solar Position) with the arrow aligned to the façade's polar compass direction as shown in the detailed example provided in Figure 14.40.

4. Note the solar positions and times of year that fall below the critical profile angle and within azimuth angles that allow sunlight through the window opening.

14.11 Assessing Visual Comfort

The visual comfort provided by electric lighting systems can be computed for a limited range of lighting systems using VCP and UGR (see 4.10 Glare and 10.9.2 Calculating Glare). The glare caused by a daylighting system is more difficult to assess due to changing daylight conditions. The Discomfort Glare Index (DGI) formula was adapted to large area sources and has been applied to daylighting with the observer usually facing the daylight aperture. Orienting the observer parallel to a window wall will in most cases provide an acceptable glare condition when the glare rating facing the window is unacceptable.

A Daylight Glare Probability (DGP) metric that has recently been introduced may provide better correlation with human subjects' response. This metric needs further study, but is available in software for studying daylight system glare.

14.12 Integration with Furnishings

In work spaces such as offices and classrooms, both the furnishings and their layout must be coordinated with the daylighting design to maximize both daylight distribution and the quality of the visual environment. Furnishings that are light in color will help to maintain higher daylight levels through interreflection. In offices, lower partition heights as well as glass partitions help to improve daylight penetration and access to view, while tall partitions block daylight. Design integration must consider the effects of lower partition heights on acoustical privacy.

In general the preferred viewing position is facing parallel to a window, allowing daylight to arrive at the task from the side while keeping the high window luminance in the periphery. When facing a window, a person will be exposed to excessive luminance ratios, while if computer monitors face the window, they will exhibit reflected glare (veiling reflections). Corner offices with windows on two walls cannot satisfy both conditions, therefore interior window shading devices are the solution. In a classroom, reflections of windows in computer monitors and white boards must be avoided.

In open offices, a corridor is often located along the window wall, which permits window blinds or shades to be raised for longer periods of time since entering sunlight will not strike work surfaces, except possibly at very low sun angles.

In spaces where the attention of occupants is focused in one direction, such as in a worship space, lecture hall, or conference room, placing daylight apertures (clear or translucent) behind the speaker will silhouette or strongly backlight the speaker, and may create veiling and/or discomfort glare resulting in poor and uncomfortable viewing conditions.

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Design | Designing Daylighting

14.13 Material Degradation

The potential damage that daylight can cause to sensitive materials is a concern in museums, stores and other spaces. Fading and bleaching is caused by the ultraviolet, visible, and infrared portions of the spectrum. Because daylit spaces generally have higher illuminance levels, it is logical that sensitive materials in daylit spaces are more likely to suffer fading and bleaching. Store merchandise placed in exterior display windows are exposed to very high levels of daylight, and therefore subject to fading if allowed to remain there for an extended period, particularly if the windows transmit high fractions of the UV portion of the spectrum. In museums, light exposure is quantified in terms of lux-hours (with UV filters applied) and must be limited to protect preservation-worthy materials (see 21 | LIGHTING FOR ART). This is why daylighting systems in museums often have sophisticated automated controls to maintain interior daylight values at or below specified target values.

UV is a well known cause of fading and is found at higher levels in daylight than in electric lighting (10 times higher than in incandescent lighting). The ratio of UV energy compared to visible energy is almost twice as high in diffuse skylight as it is in sunlight, however, sunlight is generally stronger and therefore provides more UV exposure when present. Coatings on glass can reduce the transmission of UV radiation by up to 75%. Additional absorptive films within laminated glass can further decrease UV transmission to as low as 1%. Fading and bleaching are discussed in more detail in 13.10.1 Degradation of Organic Materials.

14.14 Electric Lighting Integration

In designing an electric lighting system for a daylit space, the designer must consider how to best integrate electric light with daylighting. Integration includes selection and layout of a complete system, including lamps, ballasts, luminaires and controls. In cases where a task-ambient approach is selected, daylight may supply the room ambient lighting.

14.14.1 Lighting System Selection and Design

Some useful recommendations related to the integration of an electric lighting system with daylighting are the following.

- Select an electric light distribution that best integrates with the daylight delivery system and the room geometry. In an office environment, an indirect system will be less noticeable when dimmed, and helps brighten room surfaces within the non-daylit zone. A downlight system provides more localized lighting that may better differentiate lighting control zones, but will result in a much darker ceiling outside the daylight zone.
- Balance luminances across the space. In large daylit spaces, lighting the interior wall that faces a window helps to balance room surface brightness. Indirect lighting for the ceiling serves a similar function.
- Provide a luminaire layout and control zones that are coordinated with the daylight zone. This holds whether or not an automated lighting control system is applied. A row of luminaires along the windows can be manually switched off during daylight hours when provided with separate zone control.
- Select a lamp color temperature that integrates well with daylight, while serving the space needs. Daylight is generally very cool, with color temperatures of 5000 K and above. 5000 K lamps, however, may be unacceptably cool for non-daylight hours in a building interior. 3500 and 4100 K lamps provide acceptable color temperature when combined with daylighting. 3000 K will be noticeably warmer than daylight, but may be selected when a warm color temperature is desired at night. Daylight at the beginning and end of the day is somewhat warm and many believe that the interior should respond in a similar manner.

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14.14.2 Controls

For a daylighting system to save energy, daylight must replace electric lighting during daylight hours. This is accomplished by either switching or dimming the electric lighting. Occupant control can provide some savings when flexible personal control is provided through multi-level switching, zoned switching or dimming; however occupants are not focused on minimizing electric lighting energy as daylight conditions change. Personal control is likely to save energy when the occupant is forced to select an appropriate output setting upon entering a space, rather than have all lights turn on through a single switch.

An automatic lighting control system guarantees that lighting energy savings will occur when daylight is present. A photosensor signal can be used to adjust the electric lighting by monitoring either exterior daylight levels, the amount of daylight passing through an aperture, or the combined daylight and electric light within a space (see 16.3.5 Photosensors). For proper operation, a photosensor control system must be properly designed and calibrated. This includes establishing a controlled lighting zone that correlates with the daylit area, then selecting, locating, and calibrating the photosensor to accurately sense daylight levels and dim or switch the electric lighting system accordingly. The daylit zone should receive levels of daylight that generate significant savings in electric lighting energy. Higher daylight levels are required with photosensor-based switching as compared to dimming. Occupant overrides are important for achieving user satisfaction, with some advanced systems having the capability of adjusting control based on users' preferences.

Details on the selection and design of automated photosensor control systems are provided in Section 15.9 Photosensor Controls.

14.15 Energy

Daylighting has the potential to save building energy; however, a daylight delivery system must be properly configured to achieve these savings. When skylights are added to conditioned spaces, the reduction in electric lighting must be larger than any increased energy required to heat or cool the building resulting from the addition of skylights. This requires proper glazing selection, sizing and layout of the skylight system, as well as a lighting control system. Skylight properties (VT, SHGC and U-factor) and total glazing surface area are critical. With proper design, lighting savings will exceed HVAC losses. With a poor design or a disabled control system, energy use will increase compared to a building with no skylights. Mechanical and electric lighting annual load simulations can ensure that a proposed skylight design is energy efficient.

In the case of daylight provided through windows, the energy evaluation is not as simply, since windows are likely to be present regardless of the daylight design intentions. A well designed system with efficient glazing and exterior shading devices can potentially save lighting, heating and cooling energy compared to windows that are flush with the facade. Energy modeling can help to optimize a design and should be conducted early in the design process.

How a system performs from an energy perspective depends on the configuration of the daylight apertures and the materials used, the efficiently with which daylight is delivered and distributed across a space, the operation of adjustable shading devices, and finally on the achieved reduction in electric lighting energy. A design will waste energy if the electric lighting is not controlled, or if too much daylight is provided, resulting in higher heat gain. Each building or design is different, and optimization of a design requires the attention of all design team members and careful study of both daylight levels and energy consumption.

In some cases, HVAC cooling loads can be mitigated through stratification of air within a space. Heat from sunlight entering through a clerestory or skylight that is absorbed by surfaces well above the occupied space may elevate temperatures within skylight wells. Allowing

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heated air to remain there rather than conditioning it can save energy. Thermal mass may also be used to store heat from admitted sunlight and thus reduce the peak cooling load.

14.16 Assessing Daylight Performance

14.16.1 Performance Metrics for Daylighting

A number of metrics have been developed to assess daylighting performance. Until recently, the number and utility of these metrics was quite limited. A critical factor was the computational effort needed to evaluate the large number of hours of daylight experienced over a year, considering building, site, time and weather conditions. The daylight coefficient method [53] [54], which ties the resulting illuminance (or other photometric measure) at an interior point to the luminance of pre-established sky patches and sunlight positions, can be used to quickly assess a large number of sky conditions. Annual performance can be assessed using a variety of different metrics.

Daylighting requires a different analysis approach than electric lighting. For electric lighting, average illuminance is meaningful in spaces where uniform illuminance is desired. For daylighting, averages have little meaning and can actually be misleading. A uniform array of skylights is one design situation where daylight can be assessed by average work plane illuminance. With vertical glazing, however, the work plane illuminance distribution is non-uniform, with significantly higher values near the window. An average illuminance across such a space has little meaning.

Daylight is also variable over time. At different times of the day or year, and under different sky conditions, the illuminance in a space will vary. The average illuminance over some period of time (a day, month or year) provides little information of value. The annual metrics that have recently emerged consider binning of performance data, such as tallying the number of hours or frequency of occurrence of certain conditions. Results of this type can paint a clearer picture of performance over time, as well as the potential for energy savings.

Annual metrics address the dynamic conditions encountered at a site through representative weather data from a TMY2 (Typical Meteorological Year) or EPW (EnergyPlus Weather) file commonly used for HVAC heating and cooling load analysis. In most cases, Perez sky distributions (see 7.1.6.1 Perez and CIE Skies) are derived from these hourly weather data. To model real world conditions, annual metrics must also consider the settings of daylight control devices, such as blinds or shades. The annual performance of a south-facing sidelit classroom with no overhang will significantly overestimate the lighting energy savings if the space is analyzed without interior shading. Shading control adds an additional level of complexity to the analysis. More information on shading control strategies is provided in 14.9 Interior Shading Devices.

In applying any of thee annual metrics, a number of factors will affect the results. First, the time span applied when evaluating these metrics is important. Longer occupancy schedules may increase the number of hours but reduce the fraction or percentage of operating hours when a particular daylight condition is met. Future IES recommendations are likely to include a standard time period, such as 8 a.m.-6 p.m., although at this time, no such interval has been formally established.

The operation of interior shading devices will also impact the results obtained from annual metrics. When shades are employed for longer time periods, annual metrics that assess illuminance will produce lower values. If shading is automated, settings should be based on the actual control algorithm to be used. Occupant control of interior adjustable shading devices is much more difficult to assess since some occupants prefer a static shading condition, while others will operate them in response to external conditions. For

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this reason, implementation of these metrics in codes and standards should explicitly state modeling assumptions to apply for the operation of shading devices.

14.16.1.1 Daylight Factor

Historically, the most widely applied daylight metric has been the daylight factor (DF). The daylight factor is the ratio of the illuminance received at an interior point to the exterior horizontal illuminance produced by an overcast sky. [55] [56]

$$DF = \frac{E_{int}}{E_{kh,oc}} \tag{14.1}$$

Where

E_{int} = interior illuminance at a point
$E_{kh,oc}$ = exterior horizontal illuminance from an overcast sky

Since DF assesses system performance under an overcast sky, it is most effective in locations where the sky is primarily overcast. For many years, this was the primary metric used for evaluating and comparing daylight delivery systems. An average daylight factor in the range of 2 to 5% was recommended to provide adequate levels of daylight in an overcast climate. The major limitation of this metric is that it says little about how well a system performs under a clear or other sky condition, and it provides no information related to annual system performance at a particular site. With a daylighting system that applies skylights in a location having predominantly clear skies, a daylighting factor closer to 1% is more appropriate. Some daylight analysis tools have also applied daylight factors for clear skies, primarily to assess performance across the year, but this is a rough approximation that does not fully address the full range of sky conditions experienced at a site.

The annual daylight metrics that follow provide valuable detailed information on system performance across an extended period of time with variable sky conditions.

14.16.1.2 Daylight Autonomy (DA)

The simplest and most widely applied annual metric is daylight autonomy. This is a measure of the percentage of the operating period (or number of hours) that a particular daylight level is exceeded throughout the year [57]. This metric is used to address performance at individual analysis points, but can also be used to evaluate the magnitude and general distribution of daylight across a space. Because the metric tallies only the time when a target value is exceeded, it provides a measure of how well daylight can replace electric lighting when the electric lighting will be switched via a photosensor, and may be used to evaluate general daylight coverage and lighting control zone depth. Daylight autonomy can also be used to assess the number of hours or percentage of hours when a particular condition is exceeded, such as the illuminance on an artifact in a museum.

14.16.1.3 Continuous Daylight Autonomy (cDA)

A modified version of DA, which is referred to as continuous daylight autonomy, is more appropriate for the evaluation of system performance when the electric lighting system is dimmed [57]. With cDA, hours for which the target value is partially achieved receive partial credit. For example, if a space receives 300 lux of daylight over a one-hour period when the target is 500 lux, 0.6 hours of coverage are credited. cDA should correlate well to the lighting energy savings potential of a lighting control zone that applies dimming when analyzed at the critical task point that will be used for calibrating the lighting control system (see 16.3.5 Photosensors).

14.16.1.4 Zonal Daylight Autonomy (zDA)

Zonal daylight autonomy (zDA) is a metric for assessing daylight sufficiency across an entire space with a single value. This approach requires the designer to first define the limits of the space or area to be analyzed. Then the number of hours that each sensor meets or exceeds 300 lux is determined and then summed across all sensors. The resulting total

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is then divided by the total number of sensors and number of annual hours considered for this analysis, which effectively computes the average daylight autonomy fraction for the defined space. Higher zDA values represent longer periods of usable daylight within and across the space. Research has suggested nominal occupant acceptance of daylight sufficiency begins at zDA_{300} = 50% and satisfaction increases proportionally as the value increases. The upper limit feasible for a standard 10 hour per day annual analysis is close to 90% for zDA_{300}.

14.16.1.5 Spatial Daylight Autonomy (sDA)

Daylight autonomy can also be used to assess daylight coverage using a metric referred to as spatial daylight autonomy (sDA). This metric reports the percentage of sensors (or building area) that achieves a minimum daylight illuminance level (typically 300 lux) for a minimum percent of the analysis year (time). It is recommended that the percent time component be locked-in at 50% of the time. For this approach, each sensor point that achieves at least 300 lux for at least 50% of the analysis year contributes to the area that meets the criteria. The qualifying sensor points do not need to achieve 300 lux at the same time, just for the same percentage of the year. This approach allows the designer to plot on a floor plan iso-contours of the percentage of time each sensor reaches this goal. Research has suggested that for a given room, occupants find the daylight levels nominally acceptable when sDA_{300} > 50%, and are progressively more satisfied as the area increases above 75% to an upper feasible limit of approximately 95%.

14.16.1.6 Temporal Daylight Autonomy (tDA)

A space's temporal daylight autonomy is an estimate of the fraction of time that a target illuminance level, such as 300 lux, is achieved over 75% of the space. The value is computed by determining the 25% percentile DA value across all points within a space (this is the DA value that 25% of the analysis points are below). Since these points may not reach a particular illuminance value at the same time, tDA_{300} differs slightly from the fraction of time at which 75% of the points reach a particular target value simultaneously.

14.16.1.7 Useful Daylight Illuminance (UDI)

Another proposed metric is Useful Daylight Illuminance [58]. This metric compiles the number of operating hours that fall into three different illuminance ranges at an analysis point (often <100 lux, 100-2000 lux and >2000 lux). Useful daylight is considered to occur when the daylight illuminance is between 100 and 2000 lux ($UDI_{100\text{-}2000}$). UDI<100 evaluates the number of hours with insufficient daylight, while UDI>2000 considers the number of hours with excessive daylight that is likely to increase cooling loads and deliver higher levels glare and discomfort.

14.16.1.8 Direct Sunlight Hours

Another useful measure is the number of hours when a particular analysis point is likely to receive direct sunlight. This information signifies the length of time that operable shading devices may be required, and is helpful in evaluating exterior shading strategies and design solutions for sunlight penetration. Site weather data and neighboring structures should also be considered. A possible implementation of this metric would involve a tally of the number of hours per year when direct sunlight alone (with no sky, ground or interreflected contributions) exceeds 1000 lux based on Perez sky distributions based on site weather data.

14.16.1.9 Daylight Uniformity

Daylight uniformity is nearly impossible to achieve with sidelighting, but can be relatively easy to achieve with a uniform array of skylights. Metrics such as maximum-to-average and maximum-to-minimum may be useful in certain situations. For example, maximum-to-average of average-to-minimum evaluation would be meaningful in a space where uniform daylighting is desired. Max/min might be used to evaluate performance in a space that includes electric lighting outside the daylit zone. Coefficient of variation is another uniformity metric that can be applied to the study of daylighting systems (see 4.12.4.4 Area Tasks for more information).

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14.16.2 Applying Annual Daylight Performance Metrics

Using one or more of the annual daylight performance metrics, a designer can assess how a daylighting system performs over a typical year at a given site. To model real world conditions, a suitable space model, occupancy schedule, and shade control strategy must be considered. See 14.9.3 Occupant Control of Shading Devices for information on how users apply shading devices. Automatic shade control strategies can also be addressed in software tools that apply these metrics. Figure 14.43 provides a comparison of the above metrics for both a north and south-facing classroom space.

14.16.3 Daylighting Software

Daylighting is ideally suited to computer modeling due to its dynamic nature, complex sources, the role of interreflection, and the non-uniform distribution that occurs with most designs. Software can be configured to model arbitrary room geometry and apertures, the surrounding exterior environment, variable sky luminance distributions, and the changing position of the sun. Until recently, most computer software reported only single-point-in-time daylight performance, and feedback on annual performance was nonexistent. HVAC energy modeling tools such as DOE-2 and, more recently, EnergyPlus contain simplified daylight modeling algorithms to address HVAC and lighting loads and the annual savings generated by daylighting with photosensor-based lighting control. Lighting software is now available with annual simulation capability to address daylight harvesting in greater detail using annual metrics such as those outlined above. These programs typically apply a daylight coefficient approach to reduce execution time when modeling sky conditions on an hourly, or finer, basis.

Daylight analysis tools can be classified as general tools, application-based tools, and annual performance modeling tools. A brief description of these is provided below.

14.16.3.1 General Lighting Analysis Tools

Most of these tools address both electric lighting and daylighting. The user creates or imports room and exterior geometry, assigns reflectances and transmittances to the surfaces, then selects the daylight condition to study (calendar date, time of day, and sky type). Tabular illuminance data, illuminance contours, photorealistic renderings, and pseudo color or contoured luminance values are typical output options. In some tools, an animation sequence of the daylight distribution across a space can be generated automatically. A sequence of images can be used to visually assess direct sunlight penetration and the dynamic qualities of daylight within a space (see Figure 14.44).

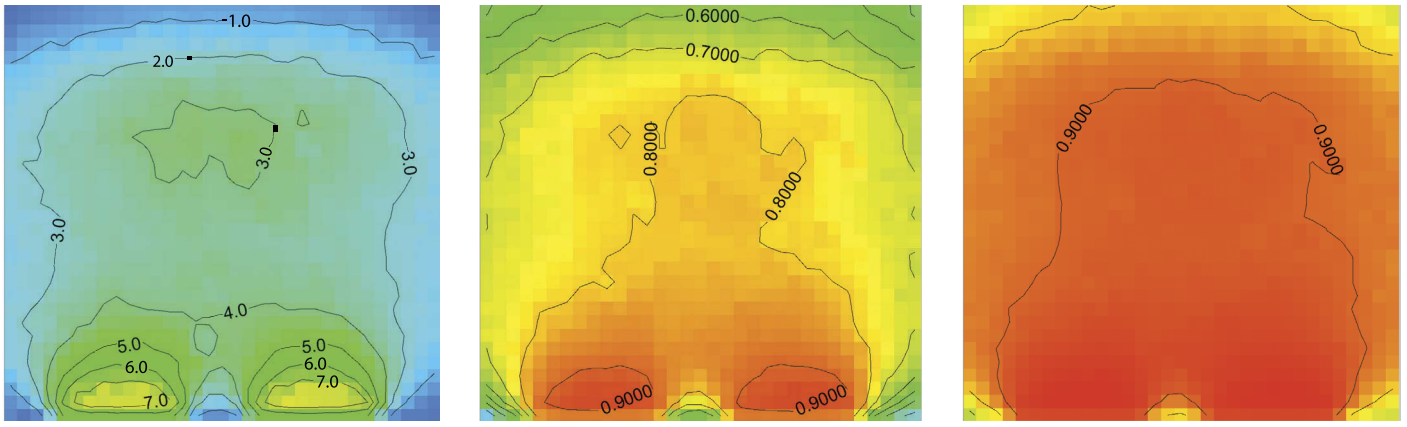


Figure 14.43 | Daylight Factor and Annual Daylight Metric Contours
A comparison of daylight factor (left), daylight autonomy (center), and continuous daylight autonomy (right) for a 500 lux target and 8 a.m. to 5 p.m. occupancy in a daylit classroom with a north-facing clerestory and two south-facing windows. 4% transmissive shades are employed on the south-facing façade when direct sunlight is incident. The center image indicates that 60-70% of the time the entire room is illuminated to 500 lux or greater.

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14.16.3.2 Simplified Energy Optimization Software

Application-based software focuses on the analysis of a particular type of system. One example of such a tool is SkyCalc® which can be used to optimize the energy performance of a uniform skylighting system [59] [60]. This tool considers the savings and losses within a space by simultaneously addressing the lighting, heating and cooling energy impacts of skylights. For daylight analysis, it applies a simple procedure known as the Lumen Method of Toplighting (see 14.18 Formulary), which evaluates the average illuminance in a space considering the combined effect of skylight material, the skylight well configuration, and coefficients of utilization for a Lambertian (cosine) distribution at the base of the well. Heating and cooling load calculations are approximated from an archived series of DOE-2 runs. The program allows the user to optimize the skylight area to roof area ratio for a particular skylight configuration based on either energy consumption or energy costs that consider lighting, heating, and cooling loads (see Figure 14.45).

Additional software tools that address lighting energy savings as well as provide performance data for use in the design, layout, and evaluation of photosensor control systems are SPOT [61] and Daysim [62]. These tools calculate annual daylight performance metrics and energy savings for photosensor control systems. They also help a user assess photosensor locations and different photosensor products and layouts. Software inputs include space geometry, an occupancy schedule, site weather data, the photosensor's directional response function, its location, electric lighting equipment and control zone layouts, the photosensor control algorithm, operable shading devices and activation criteria. Sample input and output from SPOT are shown in Figure 14.46. Output from Daysim is shown in Figure 14.43 and Figures 19.25-19.27. Daysim also permits the analysis of the glare conditions that an occupant may experience over the course of a year.

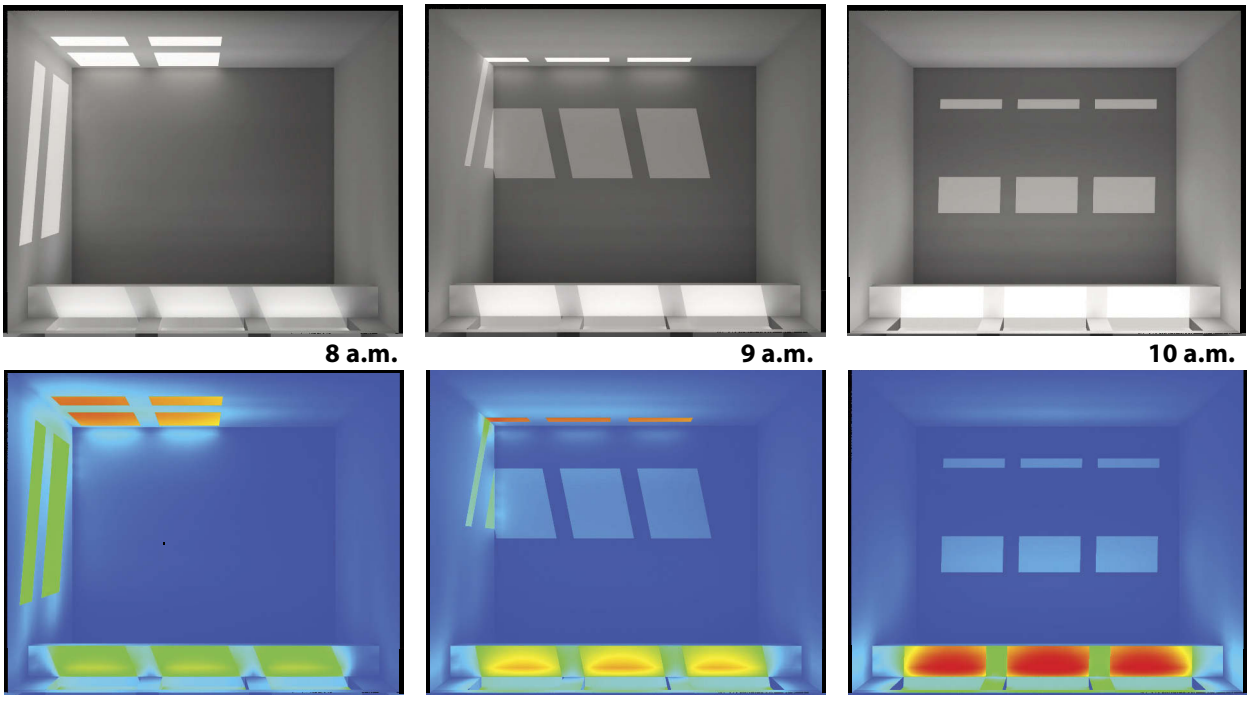


Figure 14.44 | Sunlight Penetration Images
A series of renderings looking down from above into a room with a light shelf system facing 30-degrees east of south at 40N latitude illustrates winter solstice sunlight penetration through both the window above and below the shelf during morning hours. The top row of images applies a standard view where room materials have been entered as neutral grey colors, while the bottom row illustrates performance using pseudo-color images, where different colors represent different luminance levels. A scale can also be printed to identify the luminance value assignments across the range of colors.

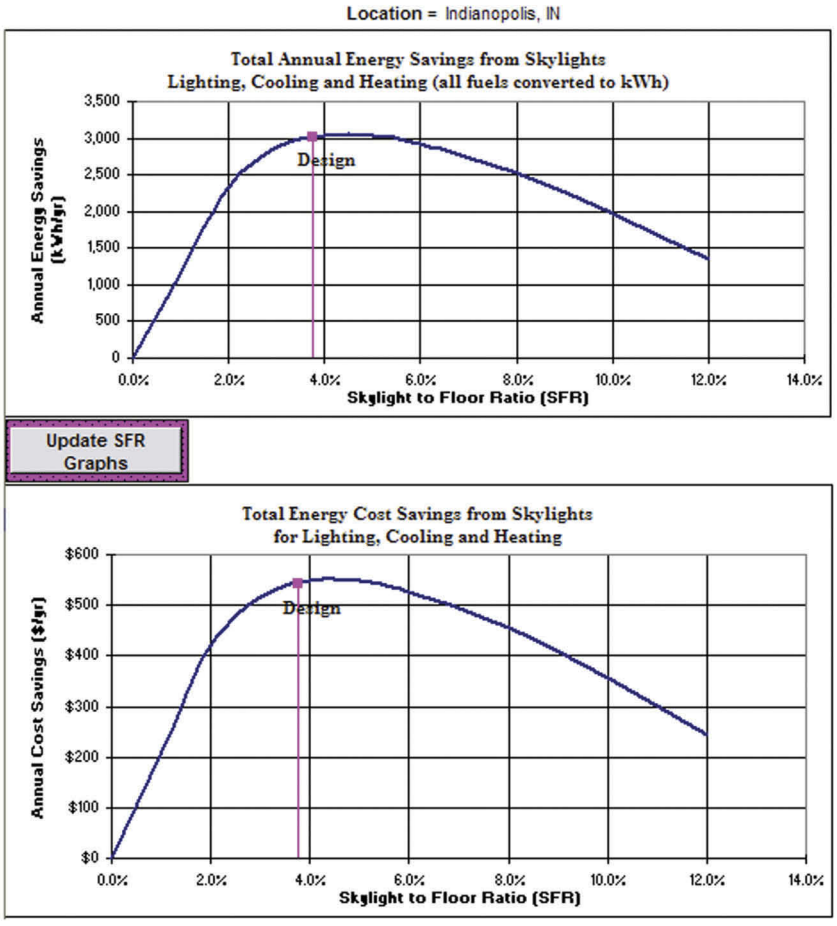
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14.16.3.3 Annual Building Energy Modeling Tools

A number of different tools exist for full building energy load modeling that include some form of daylight modeling. These tools include programs such as DOE-2, EQuest, EnergyPlus and others [63]. In most cases, these tools are applied by HVAC design or building energy modeling consultants; however, they must be properly configured to provide reasonably accurate models of lighting energy savings and the resulting impact of the lighting system on building heating and cooling. These tools require a weather file such as a TMY2 (Typical Meteorological Year, version 2) or EPW (Energy Plus Weather) file to describe the hourly weather conditions for the calculation of lighting and HVAC energy. Daylight modeling is often performed by a somewhat simplified algorithm (compared to advanced flux transfer and ray-tracing software) to estimate the potential energy savings as electric lighting is either switched or dimmed via a photosensor. These tools consider a lighting control system that operates perfectly, with the energy savings determined from work plane illuminance at one or more points. The points selected, the target levels assigned to these points, and the controlled lighting power are critical inputs for these energy modeling tools. Recommendations for properly configuring photosensor-controlled electric lighting systems are provided in 19.4.6.5 Analysis of Photosensor Systems.

14.16.3.4 Daylight Software Modeling Notes

In applying daylight analysis tools, the output received is only as good as the input provided. In many cases, the user must select and set the calculation parameters that govern



Total Energy Savings and Total Cost Savings Columns of these tables used in Graphs

Annual Itemized Energy Savings from Skylights (kWh/yr)

SFR	Lighting	Cooling	Heating	Total Energy
0.0%	0	0	0	0
1.0%	1,251	45	-119	1,177
2.0%	2,556	82	-303	2,335
3.0%	3,396	-27	-499	2,869
4.0%	3,930	-207	-678	3,045
5.0%	4,299	-422	-836	3,040
6.0%	4,565	-656	-981	2,927
8.0%	4,914	-1,150	-1,239	2,526
10.0%	5,118	-1,664	-1,474	1,981
12.0%	5,260	-2,188	-1,711	1,361

Energy Rates converted to $/kWh

Electricity Rate	$0.180 /kWh
Heating Fuel Rate	$0.180 /kWh

Annual Itemized Cost Savings from Skylights ($/yr)

SFR	Lighting	Cooling	Heating	Total Cost
0.0%	$0	$0	$0	$0
1.0%	$225	$8	-$21	$212
2.0%	$460	$15	-$54	$420
3.0%	$611	-$5	-$90	$516
4.0%	$707	-$37	-$122	$548
5.0%	$774	-$76	-$151	$547
6.0%	$822	-$118	-$177	$527
8.0%	$885	-$207	-$223	$455
10.0%	$921	-$299	-$265	$357
12.0%	$947	-$394	-$308	$245

Figure 14.45 | SkyCalc® Output
These graphs illustrate changes in energy and cost savings as skylight to floor area ratio varies for particular skylight shape and material. The tables provide breakdowns of the numerical data in the graphs for lighting, heating and cooling energy and the respective cost savings or losses in these areas relative to an opaque roof. Lighting savings counteract losses in both heating and cooling energy in both tables.

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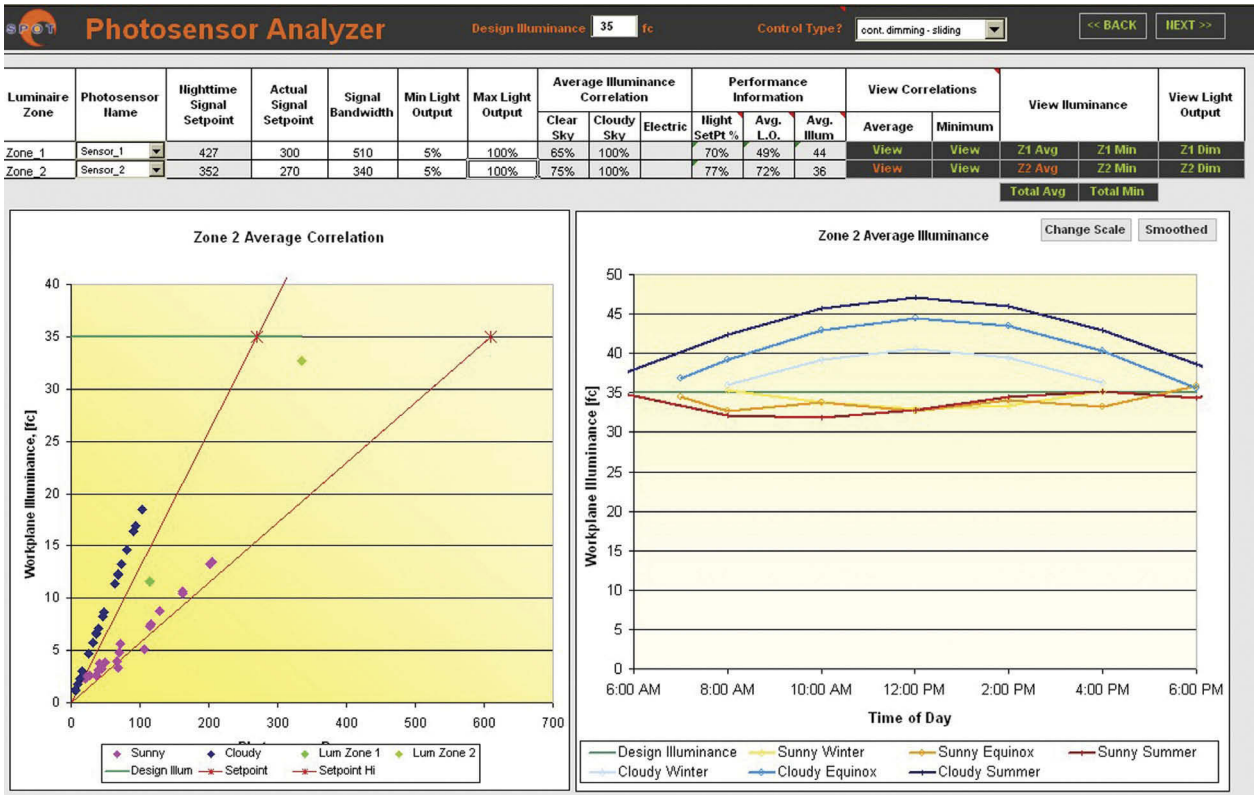


Figure 14.46 | Photosensor Performance Modeling
A sliding setpoint (linear proportional) control algorithm is applied to a photosensor in SPOT. The calbration settings are input at the top of the screen, while the graph at left shows work plane illuminance versus photosensor signal for different sky conditions and the electric light zones. The graph on right shows dimming performance on representative clear and overcast days.

the analysis, which requires some understanding of how the tool functions. Below are a few important points to consider in applying software tools.

Loss Factors

Dirt on windows and skylights reduce the daylight transmittance of glazing materials and should be included in any daylight analysis. Studies on the magnitude of these losses do not exist. Past light loss factor recommendations for daylight apertures may have been overly conservative (too low). For vertical glazing, realistic values may be in the range of 0.9-0.95, while for horizontal or sloped glazing, values between 0.8 and 0.9 may be appropriate. Local conditions may require further adjustment. Dirt factors are entered as adjustments to the glazing transmittance.

Mullions

In conducting modeling studies, mullions are often omitted when creating a daylight model as a time-saving measure. When this done, a loss factor that accounts for the effective reduction in actual glazing area must be included to adjust the glazing transmittance to account for the mullions. This factor can be entered as the simple ratio of the net to gross glazing area, although the reduction in transmittance is likely to be slightly greater due to the depth of the mullions (perpendicular to the window).

Modeling ground shadows

Most programs that analyze daylight consider the ground to view an unobstructed sky and receive full direct sunlight. In a real world condition, the ground against a building only sees half of the sky, and receives no direct sunlight when shaded by the building. The unobstructed sky assumption for the entire ground plane can reduce the amount of reflected light entering a window. When ground shadows are not automatically considered,

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an exterior polygon with an appropriate ground reflectance must be included, along with any shadowing objects, which may include other sections and floors of the building being studied. It is important to extend this ground polygon and the shadowing portion of the building facade beyond the space being analyzed

Analysis Times
Many tools make assumptions regarding daylight savings time and determine time zones based on site longitude (applying 15° wide time zones). When cities are located near the boundary of a time zone, the software may apply an incorrect time zone to that site. In addition, certain locations, such as Arizona, do not employ daylight savings time. Time adjustments can be made to address incorrect program assumptions.

Building Orientation
When orienting a building in software, the orientation with respect to polar north must be entered. This will require a correction if only the position relative to magnetic north is known, unless the software performs this correction based on site latitude and longitude. See 14.4.3 Orientation Relative to Polar North.

Calculation Settings
Daylight tools are based on either radiative transfer or ray-tracing analysis methods. If windows are modeled as light emitters and their performance is addressed by determining the luminous intensity distribution of the transmitted daylight, then applying this distribution the window area being considered, it may be necessary to subdivide the glazing area into smaller polygons to force the software to evaluate the entering daylight distribution at a collection of points across the window surface. This is necessary when the windows have nearby reflecting or shadowing elements such as light shelves, overhangs, or adjacent buildings; or when the windows are very tall. For example, the top of a window just below an overhang will transmit less light and have a different interior daylight distribution than a section near the bottom of the window. If the window is considered as one polygon, both the top and bottom may be assigned the daylight distribution that exists at the center of the window, introducing error.

When radiative transfer models are applied, surfaces that receive direct sunlight (interior or exterior) may need to be subdivided into smaller receiving and emitting patches (often referred to as the surface mesh) to resolve the edges of sunlight shadows to redirect daylight appropriately. This is especially critical for a surface such as a light shelf, which may be partially illuminated with sunlight, and is a primary source of reflected sunlight to the interior. If the shelf is treated as one emitting surface, direct sunlight that strikes only a portion of the shelf may be uniformly distributed across the shelf when computing the contribution of that light to other surfaces. This may overestimate system efficiency and daylight penetration.

In some radiative transfer programs, an adaptive subdivision feature can be enabled. This procedure subdivides polygons in areas where large illuminance gradients are detected. While this feature may further subdivide the mesh to assess incident radiation, it may have no effect on the meshing structure for redirecting this light to other surfaces.

In applying ray-tracing software, parameters that control the number of rays being spawned at each reflection and the number of bounces being considered are often under user control. Low settings may result in fast execution times but low accuracy. It may be necessary to test the performance achieved using different settings to determine the sensitivity of results to changes in ray-trace parameter settings. When daylight is distributed from small areas that are not addressed as primary light sources, a higher density of reflected rays are necessary for the rays to locate and properly assess these bright areas. One way to evaluate the overall performance of a ray-tracing tool is to check the luminance distributions across a space in a rendered image. If the patterns have a smooth and realistic appearance, then parameter settings related to the number of rays spawned at each

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reflection are likely to be acceptable. When the ray-tracing process is expected to address daylight passing through deep skylight wells or a series of horizontal or vertical blinds, the number of reflections may need to be increased above the typical setting of 5 or 6.

Locating Software Tools
The U.S. Department of Energy publishes a list of lighting software on its web site, with a brief description of each tool and contact information for the program vendor [63].

14.16.4 Physical Scale Models

Prior to the availability of computer tools for studying daylight performance, physical scale models were the primary approach used by architects and engineers for assessing daylight system design. Many design professionals still apply this technique today. The material and construction details required in a model are based on the information desired from the study, which can be purely visual, or include photometric readings.

14.16.4.1 Massing Models

Massing models are used to assess sunlight penetration and shadow lines, and can be constructed of any convenient material. Accurate surface finishes are not required, however space dimensions and aperture thickness are critical for assessing sunlight penetration. Surrounding buildings and objects that cast shadows onto daylight apertures should be included in the model. Massing models can be placed on a heliodon to model sunlight angles at any time of the year. A simple heliodon is easy to create with a point light source and a device that rotates the model about a vertical axis (see Figure 14.47). Another option for modeling sunlight penetration is to affix a sundial to a model's ground plane [52]. The model can then be taken outside and angled with respect to the sun to achieve any desired solar position.

14.16.4.2 Photometric Models

Photometrically accurate scale models can be used to record illuminance and luminance readings as well as to make visual assessments of daylight system performance [64] [65] [66]. These models must have proper reflectances on all surfaces that affect the distribution of daylight within a space, including the ground and exterior surfaces that shadow or reflect daylight onto an aperture [67]. Surfaces do not need to be the exact color, but

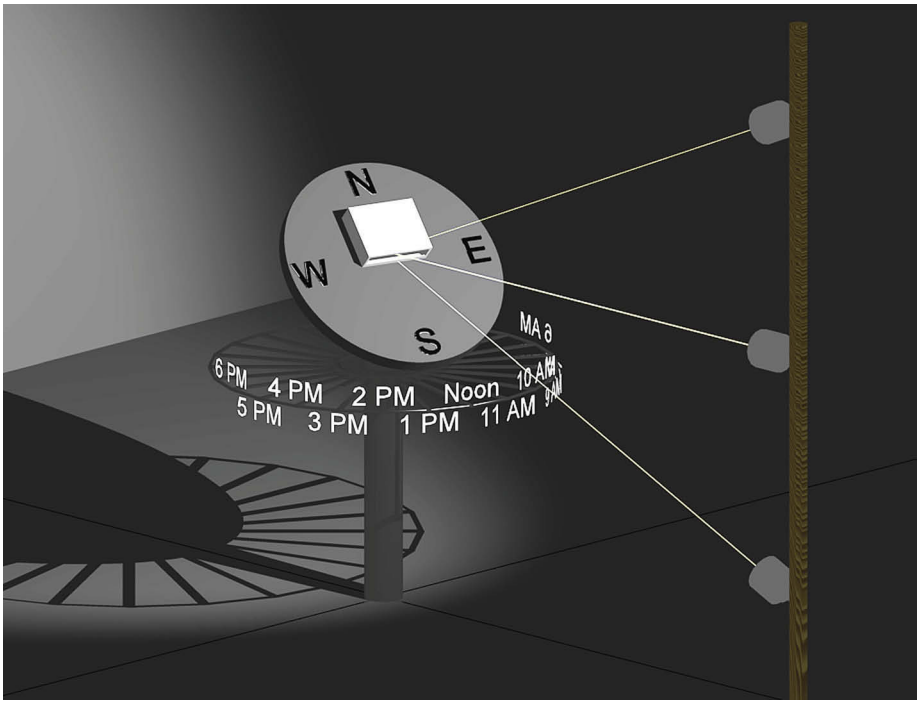


Figure 14.47 | Heliodon Setup
A scale model is placed on a rotating surface with the north direction on the model orientfacing upward. The angle of this rotating surface from the vertical is the site latitude (a horizontal orientation corresponds to the north pole). The 24 hours of the day are spaced at 15-degree rotational increments on the vertically-oriented rotating base with solar noon aligned with south. The surface is rotated so the desired solar time faces the light sources. The upper source, which corresponds to the summer solstice, is positioned at a 23.5 degree angle above the center of the model. The center source is aligned horizontally with the daylight aperture and represents the sun on the equinox dates, while the lower source represents the winter solstice and is 23.5 degrees below the equinox position.

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must have a similar light reflectance value (LRV within 5-10% is acceptable). In constructing such a model, it is important to avoid light leaks at the corners and ensure that opaque materials transmit no light. A black or reflective layer (such as foil) incorporated into the envelope helps to eliminate daylight penetration through walls and ceilings.

In scale models, it is common to consider clear windows using unglazed openings. Any photometric readings must then be modified by the desired window transmittance, a light loss factor, and a factor to consider further reductions caused by mullions that are not included in the model. Since high angle light is transmitted through glass at a reduced transmittance than light striking near the surface normal (Figure 14.9), some error will be present with this approach, particularly when direct sunlight strikes an aperture at a high angle.

To model translucent glazing, a suitable diffusing material must be installed in the model to similarly redistribute daylight at the aperture. Interior photometric readings must then be corrected using the ratio of the real-world to model glazing material transmittance if these are not identical. Some error will result when the diffusion provided by the model material does not match that of the actual glazing material.

Illuminance readings can be taken within scale models using small photosensors, taking care that meters remain at their desired orientation as readings are taken. Note that when conducting model measurements outdoors, a clear summer day can be used to approximate clear conditions at all times of the year without having to tilt the model, simply by timing measurements with the desired solar altitude, and rotating the model to the proper azimuth. To approximate high angle summer conditions during the wintertime, a model can be tilted to properly position the sun on a sundial, but the accuracy of the daylight distribution is diminished since sky and ground are interchanged at some angles in the model's world. Overcast sky simulators and more advanced sky simulators that are capable of modeling sky luminance distributions and arbitrary solar positions are available in some major laboratories and universities.

14.17 References

[1] Boyce P, Hunter C, Howell O. 2003. The benefits of daylight through windows [Internet]. Lighting Research Center. [cited on 2009 Jul 21]. Available from: http://www.lrc.rpi.edu/programs/daylighting/pdf/DaylightBenefits.pdf.

[2] Heschong-Mahone Group, Inc. 2003. Windows and offices: a study of office worker performance and the indoor environment [Internet]. CEC Technical Report. [cited on 2010 Aug 18]. Available from: http://www.h-m-g.com/downloads/Daylighting/A-9_Windows_Offices_2.6.10.pdf.

[3] Ulrich RS, 1984. View through a window may influence recovery from surgery. Science. 224:420-421.

[4] Ulrich RS. 1991. Effects of interior design on wellness: theory and recent scientific research. Journal of Health Care Interior Design: Proceedings from the National Symposium on Health Care Interior Design. 3:97-109.

[5] Ander GD. 2003. Daylighting performance and design. New York: John Wiley & Sons.

[6] Heschong L, Wright RL, Okura S. 2002. Daylighting Impacts on human performance in school. J Illum Eng Soc. 31(2):101-114.

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[7] Heschong L, Wright RL, Okura S. 2002. Daylighting impacts on retail sales performance. J Illum Eng Soc., 31(2) 21-25

[8] Heschong L. 2003. Windows and classrooms: a study of student performance and the indoor environment [Internet]. [cited on 2009 Jul 21]. Available from: http://www.newbuildings.org/downloads/FinalAttachments/A-7_Windows_Classrooms_2.4.10.pdf.

[9] Heschong L. 2003. Daylighting in schools: reanalysis report [Internet]. California Energy Commission. [cited on 2009 Jul 21]. Available from: http://www.newbuildings.org/downloads/FinalAttachments/A-3_Dayltg_Schools_2.2.5.pdf.

[10] Heschong L. 2003. Daylight and retail sales [Internet]. California Energy Commission. [cited on 2009 Jul 21]. Available from: http://www.newbuildings.org/downloads/FinalAttachments/A-5_Daylgt_Retail_2.3.7.pdf.

[11] Boyce P. 2004. Reviews of technical reports of daylight and productivity [Internet]. Lighting Research Center. [cited on 2009 Jul 21]. Available from: http://www.lrc.rpi.edu/programs/daylighting/pdf/BoyceHMGReview.pdf.

[12] Miller N, Spivey J, Florance A. 2008. Does green pay off? Journal of Real Estate Portfolio Mgmt. 14(4):385-399.

[13] Eichholz P, Kok N, Quigley JM. 2009. Doing well by doing good? Green office buildings [Internet]. University of California Berkeley. [cited on 2010 Sep 5]. Available from: http://urbanpolicy.berkeley.edu/pdf/EKQ_green_buildings_JMQ_081709.pdf.

[14] Figueiro MG, Rea MS. 2010. Lack of short-wavelength light during the school day delays dim light melatonin onset (DLMO) in middle school students. Neuroendocrinol Lett. 31(1):92-6.

[15] Krarti M, Erickson PM, Hillman TC. 2005. A simplified method to predict energy savings of artificial lighting use from daylighting. Build Environ. 40(6):747-754.

[16] Yoon Y, Moeck M, Mistrick R, Bahnfleth W. 2008, How much energy do different toplighting strategies save?, J Archit Eng. 14(4):101-110.

[17] Moeck M, Yoon Y, Bahnfleth W, Mistrick R. 2005. How Much energy do different toplighting strategies save? [Internet]. Lighting Research Center. [cited on 2009 Aug 7]. Available from: http://www.lightingresearch.org/programs/daylighting/pdf/finalreport61905.pdf.

[18] Robbins CL. 1986. Daylighting: design and analysis. New York: Van Nostrand Reinhold.

[19] IEA SHC Task 21. 2000. Daylight in buildings: a source book on daylighting systems and components [Internet]. International Energy Agency. [cited on 2009 Jul 29]. Available from: http://www.iea-shc.org/task21/source_book.html.

[20] Guzowski M. 2000. Daylighting for sustainable design, New York: McGraw-Hill.

[21] ASHRAE 2007. Energy standard for buildings except low-rise residential buildings, ANSI/ASHRAE/IESNA 90.1-2007. Atlanta: ASHRAE.

[22] Boyce PR. 1995. Minimum acceptable transmittance of glazing. Light Res Technol. 27(3):145-152 .

[23] Cuttle C. 1979. Subjective assessments of the appearance of the appearance of special performance glazing in offices. Light Res Technol. 11:140-149.

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[24] Thorpe J (ed). 2004. Daylight dividends case study: Harmony Library, Fort Collins, CO [Internet]. Rensselaer Polytechnic Institute: Troy, NY. [cited on 2010 Feb 3]. Available from: http://www.lrc.rpi.edu/programs/daylighting/pdf/HarmonyLibraryCaseStudy.pdf.

[25] ASTM. 2003.ASTM D1003 - 07e1 Standard test method for haze and luminous transmittance of transparent plastics. West Conshohocken, PA:ASTM International.

[26] LBNL. 2010. Window software [Internet]. Available from: http://windows.lbl.gov/software/window/window.html.

[27] Klems JH. 1999. Net energy performance measurements on electrochromic skylights. Energ Buildings. 33(93-102).

[28] Lee E, Yazdanian M, Selkowitz SE. 2004. The energy-savings potential of electrochromic windows in the us commercial buildings sector, LBNL 54966. Berkeley: Lawrence Berkeley National Laboratory.

[29] Lee E, DiBartolomeo DL, Klems J, Yazdanian M, Selkowitz SE. 2006. Monitored energy performance of electrochromic windows controlled for daylight and visual comfort. ASHRAE Trans. 112(2): 122-141.

[30] Lee E, Zhou L, Yazdanian M, Inkarojrit V, Slack J, Rubin M, Selkowitz SE. 2002. Energy performance analysis of electrochromic windows in New York commercial office buildings, LBNL 50096. Berkeley: Lawrence Berkeley National Laboratory.

[31] Nakajima A, Hashimoto K, Watanabe T, Takai K, Yamauchi G, Fujishima A. 2000. Transparent superhydrophobic thin films with self-cleaning properties. Langmuir, 16: 7044-7047.

[32] Blossey R. 2003. Self cleaning surfaces–virtual realities. Nature Materials 2:301-306.

[33] Murdoch JB, Oliver TW, Reed GP. 1991. Luminance and illuminance characteristics of translucent daylighting sandwich panels. J Illum Eng Soc. 20(2):69–79.

[34] Kalwall Corp. 2009. Translucent wall and skyroof systems [Internet]. Basel, Switzerland: Birkhäuser. [cited on 2009 Feb 5]. Available from: http://www.kalwall.com/pdfs/daylight.pdf. Köster H. 2004. Dynamic daylighting architecture: basics, systems, projects.

[35] Keighly EC. 1973. Visual requirements and reduced fenestration in offices – a study of multiple apertures and window area. Building Sci. 8:321-331.

[36] Keighly EC. 1973. Visual requirements and reduced fenestration in offices – a study of window shape. Building Sci. 8:311-320.

[37] Ne'eman E, Hopkinson RG. 1970. Critical minimum acceptable window size: a study of window design and provision for view. Light Res Technol. 2:17-27.

[38] Thanachareonkit A, Scartezzini JL. 2010. Modelling complex fenestration systems using physical and virtual models. Solar Energy. 84:563-586.

[39] Ward G, Mistrick R, Lee E, McNeil A, Jonsson J. 2010. Simulating the daylight performance of complex fenestration systems using bidirectional scattering distribution functions within Radiance. 2010 IES Annual Conference. New York: IESNA.

[40] Lam WMC. 1986. Sunlighting as formgiver for architecture. NewYork: Van Nostrand Reinhold.

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No part of this publication may be reproduced in any form without prior written permission of the IES. For inquiries, please contact ies@ies.org.

[41] Heschong Mahone Group. 1998. Skylighting guidelines [Internet]. Energy Design Resources. [cited on 2009 Jul 21]. Available from: http://www.energydesignresources.com/Resources/Publications/DesignGuidelines/tabid/73/articleType/ArticleView/articleId/9/Design-Guidelines-Skylighting-Guidelines.aspx.

[42] Navvab M. 1988. Daylighting techniques: skylights as a light source. Archit Light. 2(8):46–47, 50.

[43] Navvab M. 1988. Daylighting techniques: translucent and transparent daylighting systems. Archit Light. 2(5):48–55.

[44] McHugh J, Manglani P, Dee R, Heschong . 2003. Modular skylight wells: design guidelines for skylights with suspended ceilings [Internet]. Heschong Mahone Group; [cited on 2010 Aug 15]. Available from: http://www.h-m-g.com/downloads/Mod_Skylights/A-13_Skylight_Guide_5.4.6b.pdf.

[45] Mistrick R. 2006. An improved procedure for determining skylight well efficiency under diffuse glazing. Leukos. 2(4):295-306.

[46] Lee E, DiBartolomeo DL, Selkowitz SE. 1998. Thermal and daylighting performance of an automated Venetian blind and lighting system in a full-scale private office. Energ Buildings. 29(47-63).

[47] Lee ES, Selkowitz SE. 2006. The New York Times headquarters daylighting mockup: monitored performance of the daylighting control system. Energ Buildings. 38(7):914-929.

[48] Lee ES, Clear RD, Fernandes L, Ward G. 2007. Commissioning and verification procedures for the automated roller shade system at The New York Times headquarters, New York, New York [Internet]. Lawrence Berkeley National Laboratory. [cited on 2009 Jul 21]. Available from: http://windows.lbl.gov/comm_perf/pdf/nyt-shade-cx-procedures.pdf.

[49] Rubin AI, Collins BL, Tibbott RL. 1978. Window blinds as a potential energy saver - a case study. NBS Building Science Series 112.

[50] Rea MS. 1984. Window blind occlusion: a pilot study. Build Environ. 19(2):113–137.

[51] Reinhart CF, Voss K. 2003. Monitoring manual control of electric lighting and blinds. Light Res Technol. 35(3):243–260.

[52] Moore F. 1985. Concepts and practice of architectural daylighting. New York: Van Nostrand Reinhold.

[53] Tregenza P, Waters I. 1983. Daylight coefficients. Light Res Technol. 15(2):65–67.

[54] Reinhart CF, Herkel S. 2000. The simulation of annual daylight illuminance distributions – a state of the art comparison of size RADIANCE-based models. Energ Buildings 32:167-187.

[55] Moon P, Spencer DE. 1942. Illumination from a non-uniform sky. Illum Eng. 37(12):707-726.

[56] Love JA. 1993. Determination of the daylight factor under real and overcast skies. J Illum Eng Soc. 22(2):176–182.

[57] Reinhart CF, Mardaljevic J, Rogers Z. 2006. Dynamic daylight performance metrics for sustainable building design. Leukos. 3(1):7-31.

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[58] Nabil A, Mardaljevic J. 2005. Useful daylight illuminance: a new paradigm to access daylight in buildings. Light Res Technol. 37(1):41–59.

[59] Heschong L, McHugh J. 2000. Skylights: calculating illumination levels and energy impacts. J Illum Eng Soc. 29(1):90-100.

[60] Energy Design Resources. Skycalc [Internet]. [cited on 2010 Aug 15]. Available from: http://www.energydesignresources.com/Resources/SoftwareTools/SkyCalc.aspx.

[61] Architectural Energy Corp. 2010. SPOT [Internet]. [cited on 2010 Oct 18]. Available from: http://www.archenergy.com/SPOT.

[62] Reinhart CF. 2010. DAYSIM [Internet]. [cited on 2010 Oct 18]. Available from: http://www.daysim.com.

[63] Building Technologies Program. Building energy software tools directory [Internet]. U.S. Department of Energy. [cited on 2009 Jul 21]. Available from: http://apps1.eere.energy.gov/buildings/tools_directory/subjects_sub.cfm.

[64] Love JA, Navvab M. 1991. Daylighting estimation under real skies: a comparison of full-scale photometry, model photometry and computer simulation. J Illum Eng Soc. 20(1):140–156.

[65] Love JA. 1993. Daylighting estimation under real skies: further comparative studies of full scale and model photometry. J Illum Eng Soc. 22(2):61–68.

[66] Navvab M. 1996. Scale model photometry techniques under simulated sky conditions. J Illum Eng Soc. 25(2):160–172.

[67] Bodart M, Deneyer A. 2006. A guide for the building of daylight scale models. PLEA2006 – The 23rd Conference on Passive and Low Energy Architecture [Internet]. Geneva, Switzerland. [cited on 2009 Jul 21]. Available from: http://www-energie.arch.ucl.ac.be/eclairage/documents%20pdf/PLEA2006guide.pdf.

[68] Murdoch JP. 2003. Illuminating engineering: from Edison's lamp to the LED. New York:Visions Communications.

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14.18 Formulary

14.18.1 Lumen Method of Toplighting

The lumen method of toplighting is similar to the lumen method for electric lighting and is simple enough to permit manual computation. It provides a way to predict average interior daylight illuminance from a uniform layout of skylights with simple diffusing fenestration and shading devices. The lumen method of toplighting consists of four steps:

1. Determine the horizontal exterior illuminance at the skylight for both the sky and sun contribution. These can be calculated as shown in the 7.9 Formulary: Daylight Availability from IES Standard Skies.

2. Determine the net transmittance of the fenestration system. This value determines the amount of daylight entering the room through the base of the skylight well. It includes the transmittance of the glazing (which may be different for the sun and sky contributions as shown below), a light loss factor that considers dirt, a well factor that addresses losses within the skylight well, and additional factors for any obstructions or control devices that may be present within the well.

3. Determine the coefficient of utilization that considers the bottom opening of the skylight well to possess a Lambertian distribution. This functions like the CUs for electric lighting in calculating the average daylight illuminance on the work plane.

4. The interior illuminance is the product of the values determined in steps 1 to 3.

In this procedure, the skylight glazing's direct and diffuse transmittances (for the sun and the sky, respectively) generally exhibit different values.

The average horizontal illuminance on the work plane is

$$E_{wp} = (E_{kh}\ \tau_d + E_{dh}\tau_D)\,CU\,\frac{N\,A_s}{A_{wp}} \qquad \text{(F14.1)}$$

Where:

E_{wp} = average work plane illuminance
E_{kh} = exterior horizontal illuminance due to the sky (onto the skylights)
E_{dh} = exterior horizontal illuminance due to the sun
τ_d = net diffuse transmittance of the skylight and well
τ_D= net direct transmittance of the skylight and well
CU = Coefficient of utilization (Table F14.1) for a skylight given the room conditions
N = number of skylights
A_s = gross area of each skylight.
A_{wp} = work plane area (room area)

14.18.1.1 Skylight Glazing Transmittance

The net transmittances in the above equation consider the following factors, some of which may not be present.

$$\tau_d = T_d\,\eta_w\,R_a\,T_c\,LLF \qquad \text{(F14.2)}$$

Where:

T_d = diffuse transmittance of the skylight material
η_w = efficiency of the skylight well
R_a = net to gross skylight area. This factor converts the gross skylight area to the area of the actual opening (inside the frame), if they are different.
T_c = transmittance of any control devices, such as a shade.
LLF = light loss factor that considers dirt accumulation on glazing that will reduce the skylight transmittance

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Table F14.1 | Coefficients of Utilization for a Diffuse Skylight

ρ_{cc} →	80				70				50			30			10			0
ρ_w →	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
RCR																		
0	1.19	1.19	1.19	1.19	1.16	1.16	1.16	1.16	1.11	1.11	1.11	1.06	1.06	1.06	1.02	1.02	1.02	1
1	1.08	1.03	.98	.94	1.05	1.00	.96	.92	.96	.93	.89	.92	.89	.87	.88	.86	.84	.82
2	.97	.89	.81	.75	.95	.87	.80	.74	.83	.78	.73	.80	.75	.71	.77	.73	.69	.67
3	.89	.77	.69	.62	.86	.76	.68	.61	.73	.66	.60	.70	.64	.59	.67	.62	.58	.56
4	.81	.68	.59	.52	.78	.67	.58	.52	.64	.57	.51	.62	.56	.50	.60	.54	.50	.47
5	.74	.61	.51	.45	.72	.60	.51	.44	.57	.50	.44	.55	.49	.43	.54	.48	.43	.41
6	.68	.55	.45	.39	.66	.54	.45	.39	.52	.44	.38	.50	.43	.38	.48	.42	.37	.35
7	.63	.49	.40	.34	.62	.49	.40	.34	.47	.39	.52	.46	.39	.33	.44	.38	.33	.31
8	.59	.45	.36	.30	.57	.44	.36	.30	.43	.35	.30	.42	.35	.30	.40	.34	.30	.28
9	.55	.41	.33	.27	.54	.41	.33	.27	.39	.32	.27	.38	.32	.27	.37	.31	.27	.25
10	.52	.38	.30	.25	0.5	.37	.30	.25	.36	.29	.24	.36	.29	.24	.35	.29	.24	.22

Similarly,

$$\tau_D = T_D\, \eta_w\, R_a\, T_c\, LLF \tag{F14.3}$$

Where:

T_D = direct transmittance of the skylight material
Other terms are as listed in Equation F14.3

T_d and T_D are not always provided by a skylight manufacturer. However, flat sheet transmittance values are generally available for the individual glazing layers. If the skylights are domed, the material becomes thinner than the flat sheet from which it was created, which may increase the diffuse transmittance. In this case the domed transmittance is generally determined as follows:

$$T_{DM} = 1.25\, T_{FS}(1.18 - 0.416\, T_{FS}) \tag{F14.4}$$

Where T_{FS} = flat sheet transmittance.

When two layers are combined in a skylight to create insulated glazing, the combined transmittance of the two materials can be approximated using the following equation:

$$T = \frac{T_1\, T_2}{1 - \rho_1\, \rho_2} \tag{F14.5}$$

Where:

T_1, T_2 = diffuse transmittances of the individual domes computed by Equation F14.4
ρ_1, ρ_2 = reflectances of the two dome materials

In the case of three layers, the following equation applies for layers, 1, 2 and 3 [68].

$$T = \frac{T_1 T_2 T_3}{(1 - R_3)(1 - R_2 R_2) + T_1 T_2 R_3} \tag{F14.6}$$

14.18.1.2 Vertical Well Efficiency

The well efficiency for a skylight is determined from charts and equations. For a rectangular, vertical well, the well efficiency is based on the well cavity ratio (WCR) and Figure F14.1 [47].

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$$WCR = \frac{5h(w+l)}{w \times l} \quad \text{(F14.7)}$$

Where:

h = height of a rectangular well
w = width of a rectangular well
l = length of a rectangular well

14.18.1.3 Splayed Well Efficiency

For a splayed well, the well efficiency is based on the shape of the well. Assuming the top and bottom openings are rectangular and parallel, the form factor between these two openings determines the daylight contribution between diffuse glazing and the opening to the room (See Equation F10.5). An uncorrected well efficiency, η'_{well}, is then computed using this value by inserting it into the following equation, which assumes a 0% reflectance for the glazing [47].

$$\eta'_{well} = F_{t-b} + \frac{\rho_w (R_w - F_{t-b})(1 - F_{t-b})}{[R_w - \rho_w (R_w - R_b + 2F_{t-b} - 1)]} \quad \text{(F14.8)}$$

Where:

$F_{t\text{-}b}$ = flux exchange factor between the top and bottom of the well, which can be determined from Equation F10.5, for a splayed well with rectangulars cross section.
ρ_w = Well wall reflectance
$R_w = A_{walls} / A_{top}$
$R_b = A_{bottom} / A_{top}$

This well efficiency is then corrected using the following correction factor, which adjusts the well reflectance for a 10, 30 or 50% glazing reflectance, and also to account for the non-uniformity of the luminance on the walls of the well. Interpolation can be applied to obtain correction factors for other reflectance values.

For $\rho_{glazing} = 0.10$:

$$C = 1/[23.362\ F_{t-b}^{6} - 82.616\ F_{t-b}^{5} + 117.08\ F_{t-b}^{4} - 85.028\ F_{t-b}^{3} + 33.662\ F_{t-b}^{2} - 7.1436\ F_{t-b} + 1.6973] \quad \text{(F14.9)}$$

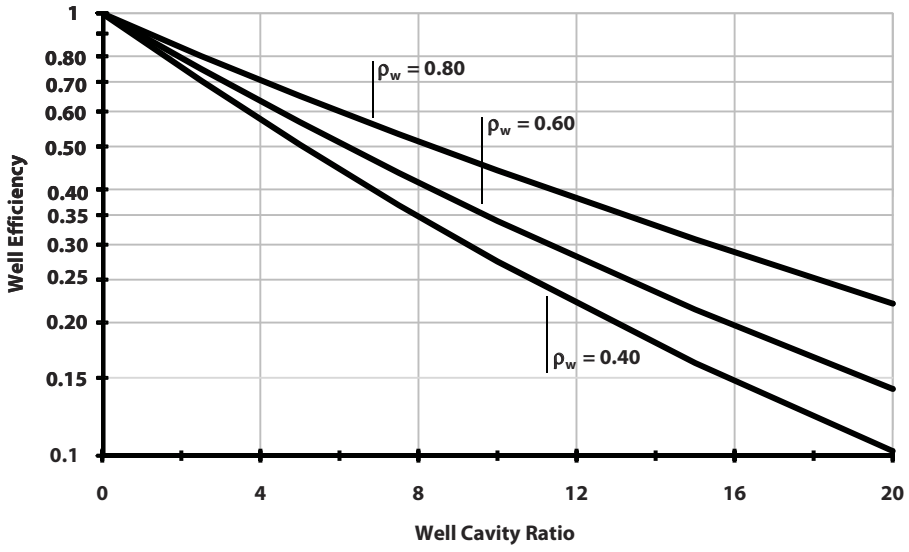


Figure F14.1 | Vertical Skylight Well Efficiency
Well efficiency is the fraction of light that passes through a well, assuming it enters in a diffuse manner. It is a function of well reflectance and well shape (WCR). The assumed glazing reflectance is 10%.

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For $\rho_{glazing} = 0.30$:

$$C = 1/[22.009\ F_{t-b}{}^6 - 78.653\ F_{t-b}{}^5 + 112.59\ F_{t-b}{}^4 - 82.482\ F_{t-b}{}^3 + 32.823\ F_{t-b}{}^2 - 6.9077\ F_{t-b} + 1.6331] \quad \text{(F14.10)}$$

For $\rho_{glazing} = 0.50$:

$$C = 1/[20.687\ F_{t-b}{}^6 - 74.463\ F_{t-b}{}^5 + 107.81\ F_{t-b}{}^4 - 79.753\ F_{t-b}{}^3 + 31.93\ F_{t-b}{}^2 - 6.6667\ F_{t-b} + 1.5692] \quad \text{(F14.11)}$$

Finally, the splayed well efficiency can be determined as follows

$$\eta_{\text{splayed well}} = \eta'_{\text{well}} \times C \quad \text{(F14.12)}$$

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15 | DESIGNING ELECTRIC LIGHTING

". . . visual truth lies in the structure of light."
Richard Kelly - 20th Century Lighting Designer, Architect

Contents

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15.2 A Lighting Scheme . . . 15.20
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Electric lighting design follows the same tenets as those for daylighting design—all outlined in 12 | COMPONENTS OF LIGHTING DESIGN. Although the presentation in this handbook may imply distinct, linear, work flows, advancing the lighting on any project involves daylighting and electric lighting and the two must integrate and work together for optimal efficiency, visual comfort, productivity, and safety. Further, lighting is not isolated from other disciplines and demands continual efforts of integration with the other building systems.

Three principal challenges in designing electric lighting are 1) establishing the breadth and depth of criteria outlined in Chapter 12, 2) integrating with daylighting to achieve an efficient, unified lighting design, and 3) finalizing schemes and equipment to address the criteria and integration. The presentation here is most related to development of lighting schemes leading to lighting designs. What follows will help the team member serving in the role of lighting designer establish and evaluate lighting schemes to address the various analytic and aesthetic aspects identified in Chapter 12. This material assumes some amount of familiarity with the preceding four chapters. This chapter addresses electric lighting for new, renovation, and restoration projects. The procedures presented here are but several of many and will not in and of themselves lead to a complete or satisfactory design solution. For the retrofit of lamps and ballasts, drivers, and transformers into existing luminaires or layouts, see 17.3 Lighting System Upgrades.

15.1 Electric Lighting Systems

Electric lighting systems consist of luminaires and controls. "Luminaires" broadly encompasses lamps, ballasts, drivers, and transformers, optical media, and housings and finishes. Many luminaires address some number of functional and/or aesthetic aspects very well. Familiarity with the extent of available luminaires and their characteristics is tantamount to success. This chapter outlines various luminaires and some of their characteristics, but is not exhaustive. Material here attempts to be commercially neutral. To a lesser degree, this presentation attempts to be fashion neutral, though installation photos alone identify trends of the era of the installation. Mockups or, in many situations, simple reviews of operational samples help the designer assess style, quality, and lighting effects.

Three fundamental lighting systems are worthy of consideration for any application, interior or exterior: *ambient*, *task*, and *accent*. None is superfluous, but there are situations where a strategy using any one or two of these techniques can achieve appropriate results.

15.1.1 Fundamental Lighting Systems

Three elemental lighting effects deemed to have profound influence on people were articulated mid-20th century by architectural lighting pioneer Richard Kelly. These were ambient luminescence, focal glow, and the play of brilliants. [1] These might also be called general background lighting, task highlighting, and sparkle or dazzle. These are distinguished today as three fundamental lighting systems: *ambient* lighting; *task* lighting; and *accent* lighting.

Ambient lighting, as used here, is a system that produces a general background of light which may or may not provide all of the illuminance necessary for task performance. This assumes that the effect is a uniform illuminance on the planes of the tasks.

Task lighting, as used here, is a system that produces light localized to specific areas of planes on which the task or tasks are located. Depending on the techniques used, highlighting of the tasks results.

Accent lighting, as used here, is a system that produces light effects for visual relief, overall brightness perceptions, visual attraction, and wayfinding. Many times accenting draws attention to designed or programmed features, objects, and details. This might address, but is not limited to 2- and 3-dimensional artwork, displays, decorative materials and finishes such as glass, metal, wood, stone, and leather, and architectural dimensional elements such as coves and niches. With some techniques, the luminaires alone serve as decorative accents.

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Lighting techniques that address those lighting design factors deemed important in 12.2 Spatial Factors, 12.3 Psychological Factors, and 12.5 Task Factors will collectively establish ambient, task, or accent systems depending on the space types and activities. Carefully administered systems consisting of various techniques can offer efficiency and visual interest benefits over single-technique approaches simply engineered to high illuminance values or approaches not founded on principles outlined in Chapter 12.

What follows is a brief guide to techniques, some equipment options, and several examples. Conformity with technical and planning criteria is de rigueur. However, lighting techniques and equipment options are limited more by the designer's imagination than by compliance with such technical criteria as illuminance targets and 12.7 Prescribed Factors.

15.1.1.1 Ambient Lighting

Ambient lighting is distinguished by its typically seamless coverage, where lighting is consistent over a broad area or zone. Ambient lighting is at least partially responsible for overall impressions of brightness and comfort, or sensations of dimness or glare, and typically affects all users in a given setting. Since ambient lighting will partly or entirely address luminance ratios, it is also responsible for the degree of visual fatigue experienced, if any, by long-term users of spaces.

The degree to which ambient lighting contributes to the total illuminance in any given area or space is typically based on the kinds of tasks and applications involved and the sizes of the task areas. Figure 12.22 illustrates the distinction between task proper and task area. There are situations where ambient lighting serves simultaneously as task lighting or accent lighting as Figures 15.1, 15.2, 15.3, and 15.4 variously illustrate.

Ambient lighting can be achieved with ceiling mounted equipment or wall-, floor-, furniture-, or grade-mounted equipment. For interior applications, ambient lighting from ceiling mounted equipment is most common. Techniques for this are recessed, semi-recessed, or surface mounted or pendant mounted. Table 15.1 outlines some aspects for linear options. Figures 15.5a, 15.5b, 15.5c, and 15.5d illustrate a few respective applications. Some options are listed as "details", such as architectural drywall, millwork, or other constructions that hide luminaire hardware from view. Other options cited consist of fully-finished off-the-shelf hardware intended to be seen.

In work situations where concentration or long duration on visual tasks is required or desired, ambient and task lighting coordinate to meet the criteria outlined in 12.5.5.5 Illuminance Ratios and in Table 12.6. Default Illuminance Ratio Recommendations. In addition to illuminance target recommendations in each application chapter of this handbook, illuminance uniformity values may also be cited. These should be used in place of default values.

Where no task lighting is planned or practical, the ambient lighting illuminance contribution may be 100 percent, such as that shown in Figures 15.1, 15.2, 15.3, and 15.4.

If ambient lighting is expected to contribute at least 30 percent of the illuminance at the task or where areas of ambient lighting coverage are greater than a few hundred square feet, then surface reflectances should be at least IES-recommended values of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively), otherwise backgrounds may be considered too dim and/or LPDs may be unnecessarily high.

As Table 15.1 implies , there are innumerable options—just for ceiling mounted ambient linear lighting. A similar array of non-linear lighting options exists for ceiling mounted ambient (see Figure 15.6) as do many options for furniture-, wall- and floor- mounted ambient lighting. Wall-mounted ambient lighting is illustrated in two forms in Figure 15.7. A floor-mounted example is shown in Figures 15.8 and 15.9. Figure 15.10 is representative of grade-mounted ambient lighting. See 8.3 Luminaire Types for more discussion on the variety of luminaires.

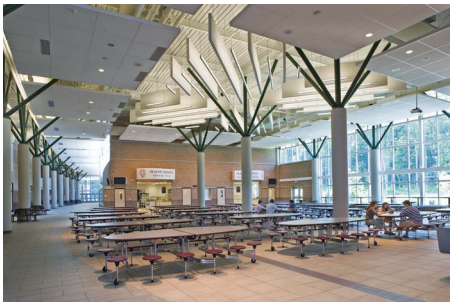
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Figure 15.1 | Ambient Lighting System
This entry/intermission lobby to a 3500-seat auditorium uses luminaires modeled after historic originals. Uplighting from the open bowl provides ceiling luminances appropriate to an overall sense of brightness and appropriate to a densely occupied assembly area where facial recognition is important to conversation. Sconces are introduced as accents at entries to the auditorium proper.
Image ©Balthazar Korab Photography Ltd.



Figure 15.2 | Ambient Lighting System
The area defined by low stacks and reading tables to the right side is lighted with linear pendants serving both an ambient role and task role. In the foreground, the lighting of the low stacks is addressed with the ambient lighting system. At reading tables in the background, the same ambient lighting system provides general light with a task lighting system comprised of table luminaires providing supplemental lighting to address the need for greater illuminances at the reading tables.
Image ©Balthazar Korab Photography Ltd.



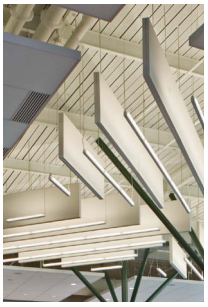


Figure 15.3 | Ambient/Accent Lighting Systems
Eschewing a flat ceiling, the architect designed a vertical-acoustic-baffle array for this high school dining/assembly area. Lighting the baffle array was identified in the programming of spatial factors (spatial definition) and luminance ratios (to prevent daylight luminances from overwhelming facial recognition—as is common where tasks are silhouetted against daylight). The baffle accenting combines with the crisp emphasis created by the downlights to create an ambient lighting system. Note the use of landscaping to minimize daylight luminances.
» Image ©Bill Lindhout Photography





Figure 15.4 | Ambient Lighting System
Lighting of this high school breakout study area was identified in programming to address pleasantness (luminaires' scale, layout, and luminances). Although budget was tight, glare, visual order, and luminaire scale (relating comfortably to people where ceilings are relatively low) were key aspects that resulted in relatively small mostly-indirect linear luminaires. The linear pendants and their indirect light distinguish the area from the more pedestrian nature of the circulation lighting.
Image ©Bill Lindhout Photography

Ambient lighting for work situations must address long-term user comfort and performance. In casual, transitional, and/or highly social situations or in situations where lighting scenes are changeable for function, ambient lighting can be quite dramatic yet appropriately safe and comfortable, particularly where users are primarily sedentary. Figures 15.11 and 15.12 illustrate dramatically-lighted situations where ambient lighting is nonuniform or considered as accent lighting.

There are applications where ambient or task lighting need not meet an illuminance target, but establishes appropriate luminance contrast for wayfinding as seen in Figure

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Table 15.1 | Ceiling Mounted Ambient Linear Lighting

Mounting	Form Factor	Configuration	Optics/Look	Distribution/Features/Caveats
Recessed	• Linear	• Continuous • Discrete	• Details[a] • Baffled • Lensed • Louvered • Open[b] • Slot[c] • Combination[d]	**Distribution:** Direct (see 8.2.2.1 | CIE System). **Features:** Custom look; width of several inches to several feet; length of several feet to unlimited; depth of several inches to several feet. Uses off-the-shelf optic/lamp/ballast/driver modules. **Caveats:** Overall cost of architectural detail may be more than off-the-shelf luminaires; photometric pedegree is elusive and demands careful modeling; lengths typically based on available lamp modules.
			• Luminaires • Baffled ❶❷❸ • Lensed • Louvered ❹❺ • Open[b] • Slot[c] • Combination[d]	**Distribution:** Direct (see 8.2.2.1 | CIE System). **Features:** Width of several inches to perhaps a foot; length of several feet to unlimited; depth of several inches to perhaps a foot. Integral optics, lamps, and ballasts/drivers. **Caveats:** Ceiling construction needs to accommodate available modular lengths and mounting methods unless customized luminaires and/or ceilings are used; longer runs demand heavy gage or extruded trims and/or housings and finely-detailed, robust joiners to maintain true linearity.
Semi-recessed **Surface**	• Linear	• Continuous • Discrete	• Details[a] • Baffled • Lensed • Louvered • Open[b] • Slot[c] • Combination[d]	**Distributions:** Direct, Semi-direct, and General Diffuse (see 8.2.2.1 | CIE System). **Features:** Custom look; width of several inches to several feet; length of several feet to unlimited; depth of several inches to several feet. Uses off-the-shelf optic/lamp/ballast/driver modules. **Caveats:** Overall cost of architectural detail may be more than off-the-shelf luminaires; photometric pedegree is elusive and demands careful modeling; lengths typically based on available lamp modules.
			• Luminaires • Baffled • Lensed • Louvered • Open[b] • Slot[c] • Combination[d]	**Distribution:** Direct, Semi-direct, and General Diffuse (see 8.2.2.1 | CIE System). **Features:** Width of several inches to perhaps a foot; length of several feet to unlimited; depth of several inches to perhaps a foot. **Caveats:** Ceiling construction needs to accommodate available modular lengths and mounting methods unless customized luminaires and/or ceilings are used; longer runs demand heavy gage or extruded trims and/or housings and finely-detailed, robust joiners to maintain true linearity.
Pendant	• Linear	• Continuous • Discrete	• Details[a] • Baffled • Lensed • Louvered • Open[b] • Slot[c] • Combination[d]	**Distribution:** Direct, Semi-direct, General Diffuse, Direct-indirect, Semi-indirect, and Indirect (see 8.2.2.1 | CIE System). **Features:** Custom look; width of several inches to perhaps several feet; continuous length unlimited; discrete length typically 4' to 8'; depth of several inches to several feet. Uses off-the-shelf optic/lamp/ballast/driver modules. Various suspension methods (stems, aircraft cable, rigid stanchions, vertical plates) for different and unique appearances. **Caveats:** Overall cost of architectural detail may be more than custom-from-factory and/or off-the-shelf luminaires; photometric pedegree is elusive and demands careful modeling; lengths typically based on available lamp modules; detailing of suspension elements and power feed(s) critical.
			• Luminaires • Baffled • Lensed • Louvered • Open[b] • Slot[c] ❻ • Combination[d]	**Distribution:** Direct, Semi-direct, General Diffuse, Direct-indirect, Semi-indirect, and Indirect (see 8.2.2.1 | CIE System). **Features:** Width of several inches to perhaps a foot; length unlimited; depth of several inches to perhaps a foot. **Caveats:** Ceiling construction needs to accommodate typical suspension and power feed types and locations, which are not necessarily spaced on incremental modules sympathetic to ceiling layout; longer runs demand extruded trims and housings and finely-detailed, robust joiners to maintain true linearity.

a. Consisting typically of millwork, drywall, or metal architectural details housing luminaires.

b. The term "open" refers to linears exhibiting bare lamps or lamps with tight lamp shrouds or guards for an open appearance into the lamp chamber.

c. The term "slot" refers to linears exhibiting return-lipped compartments for an open appearance but into a void where lamps are hidden from view.

d. Combinations of any the aforementioned optics/looks.

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Figure 15.5a | Ambient Ceiling Recessed Continuous Linear Lensed
Ambient light (to the left) for circulation and stack lighting in this library is achieved with ceiling recessed linear continuous luminaires technique ❶. Linear row consists of 6″ wide by 4′ long units mounted end-to-end. Luminaires exhibit a regressed lens for a dimensional look and use F28W/T5/835 lamps and non-dim ballasts. Other lighting is shown in adjacent areas.
» Image ©Balthazar Korab Photography Ltd.

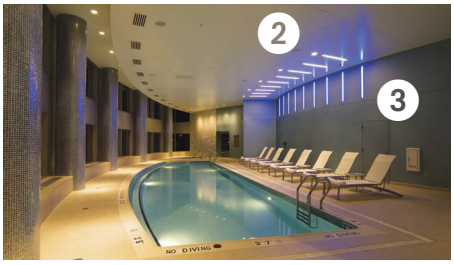


Figure 15.5b | Ambient Ceiling Recessed Discrete Linear Lensed
Some ambient light for circulation and social interaction in this indoor pool is achieved with ceiling recessed linear discrete luminaires technique ❷. Discrete luminaire consists of 3″ wide by 4′ long extruded aluminum housing. Luminaires exhibit a flush diffuse lens with a flangeless trim for a "seamless" appearance with ceiling plane and use F28W/T5/830 lamps and non-dim ballasts. Running the linear dimension perpendicular to the tangent of the arc, the close-spaced pattern works to accentuate the arc. A similar pattern of identical luminaires is wall mounted and lamped with F28W/T5/Blue lamps for a more decorative appearance ❸.
» Image ©Kevin Beswick, www.ppt-photographics.com

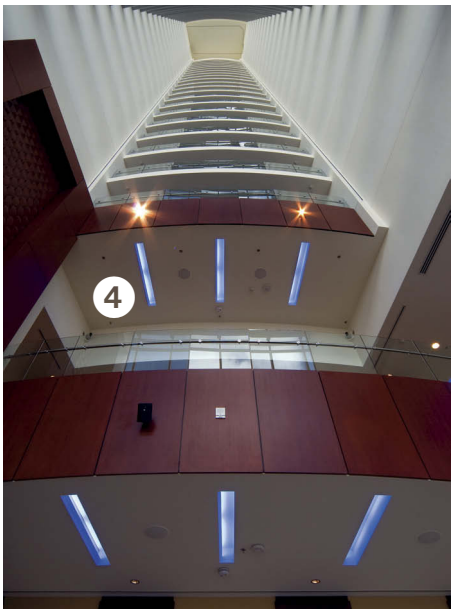


Figure 15.5c | Ambient Ceiling Recessed Discrete Linear Slot
Linear open slots create the ambient lighting of the elevator lobbies in this 18-story hotel ❹. Discrete luminaire consists of 9″ wide by 6′ long 20-gage housing and extruded aluminum trim. Slot aperture exhibits minimal trim for a "ceiling-cutout" appearance. Luminaire uses F39W/T5HO/Blue lamps and non-dim ballasts. Lamps are hidden from view along one side—essentially a linear cove. All light is reflected from within the slot. A radial layout accentuates the planning arc. At night, the colored ambient light reflects from each elevator lobby's white walls and ceiling to give the building its skyline presence ❺ without facade lights or excessive interior wattage. F32W/Triple/830 downlights at elevator doors and the effect of color constancy (colors, such as skin tones and clothing, retain their color appearance despite changes in the light source color) allow the blue light to succeed in this transition space—albeit one contributing to the overall guest experience..



» Image©KevinBeswick,www.ppt-photographics.com



Figure 15.5d | Ambient Ceiling Pendant Discrete Linear Combination
Ambient light for conferencing is achieved with ceiling mounted linear discrete luminaire technique ❻. Linear luminaire consists of 3″ wide by 4½″ high by 13′ long extruded aluminum housing. Luminaire exhibits a flush bottom lens and an open top. Downlight ambient uses F54W/T5HO/830 lamps and dimming ballasts. Uplight compartment uses F54W/T5HO/830 lamps and dimming ballasts. In combination with the direct-indirect ambient lighting, two 37W/halogenIR$_{LV}$/MR16 lamps provide supplemental task lighting.
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15.13. These are typically residential situations where code or application standards do not demand minimum illuminances or uniformity limits. In these situations, appropriately placed luminance contrast is sufficient for task performance—traversing the circular stairs from a roof deck to a ground terrace.

Regardless of the illuminance contribution of ambient lighting, all code requirements with respect to illuminance must be met. IES recommended targets are based on more than a century of research and application experience with sight and light and are indicative of appropriately safe, comfortable, and productive conditions during normal-power operation when properly designed. However, code authorities have final determination on illuminances. See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

In any event, while this discussion has centered on illuminance, success is elusive without designing lighting to acknowledge the depth of programming outlined in 11 | LIGHTING DESIGN: IN THE BUILDING DESIGN PROCESS and address the factors and criteria outlined in 12 | COMPONENTS OF LIGHTING DESIGN.

Ambient lighting control strategies vary depending on the application, the extent of task and accent lighting, the extent of daylighting and its integration with electric lighting, and the ambient lighting approach. See 16 | LIGHTING CONTROLS.

15.1.1.2 Task Lighting

Task lighting is typified by lighting specifically localized to the task in conjunction with ambient lighting to address a specific task proper or task area. In a typical office, task lighting might be accomplished with a system of luminaires on the desks or a system of ceiling-mounted luminaires correlated to the desk locations. These are designed and controlled to affect only specific task areas being lighted.

Task lighting of a library stack is illustrated in Figure 15.14. The control of this task lighting can offer significant energy reductions providing the function does not interfere with the expected use of the facility. For example, periodic rapid dimming-and-brightening cycles or, worse, on-off switching of stack lights in a public library will seriously disrupt patrons' reading unless stack areas are well-screened from reading areas.

A more conventional task lighting approach is shown in Figures 15.15. In these situations, the task lighting is a significant contributor to the overall task illuminance, but is responsible for a small proportion of the overall LPD.

Beware that functional definitions for ambient, task, and accent lighting may not parallel those with codes and standards. Classify lighting in accordance with code- and/or standards-definitions for purposes of meeting their respective requirements. For example, accent lighting may be considered "decorative" lighting by some codes.

There are task applications where task lighting need not meet an illuminance target, but establishes appropriate luminance contrast for wayfinding as seen in Figure 15.13. These are typically residential situations where code or application standards do not demand minimum illuminances or uniformity limits.

Regardless of the illuminance contribution of task lighting, all code requirements with respect to illuminance must be met. See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

Task lighting control strategies vary depending on the application, the extent of ambient and accent lighting, the extent of daylighting and its integration with electric lighting, and the ambient lighting approach. See 16 | LIGHTING CONTROLS.

15.1.1.3 Accent Lighting

Accent lighting is a necessity in many situations In work situations accent lighting minimizes the fatiguing effects of long-term close-up viewing of tasks and provides visual relief

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Figure 15.6 | Ceiling Decorative Surface Mounted Ambient
Decorative surface mounted lights provide a diffuse ambient light to this residential fitness room. Vertical illuminance (lighting of the human figure) is important for self esteem and assessment of progress (hence the mirrors).
» Image ©Andrea Rugg Photography/Beateworks/Corbis



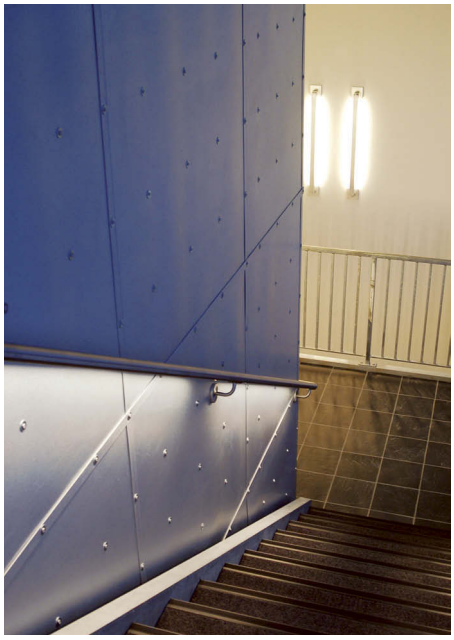


Figure 15.7 | Wall-mounted Ambient
Stairs and landings in this building are lighted with wall-mounted equipment. LED handrails are used in stairs to illuminate treads ❶. A series of five vertically-oriented linear wall sconces are used to illuminate each upper-floor landing ❷.
» Image ©Nelson Breech Nave, AIA, Architect



Figure 15.8 | Floor Recessed Ambient
A continuous in-floor uplight provides nominal ambient light given the finish and geometry of this passageway. Common lamping is linear fluorescent. Although a unique and pleasing effect, these solutions are many times driven by necessity—where else to mount and how to integrate the lighting equipment. Discrete in-floor uplights are a similar method (see Figure 15.9)
» Image ©Michael Kai/Corbis



Figure 15.9 | Floor Recessed Ambient
Discrete in-floor uplights provide nominal ambient light appropriate to a residential or some hospitality situations. Common lamping is CFL, CMH, and LED. Continuous in-floor uplights are a similar method (see Figure 15.8)
» Image ©Marc Gerritsen/Look Photography/Corbis

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Figure 15.10 | Grade-mounted Ambient
Postlights provide ambient lighting in exterior pedestrian way and terrace situations. Here, light is directed up to a reflector disc and diffused to the ground. Advantages are less glare and more uniform vertical illuminances necessary for facial recognition and improved sense of security. Common lamping is CMH.
» Image ©Alan Schein Photography/Corbis



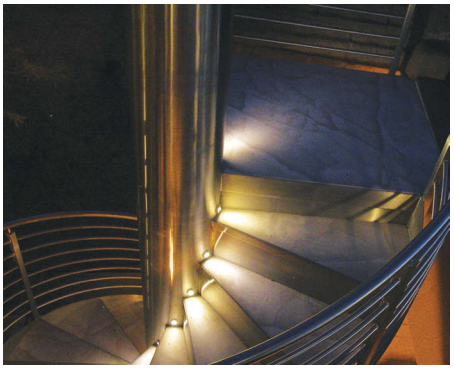
Figure 15.11 | Uniform Perimeter Accent as Ambient
Washing wall surfaces provides greater illuminance in the vicinity of the seats while providing illuminance to the floor for circulation. The task of sitting/casual reading has one IES recommended illuminance target associated with it—and the area of coverage is lap height at the sitting area. The task of public circulation has another IES recommended illuminance target associated with it—and the area of coverage is the floor. The illuminance uniformity ratio criteria over the floor area is 2:1 average-to-minimum. However, without a maximum-to-minimum recommendation, the floor zone maximum illuminance in the vicinity of the sitting area may exceed the average floor illuminance by three or even four times resulting in a maximum to minimum of 6:1 or even 8:1. Such variances are acceptable when circulation areas are relatively large and the gradient from maximum to minimum is gradual..
» Image ©Sanna Lindberg/ès Photography/Corbis



Figure 15.12 | Nonuniform Perimeter Accent as Ambient
Featuring a wall with a rhythm of scallops and highlighting darker floor patterns results in a relaxed and more private lighting condition—the table is purposely not illuminated. See Table 12.2 | Subjective Impressions. This succeeds for small areas of respite from work areas. The task of such a lounge is social interaction/conversation and has an IES recommended illuminance target associated with it—and the area of coverage for vertical illuminance is seated face height at the sitting area; with the area of coverage for horizontal illuminance is the table surface. The illuminance uniformity ratio criteria over the floor area is 4:1 average-to-minimum. However, without a maximum-to-minimum recommendation, the maximum illuminance on the floor zone in the entire view might exceed the average floor illuminance by three or four times leading to a maximum-to-minimum of 12:1 or greater. Such ratios are typically acceptable and tolerated in areas of relatively low or slow-paced traffic and where floor planes exhibit no changes in elevation and/or where material transitions are demarcated with contrast change (such as at the dark-to-light floor transition shown).
» Image ©Dan Forer/Beateworks/Corbis



Figure 15.13 | Task Contrast Alone
Each tread of a residential exterior circular stair is illuminated with a small diameter 0.5W/3300K LED step light. Here, where speed of climbing is relatively unimportant, simultaneous multi-direction passage is unlikely, volume low, and where people have ongoing familiarity with the situation, identification of each tread (and, by contrast, riser) is more important than a specific illuminance target.
» Image ©GarySteffyLightingDesign Inc.



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by addressing luminance aspects. Additionally, accent lighting addresses some spatial and psychological factors (see 12.2 Spatial Factors and 12.3 Psychological Factors). In more casual and transitional situations, accent lighting alone can address the lighting needs of the users (see Figure 15.11). Accent lighting also can be used to assist in wayfinding and establish the boundaries of space without the visual monotony and equipment and wattage burden of uniformly applying ambient lighting everywhere. Accent lighting typically affects all or many users in a given situation.

An accent lighting system accentuates objects or features or may consist of luminaires that themselves exhibit an artistic flourish or a luminous accent. Accenting may be as simple as featuring wall surfaces as illustrated in Figures 12.11a and 11b, 12.12, 15.5d, and 15.16. Figure 15.17 illustrates a conventional application of accent lighting.

Unlike ambient and task lighting systems, accent lighting may not contribute significantly to illuminance. There are no rules-of-thumb for establishing a proportion of illuminance contribution from accent lighting. Benefits of accent lighting include enhancing overall brightness perceptions and providing visual relief. Additionally, accent lighting is used for visual attraction. Table 15.2 outlines accent illuminance ratios for various degrees of visual attraction. Focal pieces with reflectances greater than 50 percent require less light for attraction than lower reflectance counterparts. In many situations, focal pieces are vertically oriented while the task illuminance used as a baseline reference applies to horizontal planes. The recommended ratios are based on this distinction between planes. So, in a traditional residence where a light-toned painting (the focal point) is to be highlighted for a subtle accent, the ratio of interest is 1:1 focal-point-to-task. Where task is the general illuminance in the room. If the painting is to be highlighted for a soft accent, the ratio is 2:1 focal-point-to-task. If a dramatic accent is preferred, however, then the ratio is 10:1 focal-point-to-task.

Two analytic aspects of accent lighting that deserve attention are the gradient of the accent effect and the uniformity across the accent effect. Criteria depend on the application involved, the design intent, surface reflectances, and user expectations. For example, a sharp gradient may be desirable and is acceptable in many applications except where concentrated visual work is involved or where study of the accented object is encouraged, such as in museums. Figures 12.12, 12.13, 15.12, 15.17, 15.18, and 15.19 illustrate sharp gradients. Softer gradients are usually more appropriate for accents used in work settings or on artworks or features where intentional and long term respite or study is expected. Uniformity across the accent effect is also most important where intentional and long term respite or study of works is encouraged and where large surface washes are desired. Over relatively small artworks or features a uniformity of 2-to-1 (2:1) average-to-minimum and 4:1 maximum:minimum is typically appropriate. Over large works or surface features, illuminance uniformities such as 10:1 maximum:minimum or less generally result in a uniform surface appearance when the surface finish is monolithic in tone. See Figure 15.16 and in later chapters Figures 28.3 (interior feature wall ❷) and 29.7 (right image illustrates ceiling accenting). Gradients and uniformities can be assessed in calculations and computer-generated renderings using actual luminaire photometry.

15.1.2 Hardware

Familiarity with design programming and lighting systems is paramount when determining techniques and developing lighting strategies. Familiarity with hardware guides refinement of schemes and leads to more detail in the latter part of the design development phase. Lighting hardware includes luminaires, lamps, ballasts, drivers, controls, and any other auxiliary devices necessary to actually produce electric light in spaces. This section discusses equipment and some of the important aspects necessary to assessing appropriateness for a given situation.

Hardware and lighting systems are intertwined in this chapter for brevity and clarity. It cannot be overstated, however, that effective lighting is designed to meet the programmed



Figure 15.14 | Task and Low Ambient
A perimeter library stack is lighted by a suspended linear luminaire optimized to address vertical illuminance at 30″ AFF. This is the task luminaire. The mounting geometry of the linear pendant enables it to also illuminate wall graphics above the stack. Ambient lighting is achieved with perimeter linear uplighting. Ambient horizontal illuminance is roughly 20 percent of the stack task vertical illuminance. Reading areas are task lighted with localized ceiling-mounted red-shade pendants.
» Image www.jmaconochie.com



Figure 15.15 | Task and Low Ambient
Two task lights address several lighting needs at this library information desk—used as wayfinding devices to the desk where facial recognition is as important as intermittent reading.
» Image ©Curt Clayton

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Table 15.2 | Accent Illuminance Ratios

Attraction	Role	Focal-point Reflectance	Illuminance Ratio[a]	Application Notes[b]	Example Applications
Strong	Dominant	≥50%	~20:1 focal-point-to-task	Used very sparingly for short duration on one or a few relatively small focal points for momentous occassion or experience. Long-term exposure may fade/degrade focal. Focal point lighted to these ratios may be a fraction of total focal area. Focal plane may be different from task plane.	• House of Worship: reverent focal element during dark-house ceremony • Retail: highly-exclusive indoor small displays such as an extraordinary piece of jewelry
		<50%	~40:1 focal-point-to-task		
	Dramatic	≥50%	~10:1 focal-point-to-task	Used sparingly on one or several focal areas for significant effect. Long-term exposure may fade/degrade focals. Focal point lighted to these ratios may be a fraction of total focal area. Focal plane may be different from task plane.	• Corporate and hospitality lobbies: exclusive wall materials such as granite • Retail: exclusive indoor display such as vignette at department or store entry
		<50%	~20:1 focal-point-to-task		
Moderate	Feature	≥50%	~5:1 focal-point-to-task	Used on focal points for visual attention. Focal point lighted to these ratios may be a fraction of total focal area. Long-term exposure may fade/degrade focals. Focal plane may be different from task plane.	• Hospitality: destination features such as concierge, front desk, wall-material features • Retail: dazzle and highlight of feature displays
		<50%	~10:1 focal-point-to-task		
Soft	Visual Edge	≥50%	~2:1 focal-point-to-task	Used on focal points or features for visual interest. Long-term exposure may fade/degrade focals. Focal plane may be different from task plane.	• Conference rooms: artwork, wall-material features • Contemporary residences:: artwork • Reception: artwork, wall-material features
		<50%	~5:1 focal-point-to-task		
Subtle	Visual Relief	≥50%	~1:1 focal-point-to-task	Used liberally on focal points for visual relief. Long-term exposure may fade/degrade focals. Focal plane may be different from task plane.	• Office: artwork, wall-material features • Traditional residences: artwork
		<50%	~2:1 focal-point-to-task		

a. Ratio of E_v (average illuminance on focal point typically of vertical orientation) to E_h (average illuminance on primary task plane typically of horizontal orientation).

b. See 21 | LIGHTING FOR ART for criteria related to preservation-worthy objects.

IESH/10e Luminaire Resources

> 8 | LUMINAIRES: FORMS AND OPTICS
- for more on luminaire characteristics

> 8.3 Luminaire Types
- for more on lighting effects
- for more on function
- for more on applications

> 8.5 Specifying and Using Luminaires
- for more on evaluating luminaires
- for more on specifying luminaires
- for more on influence/integration with other systems

needs of the users and not to showcase lighting hardware, a particular lighting technique, lowest connected load, and/or lowest initial cost at the expense of other criteria unless these aspects are the primary programmed requirements and consequences of dismissing other criteria are understood. To avoid repetition, discussions here are abbreviated and references are made to other sections and chapters.

15.1.2.1 Luminaires

Various aspects of luminaires are discussed in 8 | LUMINAIRES: FORMS AND OPTICS. An overview of the types of luminaires available and the factors involved in their selection and specification is in 8.3 Luminaire Types and 8.5 Specifying and Using Luminaires. This helps with development of a tentative lighting strategy based on intended luminaire performance to meet programmed needs. Actual luminaire performance will be different from vendor to vendor and will be evaluated in calculations, computer renderings, and review of actual samples. During development of this tentative lighting strategy, be vigilant about vendor definitions and performance explanations. For example, if programming determines that wallwashing is an important technique to meet one or several lighting design factors, then the lighting strategy includes use of a system of wallwashers

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and should identify where they are to be employed. Aspects such as size, lamping, and performance may influence luminaire selection.

Lighting techniques established during review of lighting design factors (see Chapter 12) guide luminaire selection. In the wallwash example above, assuming a ceiling-integrated application, preliminary luminaire selection is simply "wallwash." Those designers with a good familiarity of the various wallwash equipment available may simultaneously select the following:

1. The kind of wallwash effect.
2. The kind of wallwash luminaire.
3. The kind of trim and its finish.
4. The kind of lamp.

So, the general direction "wallwash" narrows the field, but additional research and review is needed to finalize luminaire selection. Ultimately, photometry of the wallwashers under consideration demands review. In work environments, uniformity of wallwash may be an important aspect to maintain appropriate luminance ratios throughout the work space. Review of operational samples will likely be necessary to answer such questions as, "Does the wallwasher create a shadow line on the wall some distance below the ceiling or just at the ceiling-wall juncture, and is this a deal breaker?" Reviews of operational samples also reveal scallop patterns, socket-shadow patterns, secondary- and tertiary-reflector or lamp-imaging patterns, and cone, trim, and optical media fit and finish and "flash." Flash is an objectionable harsh brightness on the lower part of the luminaire reflector or trim piece visible from many viewpoints. Each of these aspects influence the "wallwash" experience of the users. This level of detail establishes the best ceiling wallwash for the users and their application.

Where a ceiling-integrated adjustable accent is deemed necessary, the level of detail on its selection must eventually address such aspects as:

1. Available tilt to determine what aiming angle off nadir (straight down) is achievable. A 45° tilt is considered an optimal tilt for frontal accenting with a minimum 35° as an alternative.
2. Available rotation to determine how well the luminaire can be adjusted toward focal cues after installation. A rotation of 360°+ is preferable for maximum flexibility.
3. Available mechanisms for assisting in accurate tilt and rotation. Detents or sights are commonly employed for tilt and rotation precision. This is especially important where multiple accents are used in close proximity and where each is to produce an identical lighting effect.
4. Available locking capability to lock tilt and aim once set in the field. This minimizes if not eliminates misalignment that can occur during relamping or cleaning.
5. Available hot-aim feature whereby the lighting effect can be observed during tilt and rotation setup. Since some lamps are hot-shock-sensitive and may immediately fail, hot-aiming must be done with care. Hot-aim is less likely to cause premature lamp failure due to hot-shock if the luminaire aiming mechanisms are engineered for a smooth and fluid operation.
6. Available accessory magazine to retain a number of accessories. It is important to determine the kind of accessories that can be accommodated, such as hexcell louver, UV filters, neutral density filters, and dichroic color filters. Equally important is how or if the accessory magazine interferes with relamping. Some accent luminaires allow for relamping without removal of the accessory magazine.

Other aspects affecting luminaire selection are: housing and finish durability and longevity; modularity which affects ease of installation and ease of reconfiguration in the future; compo-

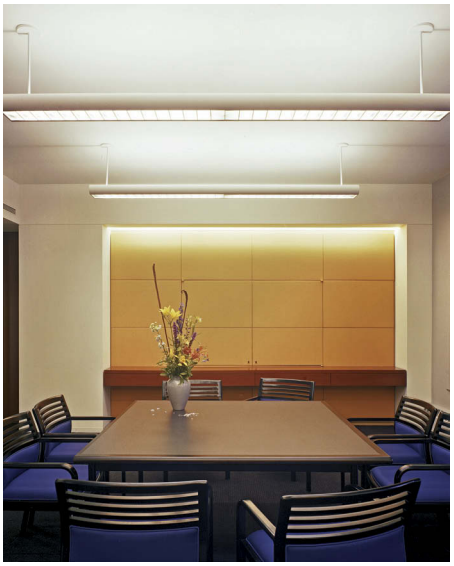


Figure 15.16 | Accent/Feature Wall
A wall niche with fabric-wrapped panels and a built-in buffet or storage credenza is accented with a fluorescent slot detail to address spatial factors (pleasantness, spaciousness, and spatial definition), board or poster presentations, and food service.
» Image ©Robert Eovaldi



Figure 15.17 | Accent/Artwork
A glass mosaic art piece is lighted with CMH monopoints to accentuate the art detail and color variegation. In addition to art appreciation, this effect is used for wayfinding and luminance balancing for nearby office users (to the left and behind the camera view).
» Image ©Beth Singer Photographer, Inc.

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Table 15.3 | Coordination Aspects

Mounting		Coordination Aspect[a]
RECESSED	Ceiling	Aperture/Lens/Frame • durability • flange overlap, if any Housing • insulation contact (IC) • airtight (AT) • size/configuration/fit Type • drywall, grid, other Earthquake requirements Substrate • thickness • material compatibility
	Wall	Aperture/Lens/Frame • durability • surface temperature • flange overlap, if any Housing • insulation contact (IC) • size/configuration/fit Substrate • thickness • material compatibility
	Floor	Aperture/Lens/Frame • durability and walkover • slip resistance • surface temperature Housing • insulation contact (IC) • size/configuration/fit Substrate • thickness • material compatibility
SURFACE	Ceiling	Projection (surface mount) • door-swing clearance • clear mounting height Suspension • clear mounting height • head height Earthquake requirements
	Wall	Projection • ≤4" at ≤68" AFF • or bottom at >68" AFF • door-swing clearance Housing • durability • surface temperature • edge conditions

a. May affect equipment selection or architectural details.

nent replacement which affects upgradability; finish and cleaning; servicing of lamps, ballasts, drivers, or transformers; and any auxiliary components and their respective characteristics, such as embedded occupancy sensors and/or photocells and/or switching/dimming controls. Where cable-mounted pendants are considered, dimming and switching scenarios affect the number and size of power cables required in addition to the aircraft cables. Alternatively, if wire management is cumbersome, stem mounts, while introducing a different aesthetic than cable mounts, offer a consistent means of addressing multiple or large power cords.

Coordination of luminaires and lighting effects with other disciplines is necessary. The more common aspects of ceiling and/or wall types must be known to make luminaire selections, as some luminaires are simply incompatible with some materials' substrates. Other aspects include ceiling types such as modular, linear metal or wood. Material substrate thicknesses are also important as are a host of other aspects that are typically addressed over the course of a project—preferably before lights are ordered and these other systems are installed. Table 15.3 outlines some physical coordination aspects. Although for most luminaires on most projects it will be convenient to specify equipment that addresses these and other coordination issues, the lighting effects, luminances, and illuminances remain ultimate lighting ends. Coordination of lighting effects with other disciplines is necessary to avoid an accent pattern on a thermostat, for example. Similarly, scallop patterns on bulkheads may be undesirable. Explore architectural and installation aspects with respective disciplines prior to compromising the integrity of the lighting design.

Table 15.1 identifies just some of the aspects of ceiling mounted linear ambient lighting. Similar ranges of equipment exist for nonlinear ceiling mounted ambient lighting, for wall and floor lighting, and for task and accent lighting. These aspects change over time because of technological and manufacturing changes and change with criteria priorities. Maintaining a current understanding of available options is necessary to competent design.

A number of luminaire varieties deserve primary consideration for particular applications or even where differentiation in application or design style is desired. These include steplights, in-floor uplights, furniture- and millwork-integrated lighting, and picture lights. All are available with efficient lamping options and most, when used properly, result in highly efficient application of light. For example, an F11W/T2/830-lamped picture light shown in Figure 15.18 is more effective in most situations relative to a 20W CMH- or LED-lamped ceiling monopoint or recessed adjustable. Style, however, plays a role in selecting a picture light or a ceiling recessed accent luminaire. Some picture lights are traditional in style and may not be well-suited to the architectural style of the project under design. LED picture lights exhibiting very slim profiles and modern finishes work well in contemporary settings. Similarly, steplights may be more effective in stair lighting than more common recessed or surface linear fluorescent ceiling or wall lights, depending on stair configuration and enclosure geometry. One caution—if lighting is more tightly associated with a specific task or function, and if luminaire selection, optics, and layout is nearly-exclusively devoted to address illuminances, it is quite likely the architectural envelope will be dim, dingy, or outright dark. A room of picture lights might look attractive and the artwork may be illuminated well, but the room may of little use except as a transition space. Another example is a stairway lighted with steplights or lighted handrails. The stair will lack luminances in the zone that is roughly 3 feet above the stair treads and which goes to the ceiling. This can be purposeful and used for effect (see Figure 15.7), but if stairs are continually frequented by many people who are unfamiliar with the building, then the lack of facial lighting and upper-architectural definition may be unwelcome.

Lamps and luminaires are mated for performance, appearance, or both. All luminaires should meet basic safety and operational expectations. Underwriters Laboratories (UL) in the United States, Canadian Standards Association (CSA) in Canada, and Norma Oficial Mexicana (NOM) in Mexico have defined standards to which luminaires with their intended lamps and auxiliary devices should be certified for their respective markets of use.

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In each North American Country, government authorized certification bodies test and certify lighting equipment to the respective standards. For example, in the United States Nationally Recognized Testing Laboratories (NRTLs) perform certification testing to the UL standards. A successful certification results in listing and labeling to the UL standards, evidenced by labeling on the respective luminaire. Although exceptions are possible and sometimes warranted, listing and labeling should not be waived. UL/CSA/NOM is used as a generic catch-all reference throughout this handbook to related standards and certifications and the associated testings, listings, and labelings for lighting equipment in respective countries. UL/NRTL is a catch-all reference to the procedure in the US whereby one of many testing labs test products to the UL standards.

Dust and water are always aspects of concern when selecting lighting equipment. In interior settings, there are situations where lighting equipment requires protection from hose-down cleaning, for example, while in exterior situations some lights might be submersed in water from time to time. To codify the degree of protection against dust and/or moisture infiltration, among other things, the International Electrotechnical Commission (IEC) devised an International Protection (IP) Rating System (commonly referred to as Ingress Protection Rating). This IP rating system is voluntarily used in North America and does not supersede any UL/CSA/NOM requirements. Vendor testing to IP ratings should be performed and certified by a qualified independent laboratory. At its simplest implementation, a 2-digit rating system can be applied to lighting equipment where the first digit (0 to 6) identifies the degree of protection from the ingress of solid particulates and the second digit (0 to 8) identifies the degree of protection from the ingress of moisture. [3] [4] [5] Table 15.4 summarizes IP ratings. For luminaires, usual interest lies with ratings exhibiting a first digit of 5 or 6 and a second digit of 5, 6, 7, or 8, where the lighting application demands equipment that has some degree of dust protection and some degree of water protection.

Customized luminaires are sometimes used where no standard luminaire is available with the desired performance, size, or appearance. An example is shown in Figures 15.19a and 15.19b where a standard 6" square downlight with an F32W/Triple/830 CFL is fitted with a customized drop-lens for a look reminiscent of 1930s modern deco styling. Although an expedient solution in time, customization may be at least one hundred percent more costly than standard equipment. Yet this is less costly than custom luminaires.

Where a specific look, non-standard size, and optical effect are required to fulfill project programming needs, custom luminaires are considered. These generally are quite costly relative to standard lighting equipment, but overall remain a miniscule percentage of the total project value. Leadtimes are lengthy for vendors to develop custom castings, spinnings, moulds, and the like. The UL/CSA/NOM listing and labeling procedure generally runs thousands of dollars and may add months of leadtime depending on specific lamping and luminaire component construction. An example of a listed and labeled custom luminaire is shown in Figures 15.19a and 15.19d.

15.1.2.2 Lamps

Lamps combine with luminaire optics to produce lighting effects. Literally thousands of combinations are possible. Table 15.5 outlines just a small representation of some ceiling mounted nonlinear dedicated-socket luminaire types and features. Four lamp types influence the majority of available luminaires and their features for this particular citation: CFL, CMH, halogenIR$_{LV}$, and LED. The range of options is nearly endless. These are common white-light lamps. Although the efficacies for these lamps vary significantly, some CMH lamps and most halogenIR$_{LV}$ and LED lamps are judged by their optical properties for delivering light to the intended target or area. So, while efficacy (lumens per watt or LPW) is typically important when considering lamps for diffuse lighting of relatively large areas, candlepower is more important for accenting and highlighting and/or throwing light over long distances. Appropriate for all lighting selections for any design,



Figure 15.18 | Fluorescent Picture Light
An 11 W T2 fluorescent lamp in a traditional picture light fitted with a UV diffusing lens provides localized lighting to the artwork more efficiently than ceiling mounted alternatives. In this historic setting, picture lights and their lighting effects were considered more appropriate than ceiling-mounted or recessed options.
» Image ©S.J. Swalwell/ArchitecturalFotographics

Table 15.4 | IP Rating System[a]

Character	IP Rating	Protection Against:
1st Digit	Value	Solid Object Ingress
	0	No protection
	1	≥50 mm diameter
	2	≥12.5 mm diameter
	3	≥2.5 mm diameter
	4	≥1 mm diameter
	5	dust-protected
	6	dust-tight
2nd Digit	Value	Water Ingress
	0	No protection
	1	Vertical dripping
	2	Dripping 15° off vertical
	3	Spraying
	4	Splashing
	5	Jetting
	6	Powerful jetting
	7	Temporary immersion
	8	Continuous immersion

a. Adapted from ANSI/IEC 60529-2004 ©NEMA with permission [5].

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Figure 15.19a | Customized and Custom Luminaires
A linear array of customized lights are recessed into a layered-drywall ceiling configuration (see Figures 15.19b and 15.19c). A custom wall sconce surface mounted on inlaid wood further evokes the deco styling (see Figure 15.19d for sketch outlining salient features of custom luminaire. Customized and custom luminaires are UL/NRTL listed and labeled for this USA project.
» Image ©Far Photography

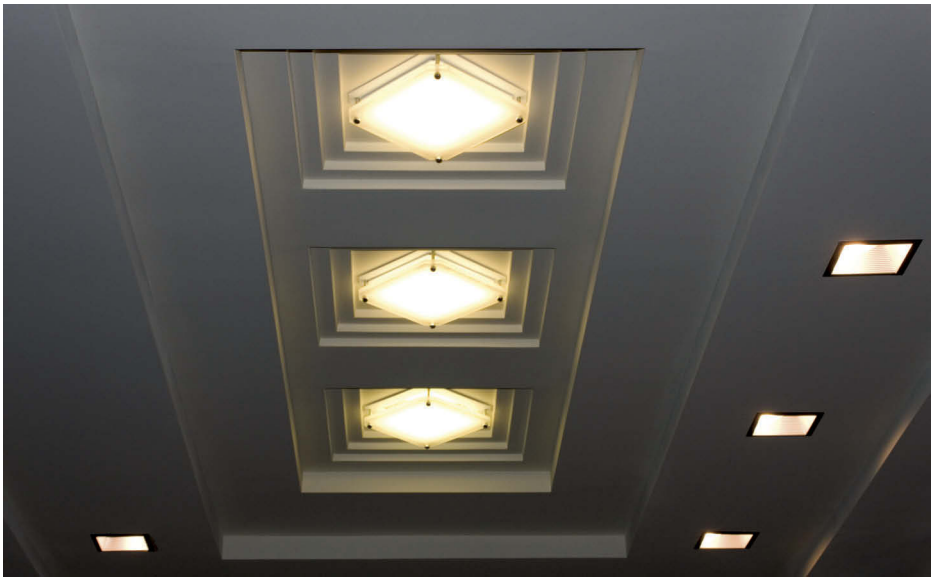


Figure 15.19b | Customized Luminaires
6″ square downlights are each customized with a drop lens. Housings are recessed into a layered-drywall ceiling in a reinterpretation of a 1930s modern deco detail.
» Image ©Far Photography

IESH/10e Lamp Resources

> 7 | LIGHT SOURCES: TECHNICAL CHARACTERISTICS
- for more on filament lamps
- for more on fluorescent lamps
- for more on HID lamps
- for more on Solid State (LED) lamps

> 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS
- for more on operational aspects

Table 15.5 also includes an abbreviated status checklist of some very important aspects: UL/CSA/NOM, dedicated socket, photometric pedigree, sustainability, and warranty.

Dedicated sockets accept lamps with unique bases. For many applications where new luminaires are used or luminaires are restored or refurbished, medium screw base sockets are no longer used. Medium screw base sockets accept any medium screw base lamp of which there are innumerable options of most any wattage and optic. Medium screw base sockets and lamps are unlikely to sustain the original design or efficiency. Every effort should be made for new-, retrofit-, renovation-, and restoration-equipment specifications to use dedicated-socket lamps and luminaires. For retrofit situations see 17.3 Lighting System Upgrades.

15.1.2.3 Ballasts, Drivers, and Transformers

Most state-of-the-art efficient lamps require an auxiliary device or collection of devices to operate properly. Few lamps can be connected directly to main voltage and operate effectively or for their rated life. Pairing these auxiliary devices with lamps and luminaires is a necessary and ultimately critical design aspect affecting light output, controllability, lamp efficacy, luminaire efficiency, lamp life, wattage, and the efficiency of the electrical

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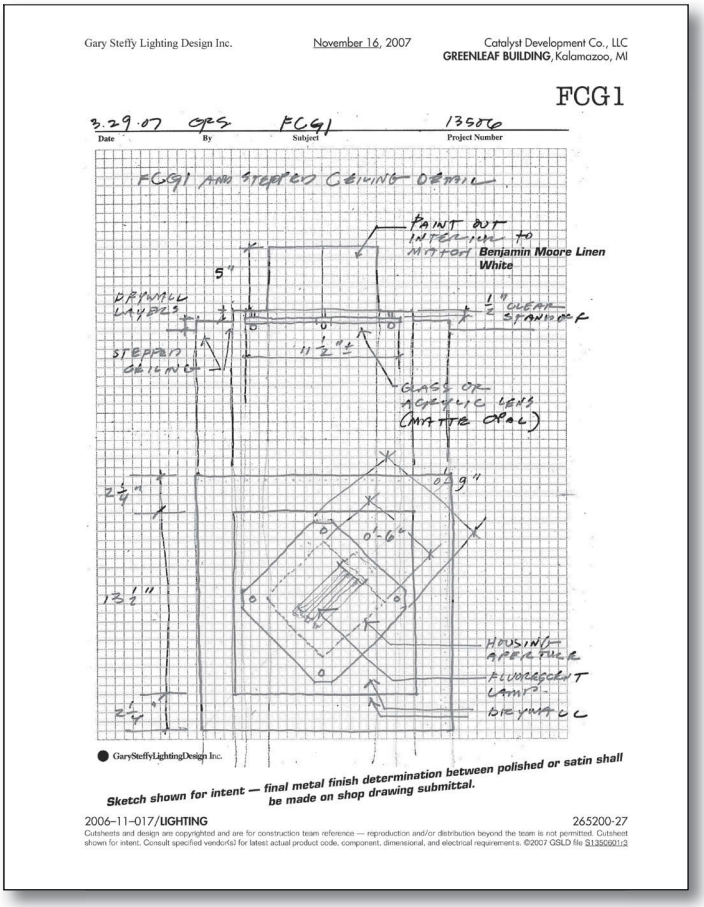


Figure 15.19c | Customized Luminaires
A section and plan view sketch developed for the specification of the customized downlights in Figure 15.19a identifies salient features. Each customized downlight uses one F26W/Triple/830 CFL lamp and a non-dim ballast. Subsequent revisions and trace overlays result in reduced contrast and quality of the graphic.
» Image ©Gary Steffy Lighting Design Inc.

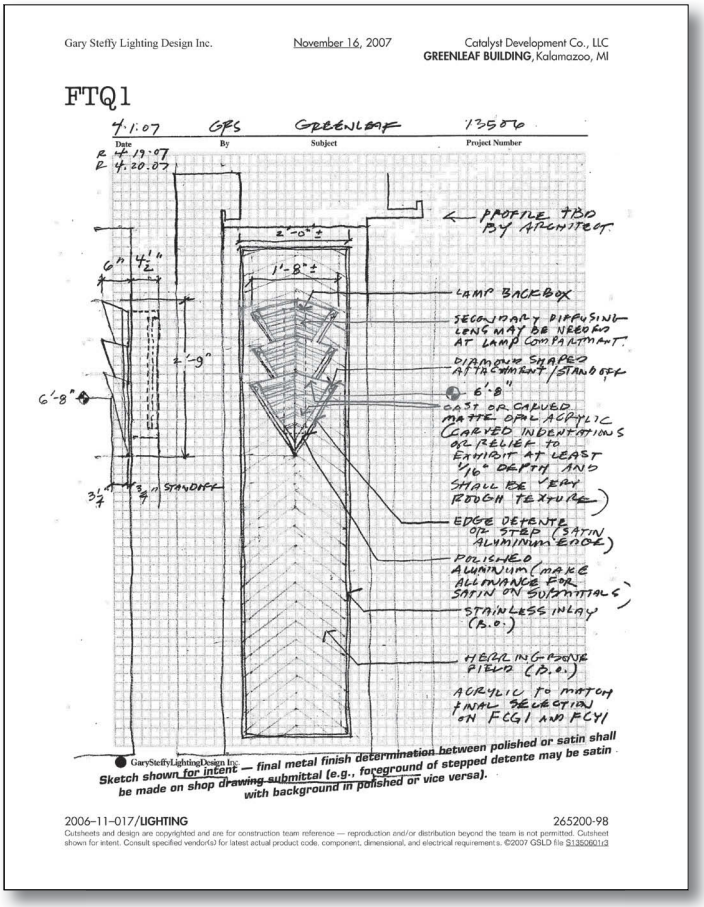


Figure 15.19d | Custom Luminaires
Salient features of a custom wall sconce our outlined in this sketch used for the specification of the custom sconces in Figure 15.19a. Each sconce uses two F14W/T5/830 linear fluorescent lamps and a dimming ballast. Subsequent revisions and trace overlays result in reduced contrast and quality of the graphic.
» Image ©Gary Steffy Lighting Design Inc.

system. These devices require space for their integration into the lighting system, preferably integral to luminaires, but this is not always practical or desirable. These devices also play a role, sometimes significantly, in tuning lighting effects, illuminances, and LPDs and/or energy use. Even when such tuning is not a design aspect, the selection of auxiliary devices must be made in the context of their influence on photometric performance. Left unaddressed, unqualified or default factory selection of these devices may negatively affect lighting criteria compliance, including that of luminances and illuminances and LPDs. Additionally, default, low-cost factory choices may result in reduced lamp or ballast life, as typically happens with instant-start ballasts controlled by occupancy sensors. During the early design phases, the existence and eventual integration of ballasts, drivers, and transformers simply needs acknowledgement. However, in the later stages of design, these devices must be carefully reviewed and paired with respective lamps and luminaires.

At this stage of design development, dimming, stepped dimming, and non-dim fluorescent ballasts are of particular interest. Key parameters on fluorescent ballasts are harmonic distortion, power factor, and ballast factor. Harmonics can be problematic if not held in check. Total harmonic distortion (THD) should not exceed 10 percent on ballasts (see 7.3.6.5 Ballasts). While typically easy to select ballasts with THDs ≤0.10 (or 10%) for lamps/luminaires with dedicated sockets, THDs are poor on many medium screw base

IESH/10e Ballast/Driver/Transformer Resources

> 7.3.6.5 Ballasts
- for more on fluorescent ballasts

> 7.3.6.6 Dimming
- for more on fluorescent lamp dimming

> 7.4.8.10 Operating Characteristics
- for more on metal halide ballasts

> 7.4.9.7 Operating Characteristics
- for more on high pressure sodium ballasts

> 17.3.2 Ballasts
- for more on lighting system performance

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Table 15.5 | Some Ceiling Mounted Nonlinear Luminaire Types and Features Matrix

Form Factor	Nominal Aperture Size	Lamping	Optical: Recessed	Optical: Surface/Pendant	Optical: Adjustable Accent	Optical: Fixed Downlight	Optical: Fixed Wallwash	Utility: Instant-on	Utility: Dimmable	Utility: Diffuse	Utility: Focused	Expectations: UL/CSA/NOM	Expectations: Dedicated Socket	Expectations: Photometric Pedigree	Expectations: Sustainability	Expectations: Warranty	Application Notes
• Round • Square	2"	CFL	Aperture too small for current-technology CFL utility.														
		CMH	■	▒	■	■	■			▒	■	■	▒	▒	▒	▒	Confirm installation and
		halogenIR$_{LV}$	■	■	■	■	▒	■	■	▒	■	■	▒	▒	▒	▒	Confirm installation and maintenance.
		LED	■	▒	■	■	▒	■	▒	▒	■	■	▒	▒	▒	▒	Confirm installation and maintenance.
	3"	CFL	■	■		▒	▩	▒		■		■	▒	▒	▒	▒	Only very low wattages.
		CMH	■	▒	■	■	■			▒	■	■	▒	▒	▒	▒	Confirm installation and maintenance.
		halogenIR$_{LV}$	■	■	■	■	▒	■	■	▒	■	■	▒	▒	▒	▒	Confirm installation and maintenance.
		LED	■	▒	■	■	▒	■	▒	■	■	■	▒	▒	▒	▒	Confirm installation and maintenance.
	4" - 5"	CFL	■	■		■	▒	▒	▒	■		■	▒	▒	▒	▒	
		CMH	■	▒	■	■	■			■	■	■	▒	▒	▒	▒	
		halogenIR$_{LV}$	■	■	■	■	▒	■	■	■	■	■	▒	▒	▒	▒	
		LED	■	▒	■	■	▒	■	▒	■	■	■	▒	▒	▒	▒	
	6" - 8"	CFL	■	■	▩	■	■	▒	▒	■	▩	■	▒	▒	▒	▒	
		CMH	■	■	■	■	■			■	■	■	▒	▒	▒	▒	
		halogenIR$_{LV}$	■	■	■	■	▒	■	■	■	■	■	▒	▒	▒	▒	
		LED	■	■	■	■	■	■	▒	■	■	■	▒	▒	▒	▒	
• Rectilinear	2" x ≤24"	CFL	Aperture too small for current-technology CFL utility.														
		CMH	M	M	M					M	M	■	▒	▒	▒	▒	Confirm installation and
		halogenIR$_{LV}$	M	M	M			M	M	M	M	■	▒	▒	▒	▒	Confirm installation and maintenance.
		LED	M	M	M			M	▒	M	M	■	▒	▒	▒	▒	Confirm installation and maintenance.
	4" x ≤24"	CFL	■			■	■	▒	▒	■	▩	■	▒	▒	▒	▒	
		CMH	M	M	M	M	M			M	M	■	▒	▒	▒	▒	
		halogenIR$_{LV}$	M	M	M		M	M	M	M	M	■	▒	▒	▒	▒	
		LED	M	M	M			M	▒	M	M	■	▒	▒	▒	▒	
	6" - 8" x ≤24"	CFL	■	■			■	▒	▒	■		■	▒	▒	▒	▒	
		CMH	M	M	M					M	M	■	▒	▒	▒	▒	
		halogenIR$_{LV}$	M	M	M			M	M	M	M	■	▒	▒	▒	▒	
		LED	Aperture unnecessarily large for current-technology LED utility.														

Legend

- ■ Will or likely to satisfactorily address parameter with right optics and/or lamp form factor.
- ▒ Uncommon and/or may not satisfactorily address parameter.
- ▩ Probably will not satisfactorily address parameter.
- blank Will not address parameter.
- Safety: Confirm luminaire assembly is UL/CSA/NOM listed and labeled for lamping and intended application.
- Efficiency - Long Term: Confirm socket is dedicated-type (not medium screwbase) to limit wild performance and wattage fluctuations with substitutions.
- Efficiency - Application: Study equipment with up-to-date photometric data for best design assessment.
- Sustainability - Upgrade/Recycle: Confirm components are replaceable/upgradable and recyclable.
- Warranty: Confirm warranty period and coverage.
- M "M" designation indicates these are typically multi-lamped luminaires with each lamp's optics and/or adjustment independent of the other.

halogenIR$_{LV}$ Lamp secondary voltage is 12V (low voltage). Smallest, dedicated-socket efficient filament lamp for general-use and accent applications.

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retrofit lamps. A building full of table lights or wall sconces retrofitted with these poor quality lamps may pose a problem for the electrical distribution system on retrofits or affect the overall design on new, renovation, or restoration projects.

Power factor (PF) is an indication of how well the power supplied by the utility is being used by various pieces of electrical equipment, with 1.0 (100%) being best (see 7.3.6.5 Ballasts). Poor (or low) power factor may result in penalty charges by the utility company. Select ballasts with PFs ≥0.90 and preferably ≥0.95.

Ballast factor is essentially the percentage of light output of a specific lamp-ballast system relative to that lamp's catalogued light output (see 7.3.6.5 Ballasts). A BF of 1.0 indicates 100% light output is anticipated from the given lamp/ballast combination. So-called normal ballast factor is 0.88 (88% light output is anticipated from the lamp/ballast combination). Lamp/ballast system watts are related to BF, though not linearly. During calculations, ballast factors can be used to tune luminaires to better meet lighting criteria and lighting power densities.

Ballasts are typically electronic, operating at high frequency with no audible hum and no flicker. Fluorescent ballasts are commonly available in instant-, rapid-, and programmed-start varieties (see 7.3.6.5 Ballasts). Although each have benefits and pitfalls, programmed-start ballasts offer an excellent balance on energy consumption versus lamp life.

15.1.2.4 Controls

Automated controls establish the energy use patterns of a lighting system and yield significant energy savings compared to traditional manual on/off approaches. Automatically dimming and switching off electric lights to respond to occupancy and/or daylight availability are sustainably appropriate practices. Control zoning of the lighting layouts is as important as selecting efficient luminaires and lamps and should be denoted along with lighting strategies. See 16 | LIGHTING CONTROLS and 17 | ENERGY MANAGEMENT.

For some time, automated lighting control systems were considered part of the energy management system. Today, while certainly integrated with energy management systems, automated lighting control systems add a degree of scene-setting previously only available to high-level conference facilities where there was a need to change scenes from presentation to meeting to AV. These scenes can be building, department, or room specific and can respond to time of day, function, activity level, or all of that for a dynamically variable setting.

Automated controls allow for temporal intervention. Where utilities anticipate power shortages or clients desire to reduce peak demand charges from the utility, lighting can be selectively or globally dimmed or switched off.

15.1.2.5 Photometric Pedigrees

Reliable and accurate lighting software is employed in order to achieve best lighting effects, to appropriately control surfaces' and luminaires' luminances, to predict illuminances and ratios with a reasonable degree of certainty, and to optimize all of this for power density and energy use. So, actual, not virtual, luminaire photometric pedigrees are highly preferred. Luminaire photometry (see 9.14 Luminaire Photometry) documents how a luminaire performs with specific optics, lamping, and ballasts or drivers.

Photometry is available in hardcopy test-report form (see Figure 8.9). This offers a visual reference of the lighting distribution and a table of candlepower data. Candlepower data are also available in an electronic format with a ".ies" extension indicating the electronic file conforms to IES photometric reporting standards and is intentionally formatted for use in calculation software. This avoids the effort of importing by hand the candlepower data from a hardcopy test report. For accuracy and provenance, actual photometric files should be produced by an independent laboratory or other labs accredited by government approved certification programs to IES testing standards. As such, a cost and time frame are associated with their production and need to be incorporated into the budget or the fee and schedule.

IESH/10e Photometry Resources

- > 8.4 Luminaire Performance
  - for more on photometry
- > 9.13 Lamp Photometry
  - for more on lamp optical performance
- > 9.14 Luminaire Photometry
  - for more on luminaire optical performance
- > 10.3 Photometric Data for Calculations
  - for more on limits and assumptions of use
- > 10.6.1 Accuracy and Assessment
  - for more on degree of calculation accuracy

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One method of reducing testing costs and time is to develop virtual photometry. Of course, these photometric files are only as good as their source information. Virtual photometry is now relatively convenient to produce. Using software, vendors can design with good accuracy the level of performance expected from a proposed optical design and a given lamp. However, these virtual reports may exhibit a tolerance of ±20% even more where the time and skill to accurately represent real-world reflector materials and contours.

Another method to reduce testing costs and time is to use bare-lamp tests undertaken by lamp manufacturers. This is reasonable where optically-active lamps are used, such as those with integral reflectors and lenses that produce specific beam patterns such as spot and narrow flood like many lamps in the halogenIR_{LV}, CMH, and LED families. Except where bare lamps are used in simple track heads or *monopoints* with no add-on glare control devices or filter media, bare lamp photometry is inaccurate. So, where snoots are used on track heads or monopoints or where louvers or "beam-softening" lenses are placed in front of the lamp or where recessed adjustable accents or even downlights exhibit apertures that are roughly the size of the lamp-face or smaller, bare lamp photometry is a poor substitute for actual luminaire photometry.

Monopoints are track heads mounted to ceiling canopies rather than to linear tracks. See Figure 15.17

In custom situations where no photometry is available guesses on the luminaire's performance can be made. However, the degree of accuracy is much less certain. Up to the point of obtaining actual photometry from an operational sample, virtual photometry or facsimile photometry is used for proposed modified or custom luminaries. Virtual photometry is developed using software capable of building a luminaire in virtual reality and then generating a photometric report in virtual reality. Facsimile photometry involves selecting the real photometry of a real luminaire that is similar to the proposed modified or custom luminaire and using this photometry in calculations. Although lamp lumens and/or ballast factors can be adjusted to achieve lighting criteria, the basic premise for facsimile photometry is a "good guess" with tolerances likely no better than ±20%.

Lack of photometry for catalogued luminaires may offer insight on the luminaire vendor's business practices. Is the luminaire intended for commercialization in North America and has it been tested and listed and labeled for the respective lamping and intended application in accordance with recognized authorities, such as UL/CSA/NOM? Are the luminaire optics optimized for the lamp in question? Other questions include what luminaire warranty is offered and is a working sample available for review,? It cannot be overstated: without actual photometric data, it is difficult if not impossible to predict with good certainty how luminaires will perform in a given situation, defeating effective implementation of task, ambient, and accent lighting.

15.1.2.6 Sustainability

Arguably, the most sustainable solution might be doing nothing—no construction work whatsoever. This generally isn't an acceptable option to clients and/or users seeking new or restored settings for reasons they vetted before deciding some construction effort was necessary. Once decisions are made to pursue new or restoration projects, a number of methods can yield more sustainable lighting:

1. Daylighting and its integration with electric lighting—Use daylighting as primary source.
2. Detailed programming—Know the need and design accordingly.
3. Freeze designs at design milestones—Settle parameters related to lighting layouts that are specific to function, architectural and interior design aspects, and energy modeling.
4. Overall lighting efficiency—Select efficient lamps and luminaires within the classes or families best suited for the application.
5. Component longevity—Select longest-life lamps and luminaires within the classes or families best suited for the application.

IESH/10e Sustainability Resources

> 13.11 Sustainability
- for more on lamps

> 19 | SUSTAINABILITY
- for more on energy
- for more on earth resources
- for more on recycling
- for more on Life Cycle Analysis
- for more on lighting design

> 19.2 Elements of Sustainable Lighting Design
- for more on controls

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Table 15.6 | Nighttime Operational Strategies for Improved Outdoor Environmental Regard

Night	Operational Strategy(ies)[a]	Electric Lighting Operation	Environmental Regard: Migratory Bird Passage	Reduce Light Pollution	Reduce Light Trespass	Save Lighting Energy	Extend In-service Life
Design	Illuminance Criteria	Establish and design to criteria with care.					
	• criteria determination	Determine criteria based on programming data without over-targeting for hypothetical or seldom-occurring or less-important activities.[b]		✔	✔	✔	
	• S/P design implementation	Adjust exterior illuminances in mesopic vision situations to account for S/P ratio of selected lamp.[b,c]		✔	✔	✔	
Electric Lights	Automate Complete On/Off Operation	Completely extinguish interior and/or exterior lighting.[b]					
	• seasonal astronomical time clock	If practical, extinguish **all interior** lighting above 5th floor seasonally at key nighttime bird-migratory hours (e.g., 11 PM - 6 AM mid-March to late May/mid-August to late October).[b,d] Alternatively, deploy shades (see below).	✔	✔	✔	✔	✔
		If practical, extinguish **all exterior** lighting above 5th floor seasonally at key nighttime bird-migratory hours (e.g., 11 PM - 6 AM mid-March to late May/mid-August to late October).[b,d] Alternatively, deploy shades (see below).	✔	✔	✔	✔	✔
	• nightly astronomical time clock	If practical, extinguish **all interior** lighting at predetermined late-night-to-early-morning curfew.[b] Alternatively, deploy shades (see below).		✔	✔	✔	✔
		If practical, extinguish **all exterior** lighting at predetermined late-night-to-early-morning curfew.[b] Alternatively, deploy shades (see below).		✔	✔	✔	✔
	Automate Selective Operation	Selectively extinguish or dim interior and/or exterior lighting.[b,e]					
	• nightly astronomical time clock	If practical, extinguish or dim **perimeter interior** lighting at predetermined late-night-to-early-morning curfew.[b,e] Alternatively, deploy shades (see below).		✔	✔	✔	✔[f]
		If practical, extinguish or dim **some exterior** lighting at predetermined late-night-to-early-morning curfew.[b,e]		✔	✔	✔	✔[f]
Shades	Automate	Deploy shades if/when perimeter interior electric lights are in use.					
	• astronomical time clock	Lower/close shades (shade τ ≤10%) at predetermined late-night-to-early-morning curfew period when interior lights are energized.		✔	✔		
	• astronomical time clock • photocell	Lower/close shades (shade τ ≤10%) at sunset through sunrise when interior lights are energized.		✔	✔		

a. Depending on nature of facility and requirements of lighting then some, all, or none of these functions may be appropriate and/or collectively applied. Automated time clocks and photocells typically exhibit sufficient number of set points that these strategies may be implemented at varying times of year and/or night.

b. Without sacrificing lighting and criteria that are necessary for functional activity and/or code compliance and/or senses of safety and security.

c. Without sacrificing other lamp selection aspects such as color rendering and/or color temperature where these are deemed important. See 4.12.3 Spectral Effects on and implementation of S/P ratios at mesopic vision.

d. Refer to local ordinances, proclamations, or laws for dark-time requirements. Citations based on Safe Passage Great Lakes Days Proclamation. [7]

e. Trim back or set back electric lighting based on anticipated/intended levels of activity. As nighttime activity levels drop, trim lighting to provide next-lowest IES recommended illuminance target criteria.

f. Dimming typically will not extend in-service life for most lamps for these applications.

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6. Recyclability of lighting equipment and components—Select equipment that consists of recycled materials and that is prepped to be recycled at end of its use.

7. Proximity of qualified vendors to the project site—Select vendors of the classes or families best suited for the application that are closest to the project site.

8. Extensive and automated and manual controls—Automate lighting according to daylight availability, time of use, and occupancy.

9. Reduce lighting's impact on the greater night environment—Employ strategies to limit night-lighting effects. Table 15.6 identifies some operational strategies that can improve lighting's outdoor environmental regard.

10. Make the project eminently livable or workable—Make the most of the energies expended in manufacturing, procuring, installing, and operating the lighting: provide a complete and well-executed design. See 19 | SUSTAINABILITY.

15.1.2.7 Warranties

With the exponential growth of electronic components in lighting equipment, the rigors of controllability, and the array of solid state light sources now available, warranties may more significantly influence equipment selection and application. For conventional luminaires, lamps, and their ballasts or transformers with electromechanical or vacuum and gas-discharge components, warranties may be nonexistent or express or implied and should be confirmed. Typical coverage ranges from 1 to 3 years. Coverage may include the physical hardware and the labor to replace it or may simply include the physical hardware or may provide for some fixed amount of compensation.

Similar warranties may be available for solid state equipment. Here, efforts to rapidly expand use of LEDs in particular by the U.S. EPA and DOE have pressed vendors of solid state luminaires to offer at least 3-year warranties for electrical parts. [6] 5-year warranties now appear regularly on LED lighting equipment and some now offer 10 years. On these and warranties for conventional lighting equipment, confirm the following:

1. Periods of coverage—This may vary and could be from date of manufacture or date of purchase or date of installation.

2. Extent of coverage—This may vary, including the time duration of the coverage and which costs, if any, are covered such as hardware and labor.

3. Caveats—Many of which may be unstated and require inquiry. For example, solid state products are sensitive to heat and, depending on the extent of vendor testing and development of qualified heat sinks, the product warranty coverage may be limited to specific ambient temperatures.

15.2 A Lighting Scheme

Design thought starters are the resulting programming information secured from the process outlined in 12 | COMPONENTS OF LIGHTING DESIGN and in 14 | DESIGNING DAYLIGHTING. Daylighting strategies should respond to daylight availability. Daylight zones can be planned. Spatial factors and psychological factors suggest lighting techniques, luminance distributions, and their relative magnitudes which can be achieved with daylight, electric light, or both. Combine these with task factors and respective task areas and furnishings, and a lighting scheme emerges. Advancing this to a lighting design requires assessment in greater detail.

No amount of words, steps, procedures, or recipes can lead to a complete and successful design. What follows here briefly exemplifies development of a lighting design and is intended to illustrate aspects rather than codify procedure. A deliberate and iterative review of the material in Chapters 11, 12, 13, 14, and 15 is in order. There are no good shortcuts.

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15.2.1 Thought-starters

A more detailed extension of the thought-starter involves taking plans and elevations, however roughly- or well-developed, and diagramming which surfaces are to be lighted and to what degree, including features, such as architectural elements and/or artwork. Additionally, identify functional hierarchies, such as elevator lobbies, reception areas, work/living areas (of which there may be further hierarchal treatment), building entries, and important site paths as the project type warrants. The "first take" on this exercise might simply be bubble diagramming or light mapping. This light mapping is likely to be refined as the project progresses and more assessment information on the lighting design becomes available. Indeed, a back-and-forth of scheme-assess-scheme-some-more-assess-refine is a hallmark of design. Some of this is internal to the lighting design team and, as schemes evolve more firmly, some is shared with the entire design team.

15.2.1.1 Lighting Real Architectural Surfaces

Based on criteria and techniques gleaned from Chapter 12, the light mapping can detail the extent to which real architectural surfaces are to be addressed with light. Where wallwashing techniques are programmed, an entire wall or walls are typically addressed. Where light patterning techniques are programmed, portions of walls and/or ceilings are typically addressed in patterns that are symmetric and rhythmically-sympathetic to the architecture, interiors, or landscaping for conventional design styles and more randomly where avant-garde or deconstructive design styles are employed. Where focal features are programmed, such as special wall materials, the entire feature may be lighted or expressive details within the feature may be highlighted or both. Artwork is accented especially where it benefits visual rest and/or circulation/destination requirements.

Floor planes are generally lighted, but not particularly highlighted except where programming identifies feature floor patterns as important focals. So, most floor planes are addressed by ambient lighting or the background effects of task lighting depending on the nature of the tasks within the given area or room. Simply circulating from one area or space to another in short distances can be achieved with ambient lighting on the floor plane in many private-sector projects. However, if this circulation activity is intended to encourage chance interactions or brief meetings as may be found in corporate settings or public venues, or if the density of people is expected to be high or strangers are the norm rather than familiar coworkers, then the lighting not only addresses the real floor plane but addresses imaginary face-planes. IES illuminance recommendations for these kinds of circulation applications will cite both horizontal and vertical illuminance criteria as well as uniformity ratios.

15.2.1.2 Lighting Imaginary Surfaces

Identifying imaginary planes to be illuminated is also part of the thought-starter process and the further refinement of a design strategy. Face-planes in circulation areas are imaginary surfaces for purposes of design and their location and orientation are likely to be anywhere in a relatively narrow range typically placed at 60" AFF in spaces where adults are the primary users. Figure 15.20 illustrates the concept of such an imaginary plane. Other imaginary surfaces depend on the types of spaces, respective activities, and the design progress on furniture placement. In offices, closed or open, or in school classrooms, the task area is typically at 30" AFF. In waiting and reception areas, lounges, lecture halls, churches, etc, lap height (roughly at 24" AFF for typical adults) is another imaginary plane of consideration.

Once decisions have been made on which surfaces, real and imaginary, are lighted, the degree to which daylighting can address the lighting needs, and presuming the space or spaces will be used during non-daylit hours, luminaire selections can be considered and trial layouts proposed and assessed.

15.2.2 Preliminary Luminaire Selections

Preliminary luminaire selections are a confluence of the functions and effects desired of the luminaires as well as architectural style, systems integration, efficiencies and costs and

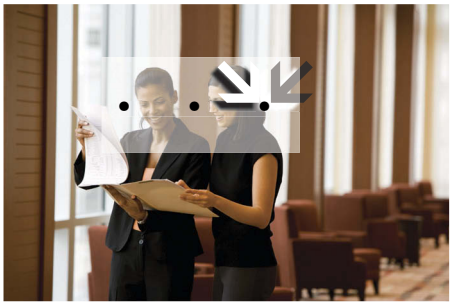


Figure 15.20 | Imaginary Vertical Plane
In a corridor or lobby setting, for vertical illuminance at faces, an imaginary plane is placed at roughly face height. Lighting calculations are made on points positioned at 5' AFF on the plane. Note the plane has two sides and illuminances are calculated on both sides. The plane is oriented perpendicular to the main directions of circulation—typically two directions in a corridor and four directions in larger circulation spaces such as a lobby. Planes might be spaced on 2' centers. Points on planes might be spaced on 2' centers.
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leadtimes. However, at this and all lighting design milestones the lighting results deserve full attention if maximum benefit is to be derived from the resources that are expended in production, transportation, and use of lighting. Delivery schedules, costs, and green scores are diversions at this stage that can easily render a lighting scheme less about lighting needs and long-term success and more about expediency of implementation and short-term recognition. This in no way diminishes the validity of schedule, cost, and green-building criteria, but is intended as a caution that primary focus on these items can easily compromise the integrity and ultimate long-term success of a lighting design.

15.2.2.1 Analytic and Aesthetic

Analytic and aesthetic aspects have been readily and extensively defined previously in Chapters 11, 12, and earlier in 15 or in the designer's own terms. Programming documents these aspects and should be used to inform luminaire selection. Respective application chapters identify specific illuminance and luminance criteria as well as application-specific design anomalies which will further influence selections. Such anomalies might include wet- and IP-rating requirements, and the need for high illuminances which affect lamping, wattage, and luminaire size.

Where wallwashing is programmed, for example, wallwash luminaires are appropriate. The extent of choices is significant: round, square, and rectilinear types identified in Table 15.5 under "fixed wallwash" that provide a flat frontal wash (see Figure 23.1 [spread lens wallwashers ❸]) or an accenting wash (see Figure 12.2), and linear wallslots that accent (see Figures 15.16 and 15.19a) or graze (see Figures 15.5d and 21.1) the wall to be lighted. Choices further extend to finish, lamping, mounting, intensity, and uniformity and depend on desired lighting effect and on illuminance and luminance criteria involved.

15.2.2.2 Architectural Style

Contemporary or modern design schemes typically command simply-designed hardware. Traditional or historic design schemes typically command small, unobtrusive recessed lighting equipment or traditional- or period-style decorative and functional luminaires or both. On the unobtrusive varieties, smaller is usually better. Very narrow linears, pinhole apertures, flangeless trims or painted-out-exposed metals work well in this regard. As might cove-, slot-, or niche-lighting techniques hidden in traditional or historic moulding or double-wall details. Regardless of style, luminaire scale and shape are also informed by spatial factors (see Table 12.1a).

15.2.2.3 Daylighting Influences

Daylighting design influences electric lighting strategies. Holistic daylighting (see 11.3.2.4 Design Strategies/Daylighting) is typically conceptualized somewhat ahead of electric lighting with respect to daylight apertures, media types and sizing, daylighted zones, and orientations and, with sufficient planning, readily accepts electric light integration strategies. To minimize electric light energy use and maximize occupant comfort, daylight aspects and electric light integration opportunities are assessed. Light shelves, perimeter daylight, and the various means of interior daylight, including atria, courtyards, skylights, monitors, and clerestories are explored. Architectural geometries and surface finishes are established for best distribution of daylighting while minimizing harsh glare. Even shades play an integral role in electric light energy use. Table 15.7 outlines various daylight aspects and electric lighting integration strategies. See 14.14 Electric Lighting Integration.

15.2.2.4 Preliminary Cutsheets

Luminaire selections are typically shared in the form of preliminary cutsheets. These illustrate style, physical, and dimensional parameters of the lighting equipment and are a convenient way to document and present this information to others. Cutsheets and brochures may offer some guidance on application, including layout and spacing diagrams as well as illuminance or luminance data. While this information is not to be used for final design, it is an excellent resource for trial layouts.

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Table 15.7 | Daylight-Electric-Light Integration Strategies

Daylight	Electric Lighting Integration Strategy	
Shelves	Uplight	Emulate diffuse quality of light-shelf-generated indirect daylight.
	• uplight from shelf	Integrate uplight into top of shelf without compromising integrity of shelf functionality.
	• uplight from luminaires	Pendant or wall- or floor- or furniture-integrated indirect or direct/indirect luminaires are recommended..
	• uplight from details	Cove detail opposite light shelf is recommended.
Zones	Discretize Lighting and Control Layouts	Correlate electric lighting layouts and control zoning with daylight zone(s).
	• perimeter	Independently control luminaires based on perimeter daylight coverage, orientations, and functional requirements. Typically consists of first and/or second rows of lights from perimeter.
	• clerestories/monitors/skylights	Independently control luminaires based on interior daylight coverage, orientations, and functional requirements.
	• atria and interior courtyards	Independently control luminaires based on proximity to atria and/or interior courtyards, orientations, and functional requirements.
Luminances	Balancing	Balance daylight media luminances with those of interior surfaces.
	• illuminate walls opposite windows	Lighting of walls opposite windows and high-reflectance (LRV ≥60%) wall surface(s) are recommended.
	• illuminate ceilings	In daylighted areas, uplighting when daylight ebbs and high-reflectance (LRV ≥90%) ceiling surface(s) are recommended.
		In areas adjacent to daylighted zones, uplighting and high-reflectance (LRV ≥90%) ceiling surface(s) are recommended.
Availability	Electric Light Response	Adjust electric lighting according to daylight availability.
	• continuous dimming	In daylighted settings where concentration and/or long duration on visual tasks are likely, real-time continuous dimming is recommended for minimal visual disturbance.
	• stepped dimming	In daylighted casual settings, real-time continuous- or stepped dimming is used.
	• on/off	In daylighted transitory settings, real-time continuous- or stepped-dimming or on/off control is used
	Automate	Adjust lighting automatically to maximize benefit of available daylight.
	• photocell	In daylighted zones, photocells are recommended to sense daylight and dim/brighten electric lights as needed to meet illuminance and luminance needs.
	Shades	Automate shade adjustment on at least East, West, and South elevations to maximize daylight illuminance opportunities.
	• photocell	Photocells are recommended to sense daylight availability and raise/lower shades as needed to meet illuminance and luminance needs without uncomfortable brightness.
	• solar position	Solar trackers are used to position shades to limit view of and glare from solar disc.

15.2.3 Trial layouts

Trial layouts are the evolution of thought starters. With some iterative review and contributive guidance from other team members, these trial layouts and cutsheets document lighting schemes if not preliminary lighting designs. These trial layouts might begin as hand sketched layouts on the light-mapping plans made earlier or might immediately be CADed if backgrounds are available in CAD. The use of CAD, while certainly great for making revisions, implies a certain finality to the design. During presentations with the team and client, it should be stressed these are preliminary layouts for testing team and client reaction and will later be used to assess criteria compliance through virtual testing.

15.2.4 Assessment

Although conceptually sufficient to convey design intent, once the team and client have reviewed and acknowledged the design direction illustrated by trial layouts or offered input

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sufficient to warrant revisions, lighting schemes at this stage need additional vetting and scrutiny before advancing to lighting design status which is then documented in plans and specifications for construction.

15.2.4.1 Specific Equipment Selections

Team and client reviews and complete or qualified acknowledgement of the lighting schemes signal specific equipment selections are in order as preparation is made to assess the schemes for criteria compliance and budgeting. Catalogic information must be gleaned from the cutsheets to establish a specific luminaire type for review in virtual assessment. Specifics such as optical configuration, lamping, wattage, auxiliary devices, and finishes must be established, if only preliminarily, in order to virtually assess the schemes.

15.2.4.2 Visualizations

Visualizations may be helpful in further conveying design intent or, more importantly, in exploring the extent and depth of the lighting scheme. 2-dimensional plan views of lighting layouts and mapping of lighted surfaces are unable to convey the overall character of the scene with respect to the nuances of the architecture, interiors, and landscaping. Preliminary visualizations can be useful, but only if limitations of the media and process are qualified. These visualizations typically include some sort of 3-D modeling, electronically-manipulated photos, hand-sketch renderings, or scale models, or some combination. Regardless of how professional the presentation may appear, these methods typically lack visual accuracy of lighting hardware, details, and effects unless actual photometry of luminaires is used in their creation. Of course this is a Catch-22. Without having team and client acceptance of the lighting schemes, the time investment in generating renderings or models of such preliminary schemes with photometric accuracy may be difficult to justify. Yet, without some sort of visualization tool, many clients and some team members may be unable to appreciate the proposed lighting schemes. So, visualizations without final photometric accuracy are the norm at this stage—limitations must be made clear.

15.3 Modeling

Testing lighting schemes is part of their further refinement toward a lighting design on a project. With specific luminaire selections, actual luminaire photometry can be secured from luminaire vendors. Using trial layouts, each luminaire is assigned or designated a type, which is an alphanumeric code to track luminaires on plan and in luminaire specifications. Respective photometry is then associated with each luminaire type as the trial layout is imported or created in calculation software.

This modeling then typically tests the trial layouts for lighting criteria compliance and for their visual effects in 3-D computer representations of the project. Important criteria that are readily assessed include luminances, illuminances, uniformities, and lighting power densities.

15.3.1 Calculations and Renderings

Interpreting numeric values in calculations and refining schemes is an iterative effort. As with any use of earth's resources, an optimal situation is when criteria are just met. IES recommended criteria targets are purposefully called *targets*. Calculations and renderings can help the designer identify luminaires and layouts to meet the various design criteria and to help refine promising layouts or reject marginal layouts. Lighting software tools are available for just these purposes. Some are basic. Some provide a suite of calculations and renderings. Some address daylighting. Some can model complicated shapes and objects. Some are free. See Table 15.8 outlines key software aspects, some specifics of interest, and assessment measures to evaluate lighting software. [8]

Targets for illuminance and luminance represent design goals. Once illuminance targets are established, then any calculated deviation from them should be limited. Standard engineering allowance of ±10% might be acceptable for illuminance targets gauged as average unless contractual or code obligations demand otherwise. Minima and maxima must be achieved as intended. Uniformity ratios are targets that define the widest recommended ranges.

Designs should be adjusted until predictions are within allowance for averages and meet minima and maxima. For additional information, see 4.12.4.2 Recommended Illuminances at Occupancy Time, 4.12.5 Illuminance Ratios, 9.15.1.1 Average Illuminance, and 10.8 Assessing Computed Results.

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Table 15.8 | Lighting Software Survey

Software Aspects	Specifics	Determine or Assess
Package	Price	
	• Base	Features included; single- or multi-seat license
	• Options	Features available and associated costs
	• Updates	Update cycles; procedures required to update; subscription service
	Technical Support	
	• Complimentary	FAQs, breadth, depth, duration, response time
	• Experience/Knowledge	Years in operation, staff experience in lighting industry
	Documentation	
	Demo Download	Check software interface; output examples; runtime; testimonials
General Applications	Interior	
	Exterior	
	Roadway	
	Flood/Sports	
	Stage	
Specifications	Infrastructure	Hardware and operating system requirements
	Max Calculation Areas	Maximum number of calculation areas that can be analyzed at one time
	Max Luminaire Types	Maximum number of different luminaire types that can be analyzed at one time
	Max Luminaires	Maximum number of total luminaires that can be analyzed at one time
	Max Daylight Ports	Maximum number of windows/skylights that can be evaluated at one time
	Units	Metric vs. US Customary; is this assignable
	Runtime	Typical time required for simple vs. complex geometry on minimum hardware
Analyses	Illuminance	On any plane orientation; average, max, min, coefficient of variation
	Luminance	Of any plane orientation; average, max, min
	Interreflected	Number of reflections used in calculation; is this assignable
	Surface finishes	Reflectances from 1% to 99%; specular, semi-specular, diffuse; color
	Daylight	Daylight autonomy; hourly; daily; annual; summaries
	Glare	
	Economics	
	Energy	LPD and KWH information computed and tracked
Features	Aiming Diagram	Aiming diagram as part of output
	CAD Files	Importable and exportable CAD to expedite calculational and output setups
	Objects in Space	Obstructions and 3D elements acccommodated
	Geometries	Simple 2D vs. complex 2D and 3D geometries
	Processing	Sngle calculations and batch processing of many calculations
	Masking	Any shape mask to customize output to specific areas
	Printout Formatting	Customizable fields, fonts, output views, and pagination
	Output Templates	Input data are automatically reported; customized formats and render views
User Interface	Entries/Edits	Graphical and/or tabular
	Input Devices	Keyboard; mouse; digitizer
Output	Point-by-point	Default grid setups and user assignable setups
	Isocontours	
	3D Model View	Fly-throughs and variable views
	Renders	Grayscale or complex grayscale or color with realistic highlights
	Scaled Plots	Superimpose lighting output on architectural/landscape backgrounds
Photometry	Data Manager	Customization of photometry for advanced users
	Viewer	Graphical view of photometry
	Photometric Formats	Input formats such as IES files from any luminaire vendor

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Calculations should be point-by-point, that is, a grid of points is established on a spacing that is related to the size of the area or areas being lighted and illuminances and luminances are calculated at these points. Such an analysis has an appearance of a high degree of accuracy, especially if the software reports data to more than one decimal place. Yet there are too many variables over which the designer has little or no control for a high degree of accuracy.

Point-by-point calculations can provide descriptive and visual output that enables the designer to better review and understand minima and maxima locations, local variations, dark spots, bright spots, streaks, and scallops that only a calculation and render of a grid of points reveals. A calculation method such as the Lumen or Zonal Cavity Method would not reveal such information. See 10 | CALCULATION OF LIGHT AND ITS EFFECTS for more detail.

A grid of points gives guidance about the appropriateness of luminaire placement, intensity distribution, and aiming. Although one always hopes for "accuracy," unknown installation and light loss factors, and the variances in luminaire photometry and calculational accuracies suggest that we interpret the absolute values produced by calculations with considerable leeway. As the iterative schematic process segues to a design, calculations which show that proposed layouts and luminaire selections have missed criteria targets by more than 30% should be re-evaluated. Consider revising layouts, lamping, or luminaire types until tighter margins are achieved (see 4.12.4.1 Recommended Illuminances at Design Time).

Nevertheless, calculations should be meticulously defined with all information cast as accurately as practical, including such aspects as moveable partitions, as may be found in open offices, or shelving, as sometimes found in libraries, warehouses, and storage rooms. However, body shadows are not accounted given their temporal nature and/or unknown density. Nor, typically, are vehicle shadows accounted given their unknown profiles, proximity to other vehicles, and use patterns. Assessments of input and output data should be thorough. See 10.8 Assessing Computed Results. Architecture and interiors and/or landscapes cannot be allowed to change without lighting layouts and calculations re-evaluated. This degree of rigor should be used to continually gage numeric criteria compliance throughout the DD and CD phases.

Table 15.9 identifies some of the key influences affecting the outcome and interpretation of lighting calculations and renderings. The less attention given to these influences, the more likely are calculations to be flawed and the greater the flaws. Calculated results can be off by as much as 50% to even 100% if the integrity of just some of the input data is suspect.

The interpretation of renderings is limited to input data and the output media. As previously noted, actual luminaire photometry is best. Other input data include the color and reflectance values of surfaces and objects, the extent of architectural detail carried into the model, and the daylighting situation. Colors and reflectances should be as accurate or appropriate for the then-current project design status. If interior designers have yet to finalize finishes, discuss what might be possible while simultaneously recommending more sustainable high-reflectance (high LRV) finishes for better use of lighting energy. Architectural detail is important to realism and accuracy, yet details that are complicated and/or extensive will affect calculation time—best held until early rounds of calculations are made to refine and settle the lighting design.

Renderings are used to roughly assess relative luminances and their uniformity, nonuniformity, symmetry, asymmetry, and irregularities. Renderings are best judged on computer screens since these can display a greater range of luminances than can printed images. Figures 11.3a, 3b, and 3c illustrate how a series of renderings can be used to evaluate relative luminances. See 10.5 Renderings Based on Calculations.

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Table 15.9 | Calculation Influences

Factor	Influence	Calculation Adjustments	Data Source[a]: Lighting Designer(s)	Other Team Member(s)	Vendor(s)	Client(s)/User(s)
Lighting	Lamp					
	• lumen output	Identify vendors' current lumen ratings for lamps under consideration.	✔		✔	
	• lumen depreciation	Establish relamping cycle(s) and identify vendors' current lumen depreciation ratings for respective lamps under consideration.[b]	✔		✔	✔
	• tilt	Identify vendors' current lumen ratings for tilted lamps under consideration.[c]	✔		✔	
	Ballast					
	• ballast/lamp output	Identify BF(s) for ballasts/lamps under consideration and adjust light output accordingly.[c]	✔		✔	
	Voltage					
	• variation from norm	Identify expected voltage variations, if any, and identify ballast/driver/transformer vendors' anticipated performance results.[c]	✔	✔	✔	✔
	Accessories					
	• types and quantities	Establish anticipated add-on filters and/or louvers and adjust luminaire vendors' photometry accordingly.	✔		✔	
	Luminaire					
	• photometry	Establish anticipated luminaires, including reflector/trim finishes and optical requirements, and identify luminaire vendors' current photometry for same.	✔		✔	
	• dirt	Establish anticipated cleaning cycle and luminaire dirt depreciation factor.[b]	✔		✔	✔
	Controls					
	• output settings	Establish intended control settings and adjust light output accordingly.	✔		✔	✔
Environment	Temperature					
	• ambient	Identify anticipated ambient temperature and adjust vendors' photometry as necessary.[c]	✔	✔	✔	✔
	Reflectances					
	• room surfaces	Identify/recommend expected room surface reflectances and calculate accordingly.	✔	✔		
	• room surfaces dirt	Identify/recommend anticipated cleaning/refinishing cycle and establish room surface dirt depreciation factor.[b]	✔			✔
	Obstructions					
	• above task plane	Identify partitions or other relatively-fixed light-blocking objects and establish calculation adjustment factors accordingly.[c]	✔	✔		✔

a. Although vendors have or should have much of this technical data, the lighting designer secures this information based on specific project needs.

b. See also 10.7.1.2 Recoverable Light Loss Factors.

c. See also 10.7.1.1 Non-recoverable Light Loss Factors.

Daylighting affects the renderings quite significantly. If the design is intended to be functional during dark hours, daylight need not be a part of the preliminary calculations where refinement of the electric lighting takes place. However, a series of daylighting calculations will ultimately be necessary to further refine electric lighting layouts, photometric distributions and intensities, and control zoning to best integrate with the daylighting and maximize electric lighting operational energy savings. Daylighting calculations alone are necessary to refine daylighting schemes and should occur prior to analyzing electric lighting schemes.

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15.3.2 Field Results

While calculations assist in finalizing design schemes and equipment selections, their reliability only extends to helping the designer and team and client predict appropriateness of the solutions in meeting criteria. Calculations and renderings do not guarantee that criteria will be met nor that all will be satisfied with the result. To limit disappointment, team members and clients/users should be continually informed if not part of the process of programming and designing.

To further limit disappointment or surprise, it is useful to look ahead to post-construction. Field results are counterpoint to the predictive nature of calculations and renderings. As Table 15.10 outlines, a number of variables, some which are addressed in calculations, will influence criteria compliance and perceptions of compliance. Some of these are a matter of informing or educating team and client. For example, some lamp technologies require a lengthy "warm-up" period from the time they are energized until they reach reasonable or optimal operation. Others are a matter of specification, procurement, thermal environment, electrical integrity, and installation. Although an installation might be considered acceptable if measurements show that illuminance criteria are within 30 percent of their targeted values (having accounted for effects of light loss factors not evident in initial readings), the operational, environmental, and installation aspects can easily yield field results that are 50 percent or more off targeted values. Table 15.10 is a troubleshooting guide that identifies factors contributing to differences between field performance and predictions. Individual applications may have different criteria tolerances.

The more finite the criteria assessment, the more elusive may be compliance. Assessing and complying with average values are typically less challenging than assessing and complying with minimum values.

IESH/10e Field Assessment Resources

> 4.12.4.2 Recommended Illuminances at Ocupancy Time
- for more on interpreting field measurements
- for significance with respect to visual performance

> 9.8 Measuring Illuminance
- for more on illuminance meters

> 9.15 Field Measurements
- for more on determining average illuminance
- for more on measurement procedures

15.3.3 Budgets

Budgets are typically an ongoing and interwoven process with lighting (and the other building disciplines). As trial layouts are calculated and rendered and evolve into final layouts, lighting costs should be assessed with respect to budget expectations. Variances should be noted and explained. Reconciling estimates with budgets is a necessary and sometimes challenging exercise. The end of design development is an especially important milestone for reconciling costs and budgets. On many projects, lighting constitutes a small fraction of the total project cost. Ironically, however, lighting is nearly solely responsible for how the architecture, interiors, and/or landscaping is rendered and whether the embodied energies in those categories are therefore well-served, let alone the comfort and function of users. Further, on most projects, if efficiency and photometry are left unaddressed, then lighting can be responsible for a substantial percentage of connected load and of energy use. So it is, that during reconciliation of costs, discussion of these very aspects is paramount. Bona fide value-engineering (VE) exercises will attempt improvement of the life-cycle value and economy of the lighting by lighting-qualified professionals studying alternate design schemes, materials, and methods without compromising the program criteria. VE should not be a cost-cutting exercise and should not be a scope or fee burden on the design team. [9] See also 18.2 Estimating Costs.

15.4 Layouts

After design scheme, calculation, and render iterations, the designer and/or team document the latest calculations and records of LPDs, energy assessments, and green-score efforts as applicable. This level of effort results in lighting layouts and luminaire selections and typically concludes design development. Design changes by other disciplines arise and ongoing lighting refinements addressing integration and specification efforts are undertaken during construction documentation.

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Table 15.10 | Field Measurement Influences and Troubleshooting Guide

Factor	Influence	Effects	Information Source: Lighting Specification	Other Discipline(s)	Installation	Vendors	Educate Clients/Users
Lighting	Lamp						
	• seasoning	Except LEDs, lamps should be seasoned a minimum of 12 hours and up to 100 hours prior to normal use. Unseasoned lamps may exhibit coloration and light-output anomalies during initial operation and, in the case of fluorsecent lamps on dimmer conrols, may exhibit shortened life. Consult lamp and controls vendors for optimal and warranted conditions.	✔		✔	✔	✔
	• substitutions	Light output is lamp--type and brand specific.	✔		✔		✔
	• warm-up	With the exception of LEDs and halogenIRs, lamp warm-up from a "cold start" (lamp extinguished for at least an hour and/or ambient temperatures are less then lamp-vendor-optimal) to stabilized output may take up to 1 hour.					✔
	• operating position	Light output is position sensitive for some CMH and fluorescent lamps..	✔				
	Ballast						
	• substitutions	Light output is ballast-type and brand specific.	✔		✔		✔
	Voltage						
	• nominal available	Primary or secondary voltage may affect light output and component life.	✔	✔	✔		
	Accessories						
	• types and quantities	Filters and/or louvers affect light output and/or distribution.	✔		✔	✔	✔
	Luminaire						
	• photometry	Incorrect or bad photometric data greatly affect lighting results.	✔			✔	
	• reflector/trim finish	Incorrect finishes greatly affect light output and/or distribution.	✔		✔		
	• lensing	Incorrect lensing greatly affects light output and/or distribution.	✔		✔		
	• handling protection	Reflector, louver, and/or lens protective coatings and/or packaging, if left in place, are detrimental to performance.			✔		
	• dirt	Construction dust/dirt/paint overspray affects light output and distribution.	✔		✔		✔
	Controls						
	• trim settings	Some controls are factory-shipped or field-programmed with trim settings at reduced levels which greatly affect light output and may affect overall system efficiency.	✔		✔	✔	✔
Environment	Temperature						
	• ambient	Ambient temperature can be detrimental to lumen output of fluorescent and LED lamps. Confirm optimal and warranted conditions with vendors.		✔		✔	✔
	• luminaire	Temperatures in luminaires can be detrimental to lumen output and/or life of fluorescent, halogenIR, and LED lamps and/or ballasts/drivers/transformers. Confirm optimal and warranted conditions with luminaire vendors.				✔	
	• lamp components	Most lamps exhibit some componentry sensitive to temperature, some near their limits when simply operated in free air. Confirm lamp compatibility and operational limitations with luminaire vendors.				✔	
	Reflectances						
	• ceilings	Lighting results from strategies exhibiting any amount of uplight are greatly affected by ceiling reflectances.		✔	✔		
	• walls	Lighting results from strategies exhibiting diffuse downlight are affected by wall reflectances.		✔	✔		
	• floors	Lighting results from strategies exhibiting downlight are affected by floor reflectances.		✔	✔		

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15.4.1 Layouts

For layouts, luminaires are represented by symbols which are assigned luminaire types to track their location and salient features of each variety. On many projects, it is by this point that layouts are documented in 2-D or 3-D CAD. Luminaire symbols are an artifact of the project-specific standards or, lacking any, the designer's typical approach. National CAD Standards and ANSI-IES standard symbols are options, but additional degrees of visual information beyond simple circles and rectangles may be desired or required for many projects. [10] [11] Much can be gleaned from 2-D plan reviews prior to construction commencement with detailed symbols. For example, which lights are louvered, which lensed, which exhibit double-basket recessed-indirect optic and which exhibit single-basket recessed-indirect optic and respective directions of orientation can readily be conveyed with appropriate symbols. This can facilitate plan referencing during construction. See 20.3.1 Lighting Plans.

15.4.2 Luminaires

Luminaire selections through DD phase are typically recorded on spreadsheet schedules and/or with a collection of cutsheets. DD schedules are typically arranged by luminaire type in alphanumeric order for convenience as are cutsheets. This information can later be used for development of luminaire specifications.

15.4.3 Controls

Controls are typically cross-discipline systems. Unless the team member serving in the role of lighting designer is also the electrical engineer, then some degree of coordination must take place between lighting layout plans and implementation and specification of controls. At the DD phase of the project, lighting layouts should be vignetted if not fully developed with control-zone schemes and potential control station locations. Indications should be made of areas to be photocell, occupant-sensor, and/or time-clock controlled.

15.4.4 Installation and Maintenance

Systems Factors outlined in Chapter 12 identify, among other things, installation and maintenance as part of the design process. Lighting schemes should be reviewed with respect to installation and maintenance before finalizing a design. Although equipment leadtimes and maintenance cycles are important, the actual location of the lighting equipment in 3D space and how or if it can be installed and maintained must be considered. Accessibility should be reviewed with other team members, notably the architect, and with the client. Where contractors are on the design team, they should be consulted for expertise. Sometimes there are no design options other than to locate lighting equipment in difficult to access areas. The degree of difficulty will determine the extent of costs involved in installation and ongoing maintenance. In some situations, installation may be relatively straightforward, for example, a large four-wheeled articulating boom lift may permit installation where ceiling heights are more than a few stories or where lights are over inaccessible areas such as pool depressions. However, in order for this same lift to address maintenance after project completion, provisions must be made to allow the large lift to enter the building and travel to the area of interest.

Where maintenance locations are difficult to access, longer- rather than shorter-life lamps are best. Even where two or three different vendors offer lamps of equal performance, if one exhibits a longer rated life, preference for that lamp is appropriate. If two or three different luminaire vendors offer equipment of equal performance, if one exhibits a less cumbersome maintenance procedure, preference for that luminaire is appropriate. Where multi-lamp luminaires are used and the lighting can be controlled in two or more zones, automated alternating control may provide longer in-service life cycles, such as done in Figure 15.21. This can result in less-frequent relamping.

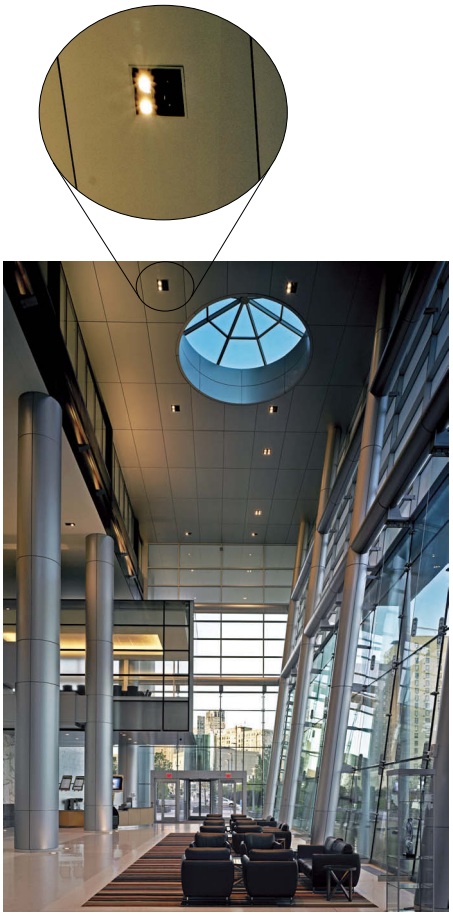


Figure 15.21 | Maintenance
Depending on daylight conditions none, some or all of the lights are used in this lobby. One control strategy that may lengthen relamping cycles is to automatically alternate between sets of lamps during situations where only half the lamps are needed. Although all lamps may be energized during dark hours, only the left pair of lamps are energized during daylight hours on odd days when photocells or time clocks deem electric light is necessary. Only the right pair of lamps are energized on even days.
» Image www.jmaconochie.com

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If ladders or lifts cannot be used to access lighting equipment, scaffolding or riggers may be required. The cost or disruption of these techniques must be evaluated by the client before lighting schemes are finalized. Although the promise of extraordinarily long life LEDs seems the panacea for difficult to access lighting locations, LEDs have been known to fail once installed. Discuss these aspects and vendor warranties with clients so that educated decisions are made about use of these lamps in hard-to-reach locations. See the IES document IESNA/NALMCO RP-36 Recommended Practice for Planned Indoor Lighting Maintenance for additional information.

15.5 References

[1] Kelly R. 1955. Lighting's Role in Architecture. Archit Forum. 102(2):152-169.

[2] Steffy G. 2004. Design problems associated with aisle lighting. Leukos. 1(1):25-42.

[3] IP - Ingress Protection Rating, The Engineering ToolBox. [Internet]. cited April 2010. Available from: http://www.engineeringtoolbox.com/ip-ingress-protection-d_452.html.

[4] IP Code, Wikipedia. [Internet]. cited April 2010. Available from: http://en.wikipedia.org/wiki/IP_Code.

[5] ANSI/IEC 60529-2004, Degrees of Protection Provided by Enclosures (IP Code) (identical national adoption). Washington, DC: NEMA .

[6] [DOE] US Department of Energy. 2008. Energy Star Program Requirements for Solid State Lighting Luminaires: Eligibility Criteria - Version 1.1. Washington, DC: USDOE.

[7] Office of the Governor. 2010. Safe Passage Great Lakes Days, 2010 Proclamations. [Internet]. cited April 2010. Available: http://www.michigan.gov/gov/0,1607,7-168-25488_54480-232454--,00.html.

[8] [IESNA] Illuminating Engineering Society of North America, Computer Committee. 2002. IESNA Lighting Design Software Survey 2002. LD+A 32(7):35-43.

[9] Cullen S. 2006. Value Engineering. In: Whole Building Design Guide. [Internet]. cited July 2010. Available from: http://www.wbdg.org/resources/value_engineering.php.

[10] United States National CAD Standard® - Version 4.0. Washington, DC: National Institute of Buildings Sciences, 2007. p. UDS-06.122.

[11] [IESNA] Illuminating Engineering Society of North America. 2000. Design Guide for Application of Luminaire Symbols on Lighting Design Drawings, ANSI/IESNA DG-3-00. New York: IESNA. pp 4-6.

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16 | LIGHTING CONTROLS

In the right light, at the right time, everything is extraordinary.
Aaron Rose, film director, art curator.

Lighting controls are an essential component of any lighting system, serve multiple purposes, and range from simple user-activated switches to advanced scene controllers, automatic sensor controlled systems, and networked digital control systems. In addition to basic on/off control, they are used to tailor lighting to space functions, tasks, and user preferences while enhancing comfort, performance, aesthetic appeal, and energy savings. For tricolor systems, such as RGB LEDs, the control system can vary source color.

Lighting controls play a key role in energy management. As electric light sources have become more energy efficient and installed lighting power density has declined over the past forty years, lighting control has become the primary means to achieve additional energy savings by minimizing or eliminating the use of electric lighting whenever possible. Lighting control that reduces lighting power for aesthetics also saves energy.

This chapter outlines the design process for lighting control systems, followed by a discussion of the available technologies and their benefits, and how these systems are applied.

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16.1 Lighting Controls: The Design Process

Lighting controls must be addressed during each phase of the lighting design process which is described in 11.3 Building Design Process. The design process begins with a programming phase and ends with commissioning of the lighting system and control equipment. Following are some of the key lighting control considerations to address during the various phases of design.

16.1.1 The Control Program

During the programming phase, the lighting designer develops a program for the lighting controls, listing special control requirements for each of the spaces, for the building as a whole, and for any required interface to outside equipment such as a campus-wide control network. System requirements related to codes, daylighting, space tasks and functions, performance features, control flexibility, energy management, and systems integration help to define the control system, and may influence source selection and luminaire layout. Applicable energy and life safety codes must be reviewed for the building and individual space types, since these may restrict or require specific lighting control features or devices. The control program must also address space users and how they will interface with the lighting control system. Research has shown that users are more satisfied with their work environment when they can control the lighting system, and their use of these controls delivers energy savings when they select lower output settings or only activate a portion of the system [1] [2] [3] [4] [5] [6] [7] [8] [9]. If an energy saving control system produces occupant discomfort or annoyance, it is likely to be disabled and any intended energy savings are lost.

16.1.2 Schematic Design

The schematic lighting design process begins to refine the control program, as the design team proposes solutions that address space and operational needs, as well as the project's

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budget. At this phase, lighting control system operation is outlined for the proposed lighting scheme. This is particularly important when daylight-responsive photosensor control, a centralized control network, or building-wide control system is being considered.

16.1.3 Design Development

Design development involves the selection, analysis and layout of all lighting hardware, including the control system. Control system hardware is selected and finalized once the lighting equipment layout is available, the control zones have been determined, and lighting loads within these zones are known.

16.1.3.1 Control Zones and Load Schedules

Control zones (sometimes referred to as control channels) are groups of luminaires that are switched or dimmed together, and should be arranged to provide flexibility, appropriate light distributions for functional and aesthetic effects, and energy savings. Load schedules, which consider source and/or ballast type and lighting power within each zone are used to size the lighting circuits and lighting control equipment. For zones that are to be dimmed, control zones consist of luminaires and/or lamps of the same type for consistent, reliable dimming.

The layout of control zones is generally based on groupings of lighting equipment according to one or more of the following:

- By the architectural feature, area, or task being illuminated
- By access to daylight to allow for energy savings in daylit zones
- By operating schedule for both manual and time schedule control
- To provide multilevel control in spaces through switching or dimming
- By equipment type

16.1.3.2 Equipment Selection and Layout

Lighting control needs are addressed in the selection and layout of lighting control equipment. Code requirements, the need to switch between different lighting scenes within a space, the location of control stations, and the load schedule dictate which user interface devices and control hardware are appropriate. Additional issues, such as ease of future control zone reconfiguration, the need for centralized control or monitoring, space requirements, and cost also impact system selection. Control hardware must be compatible with the equipment being controlled such as low voltage transformers, dimming ballasts, LED drivers, and in some cases lamps. More details on the available system options are provided later in this chapter.

16.1.4 Contract Documents

The selected control hardware must be properly identified and specified in the contract documents, which include lighting plans, power plans, control wiring diagrams, the control system sequence of operation, and written specifications (See Figure 20.3 | Lighting Controls Symbol Set and section 20.5 Controls Preset Schedule). In cases where alternate equipment selections are required for bidding purposes, equivalent options must be provided. A sequence of operation for the control system represents good practice, facilitates commissioning, and is required by most green building rating systems.

16.1.5 Control System Commissioning

To ensure proper system operation, it is critical that lighting control systems are properly commissioned. Commissioning includes validating that systems have been installed as described in the contract documents; that preset devices, such as scene controllers, are programmed with appropriate settings for the desired lighting scenes; and that occupancy sensors and photosensor-based systems are calibrated and tested to ensure proper operation within each space. Functional testing may also be required by building codes.

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For scene control, lighting scenes are generally established by the lighting designer to accommodate different space functions, energy requirements, or aesthetic effects. Occupancy sensors and photosensor systems must be commissioned by an individual who is familiar with the operation of the installed system. This person may be an employee of the equipment manufacturer, a commissioning agent, or an experienced electrical contractor.

16.2 Lighting Control Strategies

This section lists and describes a variety of available lighting control strategies. Table 16.1 provides a summary of these strategies, where they are applied, their advantages, and other relevant details. With many of these strategies, control intent is communicated from a wall-box controller, sensor, or central control system to a control device using either an analog or digital signal. Analog control can be sent via either a low voltage or line voltage circuit, whereas digital control typically involves communication through Cat5 cable or a pair of wires (often #16 AWG or smaller). A few applications employ a digital power line carrier signal. More details on control protocol options are provided in 16.5 Control Protocols.

16.2.1 On/Off Switching

On/off switching is commonly performed at the entrance to a space, as required by code, and at other locations of convenience to the users. Switching is generally used in spaces where lighting system operation is intended to be either on or off, or where switching individual groups of lights can provide sufficient adjustment of work plane illuminance and general or localized luminance distributions. Multilevel switching is required by some energy codes [10] [11], and involves switching of different lamps within luminaires or different luminaires within a layout to provide two or more illuminance levels within a space. In daylit spaces, this provides energy savings when a user determines that full light output is not necessary and activates only a portion of the available hardware.

On/off switching is the simplest of lighting control techniques, providing the lowest installed cost. This method of control, however, limits flexibility to either an on or off state in each of the control zones. In shared work spaces and some public spaces, occupants may be annoyed or confused by sudden switching of all or a portion of the lighting system, particularly when this control is automated.

With manual control, it is best to limit the number of switches at any one location, so as not to complicate system operation and increase clutter. When more than two switches are provided, it is useful to label the switches, particularly in spaces with multiple users, such as classrooms or conference rooms. Scene controllers are another option.

16.2.2 Dimming

Dimming control is more expensive than simple switching, but provides flexible control of output down to the minimum level provided by the dimming hardware. When dimming is applied, perceptions of space brightness are not linearly related to measured values of luminance. For example, to achieve a space that appears half as bright, lighting system output must be reduced to approximately 32%, and for one-tenth perceived brightness to approximately 2% of full light output (See 4.3.3 Approximate Brightness Calculation). Dimming systems are applied in spaces where enhanced flexibility, low output, and smooth or slow transitions between settings are desired or beneficial. The relative cost of dimming hardware is low for filament and high for fluorescent, LED, and HID systems where dimming ballasts, drivers, or more complex interfaces are required. Occupant control of light output is generally accomplished through the use of wall station dimmers or lighting scene controllers.

Most dimming systems for filament lamps involve a triac, either built into a wall switch or multi-zone wall station control device, or integrated into a separate dimming panel.

Triac: A triac (triode for alternating current) is a bidirectional electronic switch containing gate electrodes that removes a portion of each half of the voltage sine wave (varying the duty cycle). Removing a portion of the sine wave reduces the RMS voltage delivered to a filament lamp which dims the lamp.

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Table 16.1 | Lighting Control Options and Their Application

Control Method	When to Apply	Comments
On/off	• When lighting for a space or control zone will be used at full output only	• Provides occupant with control • Inexpensive
Dimming	• When a range of output levels is desired from individual luminaires	• Flexible • The lighting system can be tailored to the needs of the space and occupants • More expensive than switching. Dimming ballasts are required for fluorescent sources
Scene Control	• When users of a space will benefit from access to different presetg lighting scenes, such as when multiple lighting zones are being dimmed	• Convenient & simple for user • Flexible, adapts lighting to space functions • More expensive than standard switching and dimming
Photosensor Dimming	• When daylight is present in sufficient quantities to serve as the primary source of light for a space or area and control of the electric lighting system should be unnoticeable	• Control and energy savings in response to daylight is automatic • Payback is typically not short due to the high cost of dimming ballasts and low power densities • Requires proper lighting system layout and commissioning
Photosensor Switching	• When daylight is present in sufficient quantities to permit a lighting control zone to be turned off completely a large fraction of the time, and a sudden reduction in electric light output is acceptable	• Less expensive than photosensor dimming • Fast payback is possible • Occupants object to automatic switching systems in most work spaces • Requires proper lighting system layout and commissioning
Occupancy Control	• When lighting is likely to remain on when the space is vacated	• Relatively inexpensive • Potential energy savings are significant
Time Control	• When repeatable patterns of space use make time of day scheduling desirable	• Control of the lighting system is automatic for expected periods of occupancy • Lighting levels may be lowered for less critical functions, such as space cleaning and retail space restocking • System override actions are required • Multiple shutoff times should be provided to turn lighting off following system overrides

Filament lamps can be dimmed smoothly to zero light output, however dimming reduces both efficacy and color temperature. When dimming low voltage halogen lamps, the dimmer must be compatible with the transformer type, which may be electromagnetic or electronic.

The dimming of fluorescent systems requires special dimming ballasts that receive a signal from a control device and control the lamps accordingly (See 7.3.6.6 Dimming). This signal follows one of a number of standard protocols or a proprietary one developed by the control system manufacturer (See 16.5 Control Protocols). Dimming ballasts are typically designed to operate fluorescent lamps down to 10%, 5%, or 1% of full output. Systems with 1% minimum output or less are preferred in architectural dimming applications where

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very low space brightness is desired. Ballasts with higher minimum output are commonly applied in photosensor and other applications where the primary goal is energy savings. Dimming ballasts are available for both linear and compact fluorescent lamps, although not all lamps are approved for dimming applications. Certain screw base compact fluorescent lamps with integral ballasts and LED lamps claim compatibility with standard filament lamp dimmers, primarily for use in residential applications. It is important to check with the dimming equipment manufacturer to verify compatibility of these lamps with the dimming equipment. Some manufacturers have re-engineered their dimmers to better accommodate dimmable CFL and LED lamps.

In fluorescent dimming applications, some manufacturers recommend that lamps not be dimmed during their initial hours of operation. NEMA recommends burning fluorescent lamps at full output overnight to eliminate impurities if they show instability upon initial dimming, or if being used in a critical installation [12].

Stepped dimming ballasts are another means of achieving dimming and are available for both fluorescent and HID lamps. While stepped dimming is less frequently applied in fluorescent systems, it is the most common dimming approach for HID systems. With HID stepped dimming ballasts, different capacitors are connected using relays to vary light output. Continuous dimming of HID lamps is possible with electronic dimming ballasts or line voltage ballasts coupled with a variable voltage transformer or phase control, however the dimming range is small and this approach is rarely applied.

NEMA recommends dimming HID lamps (MH and HPS) no lower than 50% of full power to avoid premature failure [13]. A 50% power level corresponds to light output of approximately 25-30%, since HID lamp efficacy is reduced when dimmed. With metal halide lamps, a shift in lamp color is also likely to occur as a lamp is dimmed, with CCT decreasing as lamp color shifts towards blue-green. HID lamps should not be dimmed until they are operated at full output for at least 15 minutes following warm up. This delay feature is often built into the ballast or control system. Finally, probe-start metal halide lamps may be limited to base-up operating positions in dimming applications.

Solid state lighting equipment can be dimmed to light output levels as low as 1% through the use of an LED driver with dimming capability. Dimming is most commonly provided through pulse width modulation of the direct current supplied to the LEDs. Other advantages of LED dimming include an increase in both efficacy and life since the LEDs are operating at lower temperatures when dimmed.

16.2.3 Scene Control

Scene controls are a common control solution in spaces that are best served by pre-established settings of lighting control zones. This form of control involves the dimming and/or switching of groups of lighting equipment to alter room luminance or illuminance distributions, or to change the functionality, mood or appearance of a space. Scene control permits the user to select a preset lighting configuration by pressing a single button. For zones that are dimmed, the transition time or fade rate to apply when transitioning from one setting to another may also be adjustable. Fade rates in conference and meeting spaces should be relatively fast (<3 sec.), while preferred fade rates in spaces such as restaurants may be longer than one minute.

Examples of spaces in which scene control is commonly applied include

- restaurants, where different settings are applied for lunch, dinner and cleanup
- a conference room, where activities such as face-to-face meetings, audiovisual presentations, and video conference activities require different lighting conditions
- a lecture hall or large classroom where visual tasks vary between a chalkboard or whiteboard, projection screen, or the desktop in the case of an exam
- retail applications where settings might correspond to normal business, cleaning and stocking, and nighttime lighting, which may include operation of

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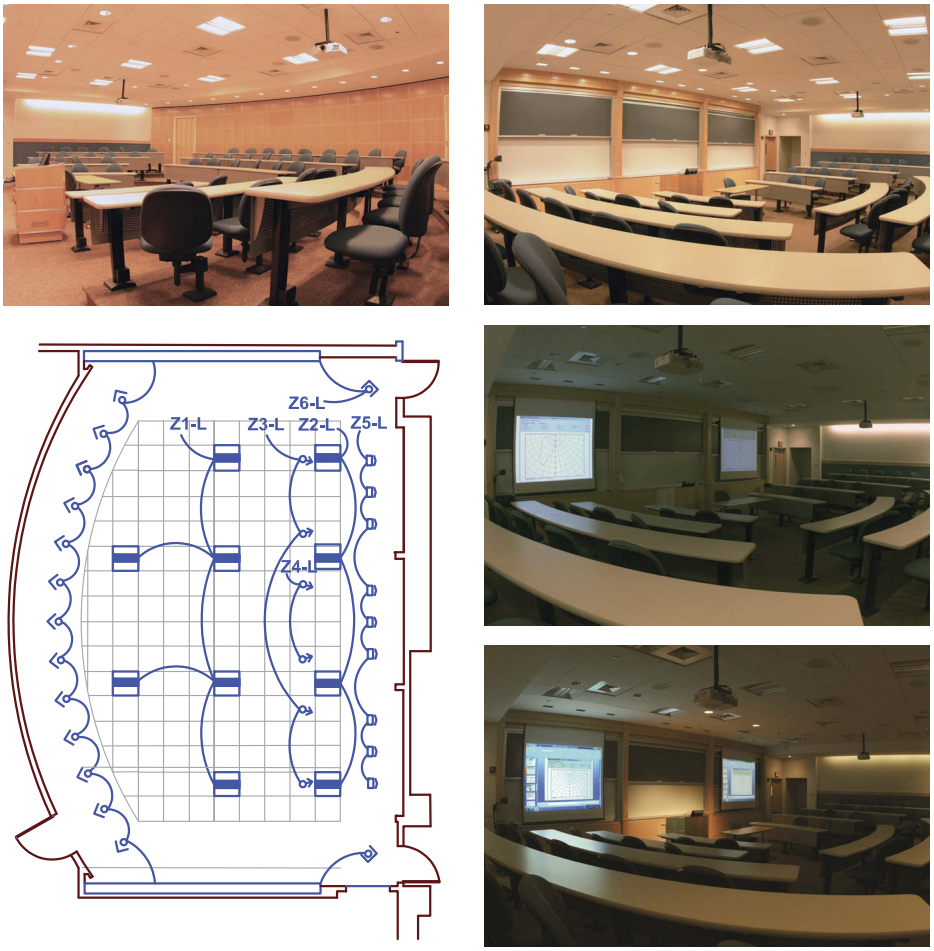


Figure 16.1 | Scene Control Devices in a Classroom

» Scene control is applied in this classroom to allow the instructor to conveniently control room lighting conditions. The reflected ceiling plan shows the six lighting zones: general lighting rear, general lighting front, left and right front speaker accents, podium (center) accent, chalkboards, and side plus rear wall wash systems. Three of these scenes are shown at right, with the top two images displaying the full-on condition.

» Images ©Richard Mistrick

Scene control devices add to the associated control system costs, but greatly simplify user interface with the lighting control system by replacing multiple switches and dimmers with a single push-button wall station or keypad that provides instant recall of available scenes. Figure 16.1 contains an example.

16.2.4 Daylight Integrated Controls

Daylit spaces offer the opportunity to achieve energy savings by utilizing daylight as the primary source of light, with electric light supplementing the daylight as necessary. Photosensors and computer-based algorithms can control electric lighting and shading devices on daylight apertures to provide appropriate space and task illuminance and to limit daylight or sunlight penetration, reduce window luminance and glare, and maintain acceptable levels of visual comfort [14].

16.2.4.1 Electric Lighting Control

Automatic control of electric light output in daylit areas can be accomplished by switching or dimming the lighting equipment based on a photosensor reading that monitors either the daylight entering a space, or the combined level of daylight and electric light within that space. These systems ensure that electric lighting energy is reduced when daylight is available. A control algorithm converts the photosensor reading into a desired dimming level or switching condition. Photosensor placement and calibration are key to achieving energy savings while meeting the needs of the tasks and occupants [15]. More details on these systems and their control algorithms are provided in 16.3.5 Photosensors.

In a few applications, electric light levels are raised in response to higher daylight levels to improve adaptation between high exterior and lower interior levels. Examples include

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the entrances to tunnels and parking garages, some vestibules, and transition spaces into theaters and auditoriums.

16.2.4.2 Shade Control

Vertical glazing in work spaces, and horizontal glazing in spaces that require highly controlled daylight (such as museums), are generally fitted with adjustable shading devices (louvered blinds or fabric roller shades) to block or diffuse direct sunlight, or to reduce interior daylight levels and window luminance. These shading devices can be controlled automatically through the use of photosensors, timeclocks, or computers that assess solar position and daylight conditions.

In the case of horizontal blinds and operable louvers, the blind/louver angle may be automatically adjusted based on solar position and sunlight intensity. With fabric roller shades, shading may be lowered to one or more prescribed positions based on measured daylight conditions.

A shading control strategy should attempt to maintain the view out a window as much as possible while providing acceptable levels of visual comfort. Given that occupant preference for shading or view may differ from the settings of an automated system, occupant overrides are provided with many of these systems. Some systems learn to adjust future settings based on data gathered from an occupant's override requests.

16.2.5 Occupancy Sensing and Control

Electric lighting that remains on in spaces which are unoccupied is usually a waste of energy. Occupancy sensors incorporate motion sensors that detect occupancy and can switch lighting on when someone enters a space and off when the space is vacated. Some energy codes require the occupant to switch lighting on, which has the potential to save additional energy, particularly in daylit spaces. When sensors are configured to only turn lighting off when a sensor detects no activity within a space, they may be referred to as vacancy sensors. For simplicity, the remainder of this chapter will refer to both configurations of these devices (on/off and off only) as occupancy sensors.

The most common occupancy control technique involves switching the lighting off after a set period of time has elapsed during which no occupancy is detected. In some cases, for safety or security, it may be desirable to set lighting to a lower level, rather than completely off, when a space is unoccupied.

A more detailed discussion on occupancy sensors is provided in 16.3.4 Occupancy/Vacancy Sensors.

16.2.6 Time Control

Time control takes the form of either a time-based schedule or timed switches. Time schedule control is a less forgiving means of occupancy control, but useful in spaces that have a well-known and consistent operating schedule. These devices can be mechanical, electronic, or computer controlled. Lighting is turned on during normal operating hours and off, or to a reduced condition, at other times. Override capability is necessary when a space is to be occupied outside normally scheduled hours. For exterior or interior applications where control should be configured to sunrise and sunset times, an astronomical time clock can control lighting equipment across the year. These devices require input of the site location (latitude and longitude), time of day, and day of the year.

Timed switches are another means of time-based control that may be applied in spaces where occupancy is generally both short and intermittent. The user turns on the lighting equipment through a dial on a mechanical device, or buttons on an electronic device, allowing the lights to operate for a specified time period, after which the system switches the controlled lighting zone off. Timed switches have historically been used in spaces such as library stacks, although motion/occupancy sensors are another option for these applications.

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16.2.7 Task Tuning

When a dimming system is present, lighting conditions can be tuned to the tasks at hand. If a lighting system provides more illuminance than required for a particular task, system output can be reduced to save energy, and in some situations improve task visibility, such as with computer tasks. Open office areas, circulation spaces, filing areas, conference areas and office cubicles can each be tuned to their recommended illuminance values. With digital ballasts, tuning is easily accomplished for each ballast in the system, while for other ballast types, tuning is only possible across an entire control zone.

16.2.8 Lumen Maintenance

Lumen maintenance involves adjusting lamp output over time to maintain constant light output as lamps age, and dirt accumulation reduces luminaire output. This can save energy since design practice requires the application of light loss factors which result in spaces that are overlit when lamps are new and lighting equipment is clean. With lumen maintenance control, either lamps are dimmed when new, or the lamp's current is increased as the system ages. A photosensor or other device that monitors lamp performance or room illuminance conditions is typically applied. As lamps age and dirt accumulates, input power is increased to compensate for system losses to hold light output constant. Today's fluorescent lamps lose only a small fraction of their initial lumen output over their lifetime, hence lumen maintenance is rarely applied with these sources. One exception is the case of closed-loop photosensors in daylighted spaces, where lumen maintenance is an inherent benefit of these systems (See 16.3.5.6 Closed Loop Control). Other applications that account for lumen maintenance involve specialized sports lighting systems and some SSL controllers that increase power to the lamps over the system life to maintain constant output.

16.2.9 Demand Response

During periods of peak electrical demand, it can be cost effective to reduce a building's power consumption to avoid higher charges for electrical power. Some examples include: time-of-day rate schedules where the cost of electricity varies with system demand; peak demand emergencies, where utilities request major users to reduce their load on the electrical system; and demand metering, where a portion of the electrical bill is based on the peak kilowatt demand recorded over 15- or 30-minute periods during the course of a month. With demand charges, ratchet clauses may set the minimum demand charge in future months as a fraction of the peak demand measured over the previous six or twelve months, providing additional incentive to reduce monthly peak demand. Under any of these scenarios, the building operator, or in some cases the utility, may temporarily reduce peak electrical power by turning off non-essential loads and dimming the electric lighting system (which may include work areas) through a centralized control system. A number of studies have assessed occupant satisfaction when systems are dimmed under load shedding conditions [16] [17]. These studies have shown that electric lighting in most applications can be slowly dimmed as much as 30% without complaints from occupants. Automatic systems such as daylight photosensor and occupancy control also reduce peak demand by lowering or eliminating lighting power in daylit and unoccupied spaces [18] [19].

16.2.10 Centralized/Networked Control

In many buildings, as well as across corporate and institutional campuses, centralized control of lighting equipment may be desired to monitor and manage building loads. Such control can be accomplished by networking control devices such as dimmed lighting circuits, dimming panels, relays or relay panels, and digitally controlled lighting equipment to allow for time scheduling, load shedding, and monitoring from a centralized location.

With centralized control, lighting can also be integrated into a comprehensive Building Automation System (BAS). These systems provide a single point of control for lighting, HVAC, security and other building systems. Information from sensing devices, such as

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occupancy sensors, can be used not only to control lighting equipment, but also for security purposes, and to control HVAC equipment that serves a space. These systems are capable of monitoring system operation, and enable a wide variety of control functions to be performed, such as scheduling, load shedding and equipment failure detection.

For lighting control equipment to operate on a BAS, the lighting control equipment must be configured to communicate with the primary control network. A number of open standards exist for these networks, with the most popular being BACnet (See 16.5.5 BACnet) and LonTalk, a commercial product. If the lighting control system is operating on its own proprietary network, a gateway device is employed to translate commands and responses between the BAS system and the lighting control device or network. In some cases, the ability to communicate with the BAS may be incorporated directly into the device, as in the case of a lighting control panelboard. Standalone gateway devices are generally used to interface to a lighting network or system that controls multiple zones or devices.

Centralized control may be used for energy management, load shifting or load shedding, and to monitor space use, outages or faulty equipment. Feedback from the system makes it easier for the building to be maintained in top operating condition, which helps maximize both occupant comfort and energy efficiency.

16.3 Technology

This section provides details on the lighting control equipment and systems used to accomplish the types of lighting control previously described.

16.3.1 On/Off Switching

Historically, most wall switches have been line voltage devices, which open and close the phase wire (hot wire) that supplies power/voltage to the luminaires. When this basic lighting control approach is applied at a single location, a single-pole switch is used, as shown in Figure 16.2. The neutral wire completes the circuit back to the panelboard. In most residential applications, the neutral wire also runs through the switch box, but it is never connected to a toggle switch.

If lighting must be controlled from two different locations, three-way line voltage switches can be used at both locations. Three-way switches are technically referred to as single-pole, double-throw switches. The first of these three-way switches receives unswitched power from the panelboard and connects the incoming power to one of two outgoing travel wires.

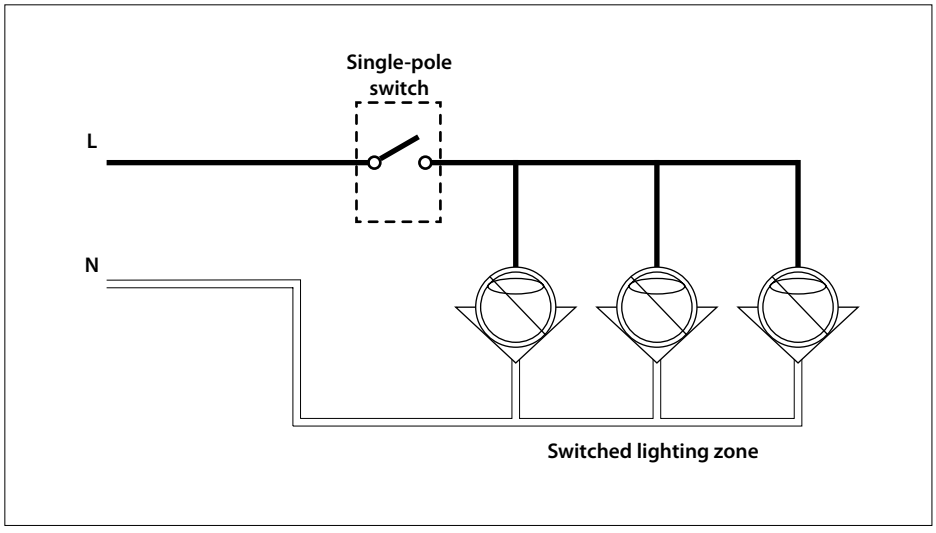


Figure 16.2 | Single-pole Switch
A single-pole switch controls the phase wire (L) to a group of luminaires. The neutral wire (N) completes the circuit back to the panelboard.

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The travel wires are routed together to the second three-way switch, which is connected in reverse to toggle between the two travel wires, and the resulting single output wire is then connected to the lighting equipment. This arrangement permits the lighting system to be controlled at either switch (See Figure 16.3).

If switching is required at three or more locations, the first and last switch in the series are three-way switches, and any intermediate switches are four-way switches (also called double-pole, double-throw switches), which connect incoming and outgoing pairs of travel wires by alternating which incoming wire is connected to each outgoing wire as the switch position changes. An example of this switching configuration is shown in Figure 16.4.

Split wiring of three-lamp and four-lamp luminaires, where the center lamps are switched separately from the outer lamps is a common means of achieving multilevel control, and permits a three-lamp luminaire to be operated using one, two or three lamps, and a four-lamp luminaire to be operated at full or half output (See Figure 16.5). In some three-lamp systems, the center lamps are tandem wired, with neighboring pairs of luminaires sharing a two-lamp ballast for improved system efficacy and economy. The allowable distance to the second luminaire is limited by ballast lead length criteria.

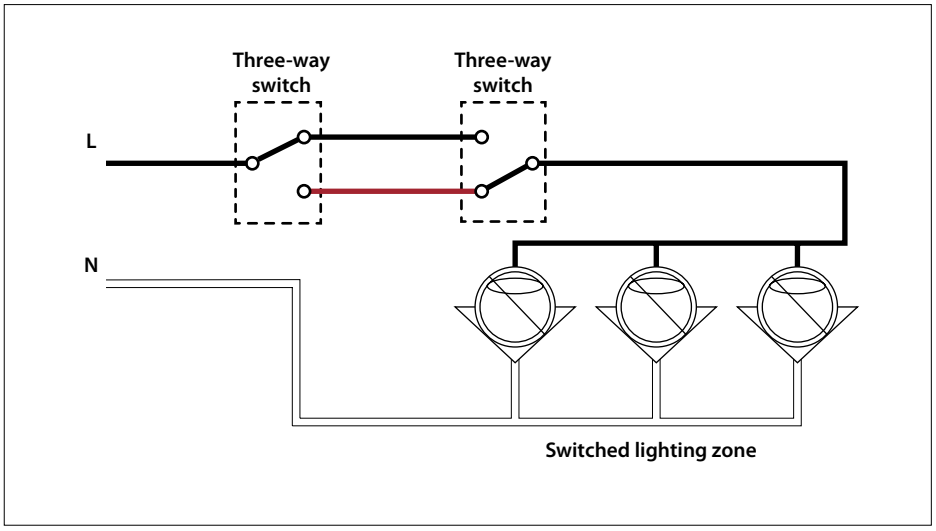


Figure 16.3 | Three-way Switch
Three-way switches permit lighting equipment to be switched from two locations. A pair of travel wires connect the two switches as shown and one of these two wires is always energized. In this diagram, the luminaires are switched off since the two switches are connected to different travel wires.

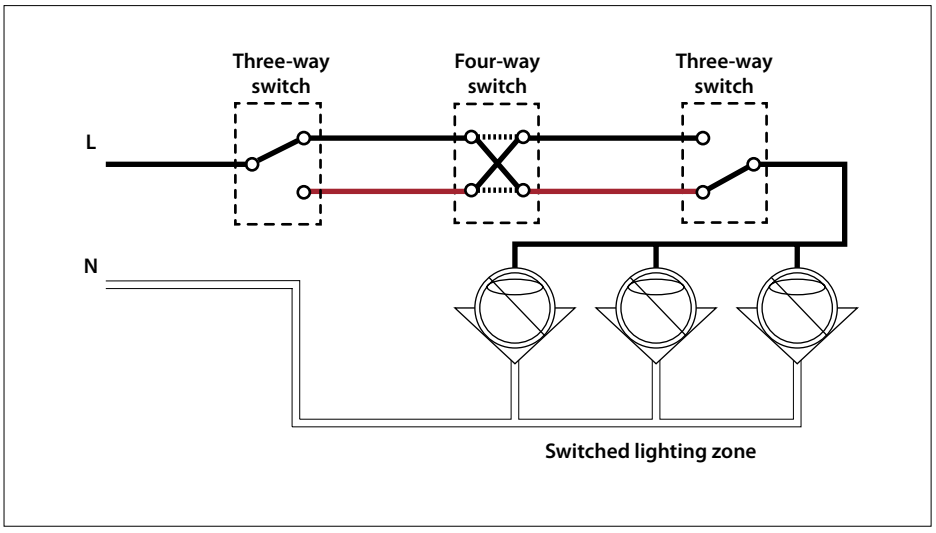


Figure 16.4 | Four-way Switch
For line-voltage switching at three or more locations, the first and last switch are three-way switches, while the intermediate switches are four-way. Four-way line-voltage switches connect the two incoming and outgoing wires either in parallel or in a crossed arrangement to alter which of the outgoing travel wires is energized. A person can change the on/off status of the lighting system by toggling any of the switches in this arrangement.

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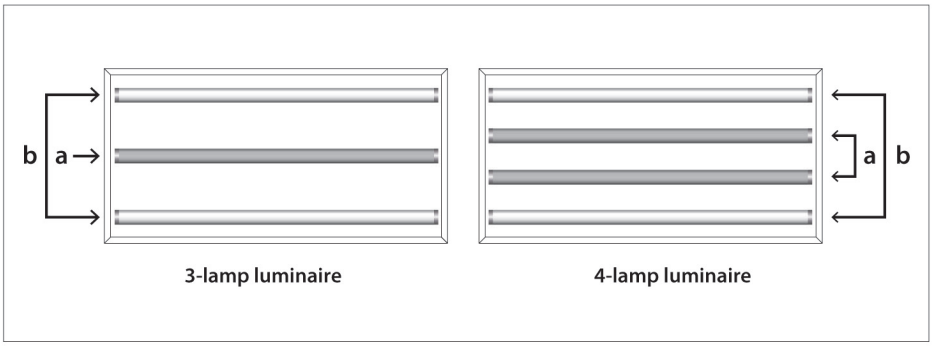


Figure 16.5 | Multi-level Switching of Three and Four-lamp Luminaires.
These arrangements provide stepped dimming through simple switching of the a and b lamp groups. Perceptually, one-third light, one-half and two-thirds light output correspond to approximately 50%, 70% and 80% of full room brightness.

16.3.2 Relays

Relays are another technology for switching lighting circuits. Relays are activated by low voltage switches or control signals received from other devices and can be installed at junction boxes near a space (See Figure 16.6) or may be mounted within relay panelboards that also contain circuit overload protection devices (circuit breakers). See Figures 16.7 and 16.8 for control system layout schematics for both configurations. Relay panels are often used when the loads being controlled are large, or when a significant number of lighting circuits are controlled by timers or remote devices. Since electronic ballasts and certain lamps may exhibit an inrush current that significantly exceeds their operating current, relays must be capable of handling the total inrush current provided by the equipment they control. Similarly, overcurrent protection devices must allow this current to pass without tripping. In some systems, relay control actions may be audible.

16.3.3 Dimmers

Dimming control is a more flexible alternative to simple switching of lighting equipment, with a variety of equipment available to provide this function.

16.3.3.1 Wallbox Dimmers

Single zone dimmers are available in a variety of styles to serve specific light source and loading conditions. See Figure 16.9 for some examples. The dimmer must be matched to both the type and magnitude of the loads being controlled. For example, different products are required to dim each variety of lamp, including line voltage, electromagnetic low voltage, and electronic low voltage filament lamps, fluorescent lamps, and SSL lamps, although these products have the same general appearance mounted on the wall. Master and remote units (sometimes referred to as slave or satellite units) that are available in some product lines permit three or four-way control, where lighting levels or scenes can be selected at more than one location. In some models, the dimming circuitry is integrated into the wallbox unit, while in others it is located in a dimming panel.

When a significant amount of lighting equipment is being dimmed, dimming panels are often employed. These panels are typically located in an electrical closet and consist of dimming modules that are too large to fit within a wall device. See Figure 16.10. The wall devices in these applications are analog or digital devices that relay a control signal to the dimming modules within the panel.

16.3.3.2 Scene Controllers

Scene controllers are wall station units that permit different combinations of lighting zone switch and dimmer settings to be recalled with the push of a button (Figure 16.11). In some cases, these devices contain dimmer modules within the junction box, while in others, they signal remote hardware to perform the control function. Master units generally have controls that permit the user to set the zone operating conditions for each of the scenes. Remote stations are employed to select scenes from locations other than the master unit,

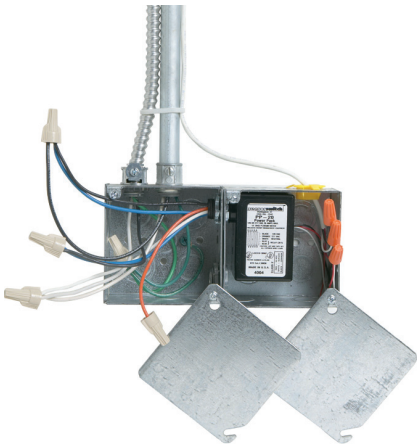


Figure 16.6 | Power Pack Relay Attached to Junction Box
A power pack provides power for occupancy and daylight sensors and other devices and provides a relay for remote switching of lighting circuits. The power pack may attach to the outside of a junction box if permitted by local codes. This photograph shows it mounted within a box.
» Image ©Sensor Switch, Inc.

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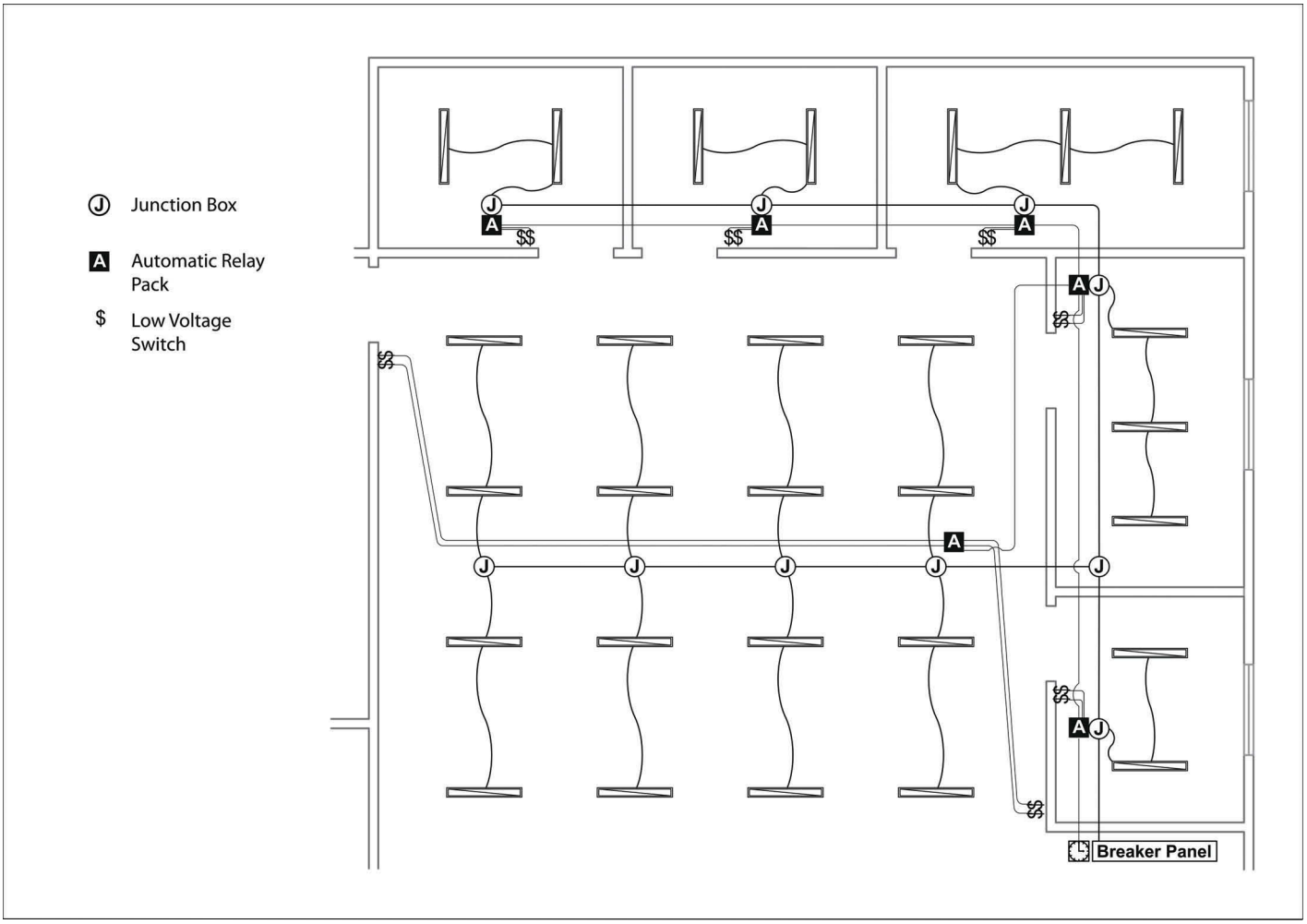


Figure 16.7 | Circuiting with Distributed Relays
Relays can be located within each room using low voltage switches and powered from a standard breaker panel. A **twisted-pair** or digital communication line is run to each of the relay devices.

Twisted-pair wire: Two wires are wound together to cancel electromagnetic interference from external sources, electromagnetic radiation from other wires, and cross-talk between neighboring wires. Typical twisted pair wire sizes used in lighting control systems are 18 AWG and 16 AWG.

and communicate a user's selection to the master controller. Some systems include the option for a wireless hand-held remote, which can be operated from a podium, or conference table. Scene controllers can also be linked to Audiovisual (A/V) equipment to lower projection screens and activate projection equipment, as well as to operate shading systems to darken a room.

16.3.4 Occupancy/Vacancy Sensors

Occupancy/vacancy sensors switch or dim the lighting in a space based on the detection of occupant movement, fulfilling the requirement for "automatic off" control required by many of today's energy codes. Occupancy sensors activate lighting when motion is detected, which is useful in circulation spaces such as corridors, or in windowless spaces such as interior toilet areas.

16.3.4.1 Occupancy Sensor Technologies

Technologies used to sense occupancy include the following:

- Infrared, which senses changes in the location of heat radiating objects (people)
- Ultrasonic, which sends out inaudible, high frequency sound energy to detect movement within a space using the Doppler principle, where the frequency of sound waves is altered when reflected from moving objects

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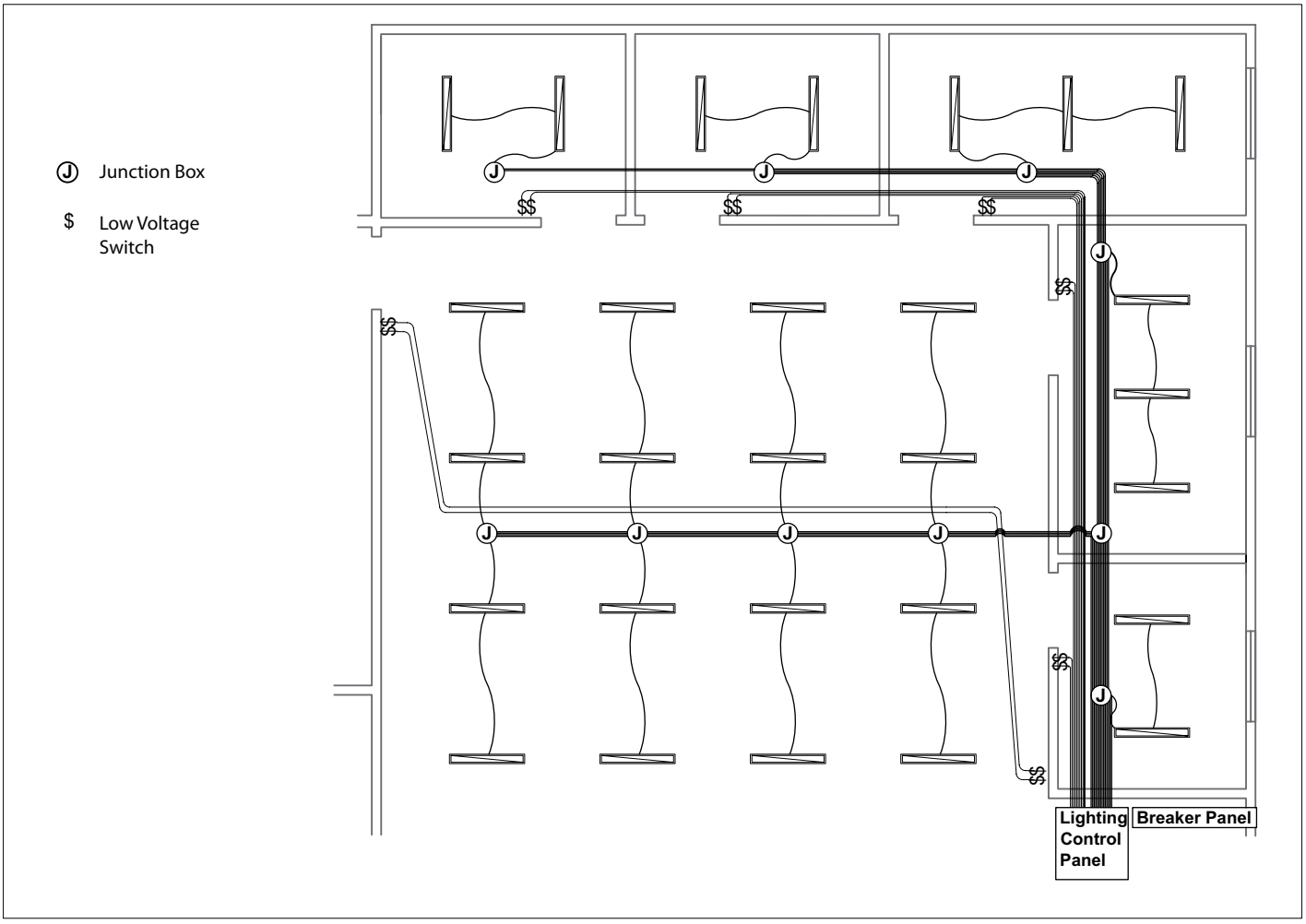


Figure 16.8 | Circuiting from a Lighting Control Panel
A lighting control panel provides centralized control of lighting circuits using low voltage or digital switches. Individual power wires must be run from this panel to each space, and separate low voltage control wires must be run from each group of switches back to the control panel, since the relay switching devices are located within the panel.

- Microwave, which uses a similar approach to ultrasonic devices
- Acoustic, which detects sounds created by space occupants

Application notes for each of these are provided in Table 16.2.

Infrared sensors are often referred to as passive infrared (PIR) sensors because they only detect radiation that is present in a space (no energy is sent into the space). These devices usually incorporate a Fresnel lens that directs the radiation received from a series of conical zones to individual receptors within the device. A change in the radiation level sensed



Figure 16.9 | Wall Dimmers
These devices are available in a variety of different styles and operational configurations.
» Images 1, 2 and 5 from left: ©Lutron Electronics
» Image 3 ©Crestron
» Image 4 ©Wattstopper

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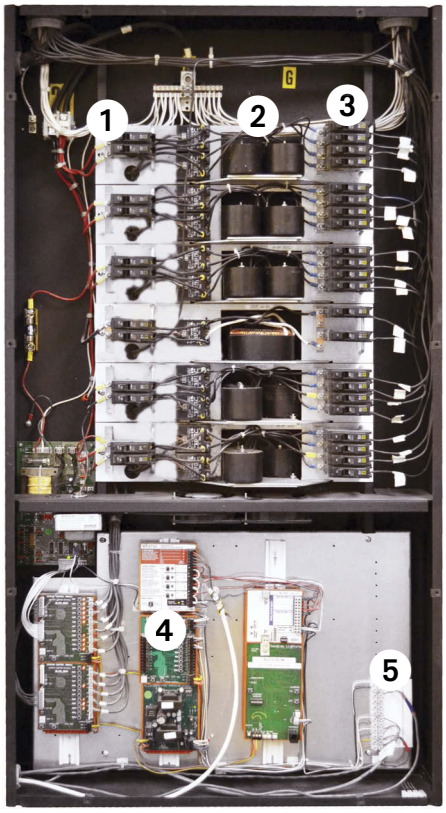


Figure 16.10 | Dimming Panel
A dimming panel houses the gear to dim multiple filament lamp lighting circuits. Components include ❶ Input circuit breakers; ❷ dimming modules; ❸ output breakers; ❹ control electronics; ❺ control input terminals;
» Image ©Douglas Lighting Controls, Inc.

within one of these zones indicates movement of an occupant. PIR sensors can detect smaller movements at close range, but larger movements, such as full body motion, are required to elicit a response at greater distances. Infrared sensors, due to their manner of operation, must have a direct view of the area they serve. In some products, the field of view can be restricted by applying a permanent masking device to the interior of the sensor's lens.

Ultrasonic sensors send out inaudible high frequency sound energy and check the returning sound for waves that have been reflected by moving objects. Because their emitted sound energy radiates in all directions, it is not possible to limit the angular response of these sensors. A major advantage of ultrasonic sensors is their ability to detect movement around partitions, particularly when the partition material is hard and reflects sound waves. Ultrasonic sensors are also good at detecting minor motion such as arm movements. Ultrasonic sensing is frequently combined with PIR technology in hybrid or dual-technology occupancy sensors to improve sensor performance. In dual-technology sensors, both technologies (PIR and ultrasonic) must sense motion for lighting to be turned on, and only one of the two is required to keep the lights on. Ultrasonic sensors should not be located within 6 feet of HVAC equipment as air movement may trigger a positive response.

Some dual-technology sensors utilize microwave energy instead of sound energy. Others combine PIR with passive acoustic sensing that listens for sounds created by the occupants, which avoids susceptibility to airflow influences. Acoustic sensors generally filter out background sounds that are present when the space is not occupied.

Most occupancy sensors offer a test mode where the delay time can be temporarily reduced to a period of less than 10-30 seconds to verify that system shutoff occurs when a space is vacated, and to test the level of motion required to activate the sensor.

Most occupancy sensors also offer a sensitivity adjustment that determines the distance over which the sensor will operate, which alters the degree of motion required to trigger the device. Most devices are provided with factory settings that allow the systems to operate out of the box, but these settings may not provide an optimum level of performance.

16.3.4.2 Products and their Application

In addition to applying a variety of different sensing technologies, occupancy sensors can be installed in a number of different locations, depending on the application. Those intended

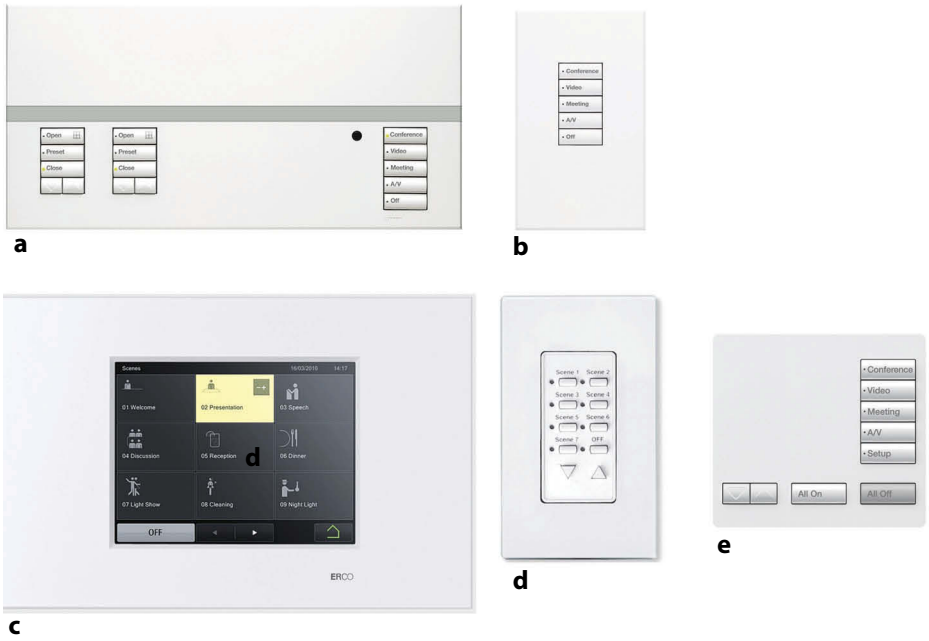


Figure 16.11 | Scene Controllers
Preset lighting scenes are recalled at the touch of a button. **a** is a master controller with a remote wall station, **b**. These devices can now be wired, digital or wireless. **c** illustrates a liquid crystal touch display. **d** is a DALI scene controller; **e** is a handheld control that includes operation of window shading devices.
» Images **a**, **b**, and **e** courtesy Lutron Electronics Co. , Inc.
» Image **c** ©ERCO, Inc.
» Imags **d** ©Leviton, Inc.

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Table 16.2 | Occupancy Sensor Technologies And Guidelines For Their Use

Occupancy Sensor Type	Application Notes
Passive Infrared (PIR)	• Use in enclosed spaces with an unobstructed line of site to the occupants • Locate to eliminate views out an open door • Locate at least 2 m (6 ft) from HVAC outlets • Check manufacturer for coverage pattern • Not for spaces with little occupant movement • Coverage patternmay be field adjustable by masking the lens
Ultrasonic	• Good for spaces with partitions • Not for use in spaces with strong air currents or moving machinery • Good for unbounded spaces
Dual Technology (Inrared and Ultrasonic)	• Best option for spaces with low activity levels • Not for use in spaces with strong air currents or moving machinery • Good for unbounded spaces
Infrared and Acoustic	• Passive acoustic sensor serves as a second sensor for sensing space vacancy conditions

for use in small private offices are often built into simple wall switches. These are available to control one or two circuits, with the latter designed to accommodate the multilevel switching required by some energy codes (see Figure 16.12). Most models have an audible or visible signal to warn users that no motion has been detected and lighting is about to be turned off. Units intended for application in large open spaces are designed to be mounted either on the ceiling or high on a wall at or below suspended luminaires to view across a space. Examples are shown in Figure 16.13 and 16.14.

Occupancy sensors are also available for use within work stations to sense the presence or absence of a worker and control cord and plug loads accordingly. Loads such as task lighting and computer monitors are turned off when the area is vacated. See Figure 16.15.

Some occupancy sensors provide a separate dry contact closure (closing a circuit which has no voltage) that can signal the HVAC system that a space is unoccupied so space conditioning can be reduced or eliminated to gain additional energy savings.

In selecting an occupancy sensor, it is important to note that most devices have a load limit less than what would be permitted on a standard wall switch. The allowable load may also be different for filament and fluorescent lighting systems.

Depending on the space and its use pattern, occupancy sensors have the potential to affect the in-service life of fluorescent lamps. Increased lamp life may occur when the operating hours are reduced significantly without frequent switching. If fluorescent lamps are switched frequently, in-service lamp life may be diminished, particularly if instant start ballasts are used. Given the more frequent switching that occurs with occupancy sensors, programmed start ballasts are recommended.

HID systems should not be placed on standard on/off occupancy sensors due to lamp restrike and warmup times. In applications such as warehouses, HID systems with bi-level ballasts can be linked to occupancy sensors via a control module that signals the ballast to switch to a low output condition when the space is unoccupied. Bi-level ballasts operate by switching between two capacitors, one that provides full power and a second that provides approximately 50% of full power to the lamps, resulting in 30-40% of full lumen output.



Figure 16.12 | Wall Switches with Occupancy Sensors
A single circuit occupancy sensing wall switch (left and center), and a dual circuit model (right).
» Images (left to right), ©Wattstopper, ©Leviton, and ©Hubbell.



Figure 16.13 | Wall-mounted Occupancy Sensor
a is a digital dual-technology sensor. **b** is a wireless IR sensor. **c** is a dual technology sensor. Slots are for the ultrasonic feature, while the lens is for passive infrared operation.
» Image **a** ©Wattstopper Legrand, Inc.
» Image **b** courtesy Lutron Electronics Co. , Inc.
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Figure 16.14 | Ceiling-mounted Occupancy Sensors
a is a wireless dual technology sensor (infrared-ultrasonic). b is a wireless infrared sensor. c is low voltage dual technology sensor (infrared-ultrasonic); and d is a low voltage dual technology sensor (infrared-acoustic)
» Image a ©Wattstopper, Inc.
» Image b ©Lutron Electronics, Inc.
» Image c ©Crestron, Inc.
» Image d ©Sensor Switch, Inc.



Figure 16.15 | Plug Load Controller
An occupancy sensor and plug load controller can turn off task lighting and other unnecessary desktop devices when a workstation is vacated. Computer and other essential loads are not controlled by the sensor, and are attached to the non-switched plugs on the power strip.
» Image ©Wattstopper Legrand, Inc.

16.3.4.3 Powering Occupancy Sensors

Occupancy sensors are powered by low voltage or line voltage power, with some newer models powered by long life batteries (capable of 8-10 years of operation). The self-powered models are suitable for retrofit applications in existing buildings, since they require no additional wiring and communicate wirelessly with a compatible wall switch that contains a switching relay. Low voltage systems generally receive power from a relay panel or from a power pack which may contain the relay switching device. Communication and power is provided through low voltage wiring for analog systems or through Cat5 cables for digital systems. See Figure 16.16

16.3.4.4 Coverage Patterns

Manufacturers generally provide coverage patterns that can be used to select and layout occupancy sensors within a space. Unfortunately, no standard test method exists to directly compare the coverage and performance of sensors from different manufacturers, although NEMA has published a voluntary testing method for reporting coverage area [20]. Examples of different sensor coverage patterns is provided in Figure 16.17. Most manufacturers will assist customers by recommending space layouts. In large spaces, it may be necessary to link together multiple sensors to cover an area.

16.3.4.5 Energy Savings Potential

Occupancy sensors are best applied in spaces where lighting may remain on when occupants vacate the space, such as shared spaces that are occupied for short periods of time. Examples include conference rooms, lavatories, storage areas, lunch rooms, and university classrooms. Occupancy sensors can also provide savings in private and open office areas. Research has shown that an occupancy sensor can provide average energy savings on the order of 25% in private offices, 40% in shared spaces that receive intermittent use (hallways, rest rooms, stairs, etc.), and approximately 30% in shared spaces with scheduled use, such as classrooms [21] [22] [23]. The savings in a particular building or space ultimately depends upon occupants' actions when vacating a space, with savings varying as much as 20 percentage points from the values listed above. For example, a university classroom may provide significantly more savings than an elementary school classroom assigned to one teacher. In a university classroom, when the teacher and class vacate a room, they may expect another class to soon occupy the space and leave the lights on, which then wastes energy if the space remains vacant. If an elementary school teacher and janitorial staff regularly turn the lights out upon vacating a room, an occupancy sensor may provide little or no added savings.

16.3.4.6 Occupancy Sensor Adjustments

Most occupancy sensors are set at the factory to provide a basic level of performance, but these settings are fine tuned when the system is commissioned to achieve the desired performance within a space. The setting options generally include the following:

Sensitivity

The sensitivity of a sensor determines the level of movement required to trigger a positive response. False positives can be induced by air motion, or by movement outside the space, such as through an open doorway to a corridor, which may occur if a PIR sensor has a view of the door, or if the sensitivity and placement of an ultrasonic sensor allows it to detect motion in the corridor. A reduction in the sensor's sensitivity may reduce the incidence of false triggers, but may also increase the number of nuisance shutoffs due to its reduced ability to detect movement in certain parts of a space.

Time Delay

Occupancy sensors turn the lights off in a space following no detection of movement over a prescribed period of time. This time delay is generally adjustable from 30 sec to as long as 30 minutes. Most systems are set to operate from as short as 5-10 minutes to as long as 30 minutes before shutoff. Shorter settings will save energy [21] but may result in increased attempts to turn off the system while the space is still occupied. Settings shorter than about

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10 minutes are likely to result in a significant number of premature shutoff requests. Some occupancy sensors are self-calibrating and adjust the time delay setting based on the occupancy profile they experience over time.

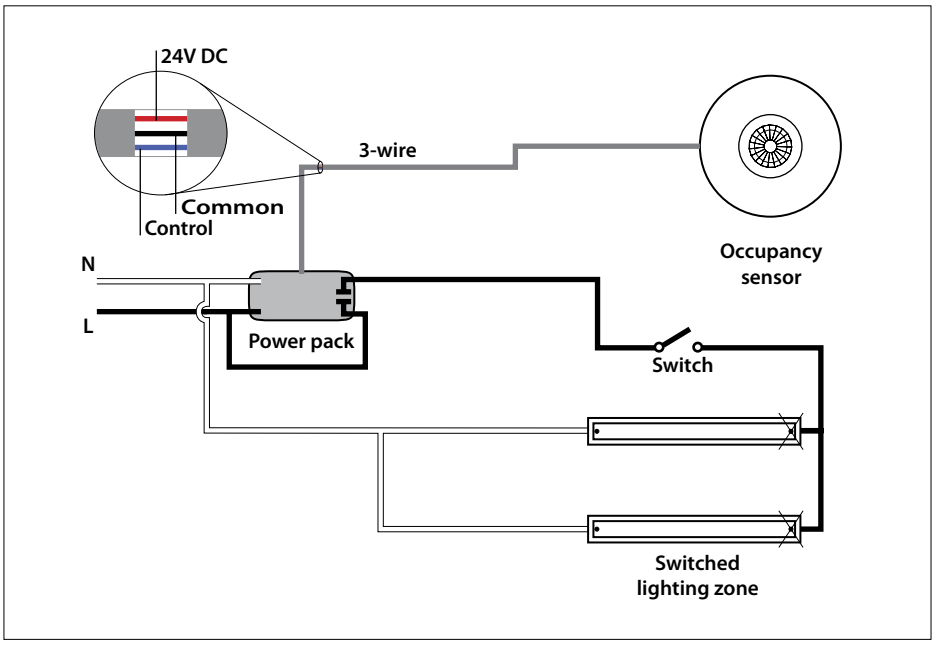


Figure 16.16 | Wiring Arrangement for a Low Voltage Occupancy Sensor
The device controls a single zone and is connected to a power pack that also serves as a relay device. The room switch is located downstream of the power pack relay.

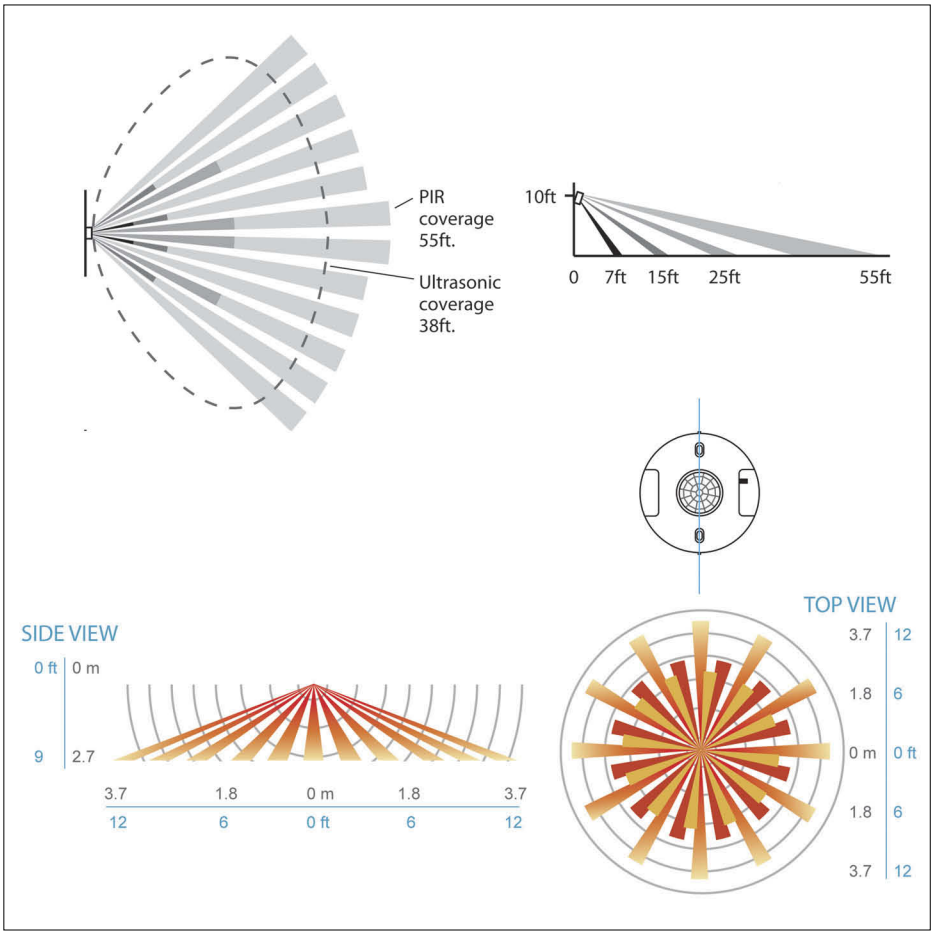


Figure 16.17 | Occupancy Sensor Coverage Patterns
Patterns are shown for wall (upper) and ceiling (lower) dual technology occupancy sensors (courtesy Watt Stopper, Inc. and Sensor Switch, Inc.) Coverage shown in these diagrams represents the maximum distance at which half-step walking motions will trigger the device.
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» Lower Images ©Sensor Switch

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16.3.5 Photosensors

Photosensors can be used to switch or dim electric lighting in response to daylight levels within a space, or to control motorized shading devices on daylight apertures by monitoring window luminance, interior daylight levels or sunlight penetration. Photosensor control of electric lighting helps to minimize energy use by applying electric lighting only when needed within areas that receive sufficient quantities of daylight. In deep spaces that incorporate sidelighting, the controlled lighting zone typically consists of the first one or two rows of luminaires.

Photosensor control systems are engineered systems. Their components must be selected to operate under given space and daylighting conditions, and must be compatible with the electric lighting equipment they control. For interior applications, the controlled lighting equipment must be zoned to correspond to the daylit area, and the photosensors must be located and calibrated to track interior daylight levels with reasonable accuracy across a variety of daylight conditions [24] [25]. Computer modeling can assist with this process. See 16.3.5.9 Photosensor System Design and Layout).

Photosensors are commonly applied in exterior environments to switch luminaires on at dusk and off at dawn. While most photosensor systems turn lighting on when daylight levels are low, in tunnels and parking garage entrances photosensors may be applied to turn luminaires on when daylight levels are high to provide an adaptation zone between high daylight exterior and darker interior areas.

Switching lighting on and off in response to a photosensor is relatively inexpensive since it can be performed with a photosensor and simple relay. Photosensor dimming of fluorescent lighting systems requires dimming ballasts in each luminaire, which leads to higher system costs. The benefits of a dimming system are that adjustments to electric lighting can be transparent to occupants, and savings can be achieved even at low daylight levels.

16.3.5.1 General Operation

Most photosensors are configured to sense light arriving at the sensor from different directions, with the directional sensitivity dictated by the photosensor's optical features. Figure 16.18 illustrates performance for a number of different products. There is no recognized optimum distribution. Wide distributions are less susceptible to localized changes in reflectance since they integrate daylight and electric light over a wide range of angles. They are more likely to be influenced by sunlight patches or bright windows within their field of view. Sensors with narrow distributions are more susceptible to localized changes in reflectance, such as a desk surface covered with white paper, but can restrict the photosensor's view to avoid receiving strong signals from a bright window or a portion of the room that experiences direct sunlight. Photosensor performance is ultimately based on how well the signal received by the photosensor tracks the daylight or total light within a space.

Microprocessors in the photosensor system contain embedded control algorithms that interpret the signal received by the photocell, then signal a relay, panelboard, or ballast to switch or dim the controlled lighting zone accordingly. In some systems, the photosensor contains this microprocessor, while in others, the photosensor signal is communicated to a separate device which processes the photosensor signal through the control algorithm.

Photosensor systems are generally classified in four ways:

1. By the type of control they provide, either switching or dimming.
2. By their intended location, for use in interior or exterior environments.
3. By the control algorithm they apply.
4. By the communication protocol they use.

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16.3.5.2 Switching versus Dimming

Photosensor-based switching is a less expensive means of automatic control that involves the use of a relay to switch luminaires within a daylit zone. This approach is common outdoors, but it is also applied indoors where daylight levels permit lighting to be switched off for long periods of time. Switching control is best applied in public spaces, such as circulation areas, where occupants are less likely to be disturbed or distracted by a sudden drop in illuminance. It is also applied as a low cost method to control the perimeter row of lighting equipment in some classrooms and offices. Figure 16.19 provides a wiring schematic for a room that contains two lighting zones; both are controlled by an occupancy sensor, with one of these also being switched by a photosensor.

Photosensor-based dimming of electric lighting is required in daylit spaces where minimal detection of changes to the electric lighting condition is desired. To provide sufficient energy savings to justify the added expense of these systems, significant dimming must occur over relatively large spans of time. Additional energy savings may be possible by providing occupants with personal control, since some occupants prefer output levels below the maximum level even when no daylight is present.

Some photosensor systems can be configured to apply stepped-level switching, where light output changes aren't as severe, but are still detectable. See Figure 16.20 for an example.

16.3.5.3 Exterior Applications

In most exterior applications, photosensor control is relatively simple. The photosensor signals one or more relays, which may be located within a lighting control panel, to turn

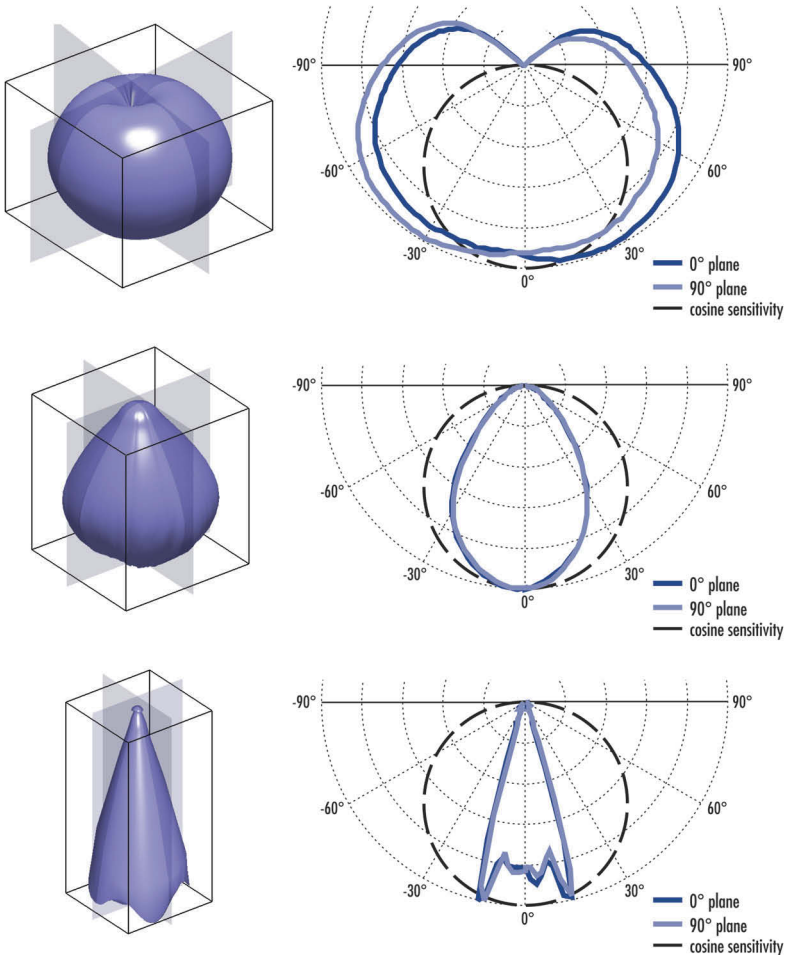


Figure 16.18 | Photosensor Spatial Sensitivity
The spatial sensitivity of three different commercially available photosensors ranging from very wide (top) to very narrow (bottom) [15].
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lighting circuits on or off based on a daylight reading. The sensor may be mounted on the building or on a luminaire. In some cases, lights that are turned on with a photosensor may be turned off with a time clock to comply with a curfew or prevent them from operating unnecessarily throughout the night. Photosensors designed for controlling exterior lighting should not be used to control interior lighting due to their limited sensitivity.

16.3.5.4 Interior Applications

In building interiors, photosensors are generally designed to switch or dim the electric lighting system using either a closed- or open-loop control algorithm as described below, or some variation of these. In sidelighting situations, photosensors are typically located on the ceiling a short distance from the window, typically 2.5-4m (8-12 ft). For skylight systems, the photosensor may be located on the ceiling to assess the amount of light within the space, or within a skylight well to monitor the amount of daylight passing through the well.

The luminaires controlled by a photosensor must provide a work plane illuminance distribution that correlates well with the area illuminated by daylight. With most dimming systems, all luminaires within a controlled lighting zone are dimmed to the same level, although some systems can dim up to three luminaire zones to different levels, based on a zone's proximity to the daylight aperture. A more advanced approach applies individual sensors to different rows of luminaires, allowing luminaires closer to a window to operate at lower output than those deep within a space. Photosensor location and spatial sensitivity must be carefully selected to avoid photosensor readings that are influenced by control actions in adjacent zones.

When located within a space, the signal from electric light should be negligible compared to the daylight signal for the system to operate in open-loop mode, perhaps not more than

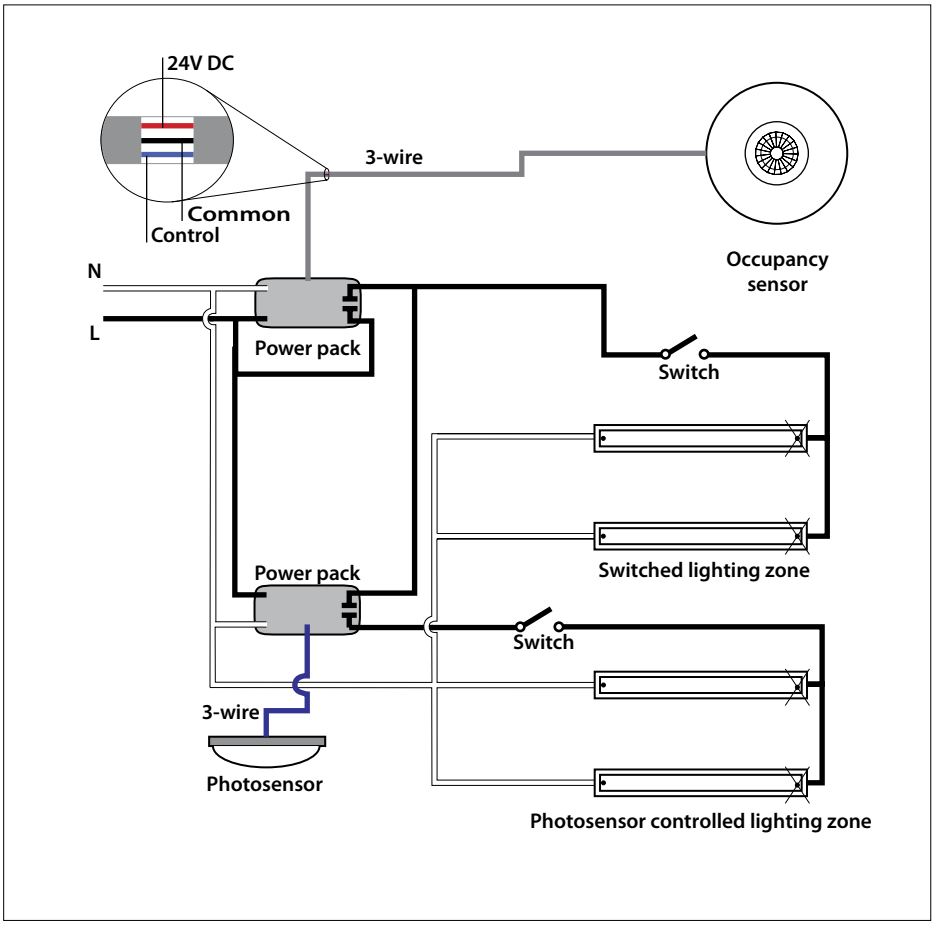


Figure 16.19 | Photosensor Switching
Schematic wiring diagram for a two-zone room with one of the two zones switched by a photosensor. Both zones are also controlled by an occupancy sensor.

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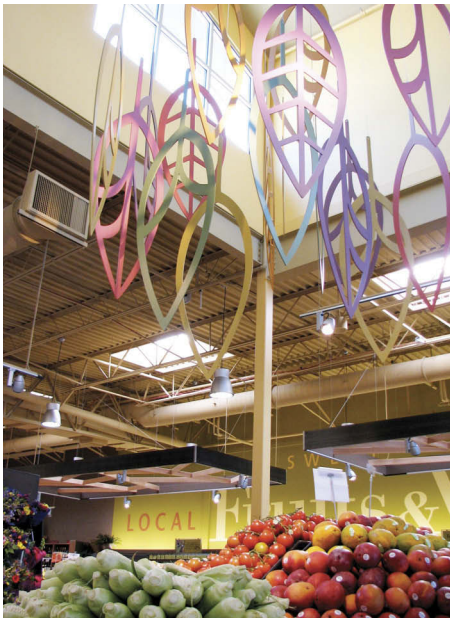


Figure 16.20. Stepped Dimming via a Photosensor
This grocery store applies stepped dimming (100-50-0%) to adjust the electric lighting in response to available daylight. Both diffusing skylights and clerestories are applied. Switching control systems typically alternate or rotate the order in which two or three zones are switched to equalize lamp operating times across the year.
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5-10% of the daylight signal required for full dimming of the electric lighting. One common application of open-loop control is skylighting, where the photosensor is mounted within the skylight well, preferably on the south side of the well facing away from the sun, or facing upward toward the glazing material [26].

Open-loop Dimming
A standard open-loop dimming control algorithm assumes a nighttime signal of zero and adjusts electric light output in proportion to the daylight signal received. The slope of this function is set at system calibration. Often this is referred to as the "gain" of the system (See Figure 16.21).

Calibration of an open-loop sensor consists of establishing the relationship between the photosensor reading and the daylight delivered to a critical location on the task plane at a representative daylight condition (that which is present at calibration time). The calibration setting determines the linear relationship between the photosensor signal and desired dimming level that is applied under all other daylight conditions.

Most open-loop systems control a single zone of lighting equipment, however products are available that control up to three zones at different dimming levels using a single photosensor. The first, second, and third row of luminaires along the perimeter of a space can therefore operate at different output levels to account for reduced daylight levels deep within a space.

Open-loop Switching
Open-loop switching is designed to turn the electric lighting system on when the daylight condition fails to meet the target illuminance at one or more task locations within the controlled lighting zone, and off when daylight levels meet the desired target. Any contribution from interior lighting that is not controlled by the system should also be considered. With switching control, the signals at which the on and off actions occur must be input to the control algorithm at system calibration. A deadband is generally applied between these two signals to avoid fluctuations between the two control conditions (see Figure 16.22). Most switching systems also apply an adjustable time-delay setting, which is the period of time over which the sensor must continuously register a shutoff reading before this action may occur.

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16.3.5.6 Closed-loop Control

In closed-loop control, the photosensor is located within a space and its signal is influenced by both daylight and electric light. The ratio of the photosensor signal to work plane illuminance (S/E) at the critical task location for both daylight and electric light is a key determinant of system performance.

For closed-loop control to operate properly, the S/E ratio for daylight must be greater than or equal to that for electric light. This ratio is a function of the following:

- The spatial distribution of the photosensor
- The location of the photosensor with respect to the daylight apertures and the electric lighting system
- The spectral response of the photosensor

The spatial distribution of the photosensor determines the range of angles from which it receives light, and how sensitive it is to light from each direction. A wide distribution is more likely to receive direct light from a window when located on the ceiling, which will produce a higher daylight S/E ratio. If a photosensor receives significant direct light from luminaires, which can occur if mounted too close to indirect lighting, the electric light S/E ratio will be

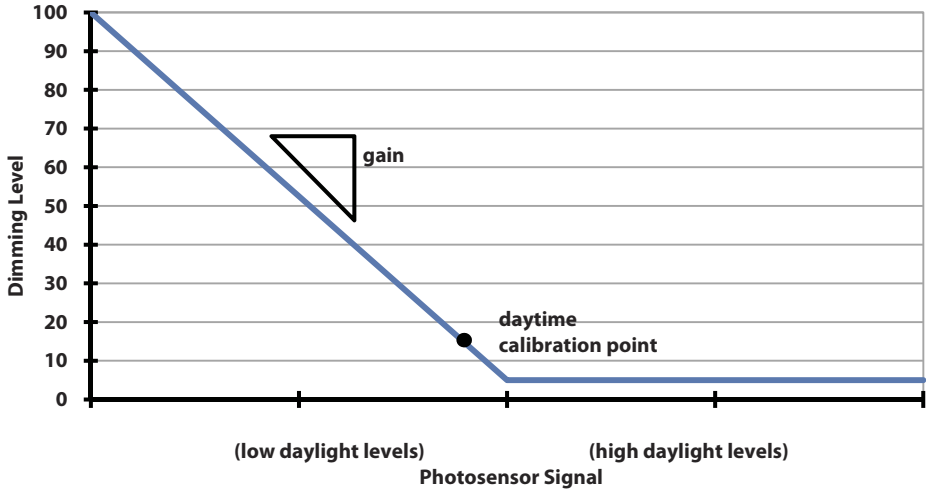


Figure 16.21 | Open-loop Dimming Control Algorithm.
A single daytime condition is used to determine the system gain, with a daylight signal of zero corresponding to full output of the controlled lighting zone.

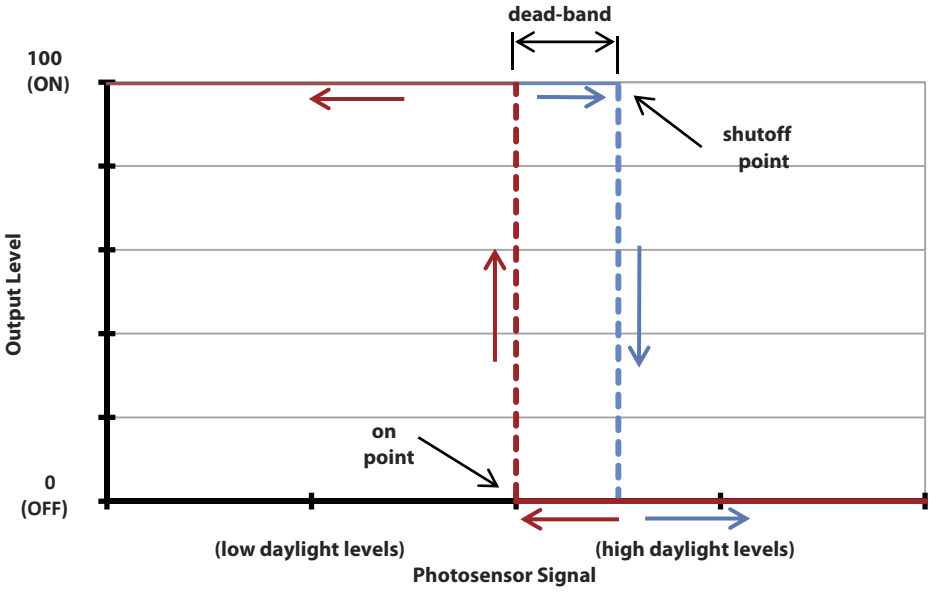


Figure 16.22 | Open-loop Switching Control Algorithm
The algorithm turns the system off and on at specified signals that are separated by a dead band. The on signal is configured to be just below the target illuminance level. Arrows in this diagram indicate control operation as rising and falling daylight levels are recorded through the photosensor signal.

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high. The photosensor's spectral response function may also affect the S/E ratios, particularly when it is not closely aligned with the photopic sensitivity curve, V(λ) [27].

There are two different types of closed-loop dimming control: constant setpoint, which is also referred to as integral reset control, and linear proportional control, which is sometimes referred to as sliding setpoint control [24].

Constant Setpoint Control

Constant setpoint control is a relatively simple control approach where the control system attempts to maintain a constant photosensor signal by adjusting electric light output (Figure 16.23). This is what would be required in a control algorithm for a photosensor located at the task plane. When located on the ceiling, this approach is valid when the photosensor signal to critical work plane point illuminance (S/E ratio) is the same for both electric light and daylight, allowing an equal trade-off between daylight and electric light at both the photosensor and the work plane. This requires the photosensor to receive minimal input from the window or other bright surfaces, such as the floor adjacent to a window. If the S/E ratios are identical, this algorithm permits the system to be self-calibrating by configuring the system using the electric lighting system nighttime signal, which also permits automatic and periodic recalibration to account for changes in room surface reflectances or furnishings over time.

If the photosensor signal to work plane illuminance ratio is higher for daylight than for electric light, which is common in most sidelighting applications, an integral reset control system will dim the electric lighting too low when daylight is present if it has been calibrated to the nighttime electric light signal. To provide reasonable control in these situations, the system's setpoint can be increased, which will cause the electric lighting to dim only after a predetermined daylight contribution is received. The presence of different S/E ratios is likely to result in incorrect self-calibrations, unless the setpoint can be adjusted upward from the nighttime signal during the calibration process and in any recalibration.

Because daylight often produces a higher S/E value than received from the electric lighting system, following calibration the performance should be checked at one or more daylight conditions that require partial dimming to verify that appropriate dimming levels are being applied. This verification should be included as part of the commissioning process.

Proportional Control

Proportional control is a more flexible control algorithm that accommodates the different S/E ratios for daylight and electric light that are likely to occur with sidelighting systems. With proportional control, electric lighting is dimmed as the photosensor signal increases, with the exact relationship established at system calibration. A proportional control dimming algorithm generally requires two input conditions from which to construct a linear

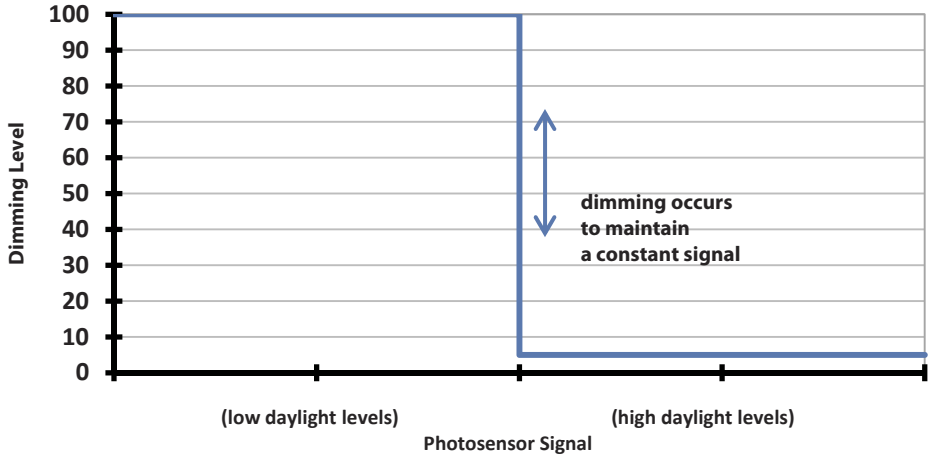


Figure 16.23 | Closed-loop Constant Setpoint Control Algorithm
This algorithm varies the output from the controlled lighting zone to maintain a constant photosensor signal. Once daylight exceeds the level provided by the electric lighting system, the electric lighting system is at its minimum dimming level.

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relationship between the photosensor signal and the preferred dimming level (Figure 16.24). The first of these points is the signal received from the electric lighting system at night. Some systems automatically record the electric light signal during the calibration process by taking a reading with the electric lights both on and off. The second condition for determining the slope of the dimming curve considers a representative daylight condition. At this condition, the controlled lighting zone's dimming level is set to provide the desired daytime target illuminance at the critical task point (See the daytime calibration point in Figure 16.24). This daylight condition must result in a dimming condition above the minimum, but preferably close to it. If too much daylight is present, it may be necessary to adjust shading devices to lower the daylight level to a setting that requires a dimming level above the minimum. With proportional control, it is also possible to tune the nighttime condition to a target illuminance that will provide for lumen maintenance, which will save additional energy when a system is new and clean (See 16.2.8 Lumen Maintenance).

In selecting a daylight condition to use for calibration, it is best to select one that provides a strong daylight contribution to the photosensor and requires significant dimming of the controlled electric lighting zone. A strong signal may be achieved when the ground viewed by the photosensor through the window receives direct sunlight, or when horizontal blinds are angled to maximize the photosensor's signal relative to the work plane illuminance. Calibration at a high S/E ratio will cause the system to deliver more light than needed at daylight conditions when lower S/E ratios are present. Calibrating a closed-loop control system under a daylight condition with a low S/E ratio, such as under an overcast sky, should be avoided, since this will result in overdimming of the electric lighting system under daylight conditions with higher S/E ratios, and could draw complaints from occupants. Generally, a photosensor should not be calibrated with direct sunlight entering a space, unless the system is expected to operate under these conditions.

Calibration of both open-loop and closed-loop photosensors should be conducted after the space is furnished to account for the effect of furniture and shading devices on both the photosensor signal and the work plane illuminance.

Switching Control

Closed-loop switching is very similar to open-loop switching except that a drop in the photosensor signal occurs when the electric light is turned off (See Figure 16.25). The difference between the signal at which the electric light is turned on and the signal at which the electric light is turned off, the deadband, must account for both the electric light signal from the controlled lighting zone and an additional amount to prevent oscillation of the lighting system on/off condition. A time-delay setting is also generally provided.

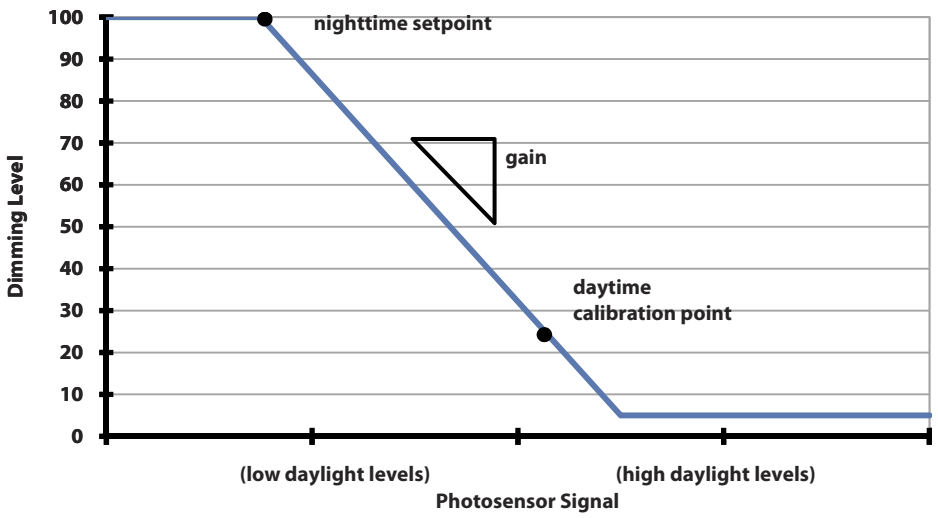


Figure 16.24 | Closed-loop Proportional Control Algorithm
A nighttime setting and a daytime calibration point are used to create a relationship between the photosensor signal and dimming level for the controlled lighting zone. A daylight condition that produces a relatively high photosensor signal and requires light output near the minimum dimming level is preferred.

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16.3.5.7 Dual-loop Control

Photosensor control algorithms that employ both a closed-loop (downward oriented) and open-loop (upward oriented) photosensor have been developed for skylighting [28]. This dual sensor approach recalibrates the closed-loop sensor each night under full electric lighting to account for changes in objects and surface reflectances beneath the sensors. During the daytime, it assesses readings from both sensors, then responds accordingly.

16.3.5.8 Photosensor Placement

Open-loop sensors are typically placed outdoors, or at the daylight aperture, such as at a window (facing outward) or within a skylight well. The location must provide a photosensor signal that is correlated to the amount of daylight entering a space. With open-loop control, the signal contribution from electric light must be eliminated or be very low relative to the daylight signal it receives.

In sidelighting situations, closed-loop control is typically applied with photosensors located on the ceiling. In private offices, research has shown that a sensor facing the wall opposite the window can also provide effective control [29]. Closed-loop sensors generally are located a short distance into the room (2.5- 4m or 8-12 ft), with a mounting position that minimizes direct light from both the electric lighting system and the daylight apertures, while still maintaining a relatively strong daylight signal. When ceiling mounting is applied with pendant luminaires and uplight, the photosensor is best placed midway between rows with a directional sensitivity that limits the signal it receives from the luminaires. Photosensors may also be integrated into pendant luminaires facing downward with either integral reset or sliding setpoint control. One drawback of this approach is that it places the photosensor closer to the work plane which limits the area being viewed, making the system more susceptible to localized changes in reflectance.

16.3.5.9 Photosensor System Design and Layout

In designing a photosensor control system, the designer must decide on the type of control that is appropriate for a space, considering both the method of daylight delivery and the electric lighting system being controlled. Key decisions involve the selection of dimming versus switching, and whether an open- or closed-loop system is more appropriate for the daylighting system and space. Table 16.3 contains a list of photosensor control system characteristics to consider when selecting hardware. This assessment, plus the anticipated system costs, will lead to one or more preliminary system selections, for which the designer must then investigate equipment options, system layout, and, where possible, performance.

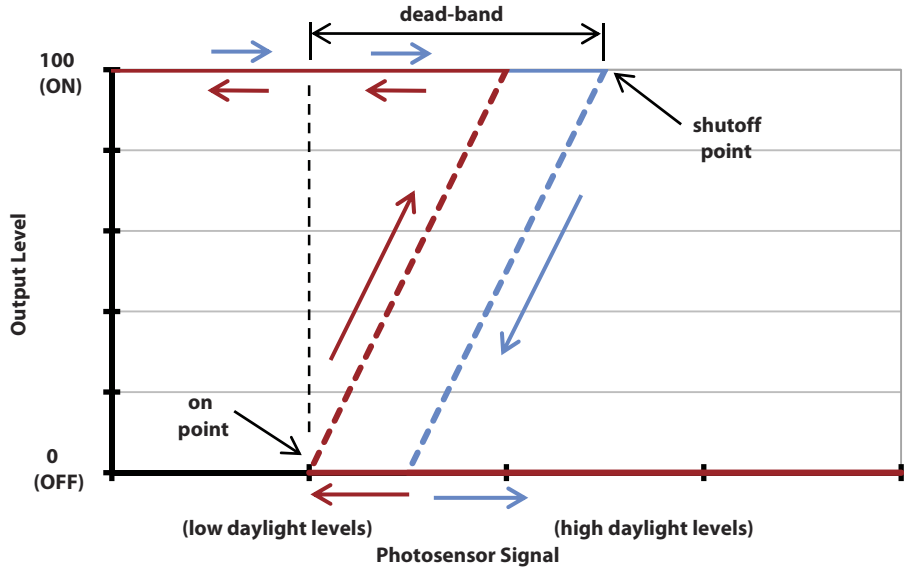


Figure 16.25 | Closed-loop Switching Control Algorithm
The difference drop or rise in signal when the lighting system is turned on and off represents the controlled lighting zone signal. The deadband must be greater than this signal to prevent oscillation of the lighting control zone operating condition. The blue line is the signal path for increasing daylight levels, while the red path is the signal path as daylight levels are decreasing.

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With photosensor control, the controlled lighting zone must provide a work plane illuminance distribution that correlates well with the daylight coverage area. If the electric lighting system to be dimmed or switched extends beyond the daylight zone, energy savings will be limited, or a portion of the space will be underlit. Lighting analysis software can be applied to assist in the layout of the controlled lighting zone as shown in Figure 16.26.

16.3.5.10 The Critical Task Location

In calibrating a photosensor control system, system performance is aligned with work plane illuminance at one or more points. The system should be calibrated to a task location that requires the most light from the controlled lighting zone. If the target illuminance is met at this point, then all other work plane points within the daylit area should also meet their target illuminance. Usually this critical task point is located near the interior boundary of the controlled lighting zone, most likely to one side of the space, near a wall where daylight levels are lower. Figure 16.27 illustrates how the location of this point can be determined for a large open space that contains both a dimmed and non-dimmed lighting zone.

When calibrating a system, this point can be located using the following steps:

1. Turn the controlled lighting zone off and determine the task location within or adjacent to the controlled lighting zone that falls farthest below the target level when only daylight and non-photosensor controlled lighting are considered.

2. Activate the photosensor-controlled zone and calibrate the control system to provide the desired illuminance at the point selected in Step 1, then determine if any other task location within or just outside the controlled lighting zone remains below the target illuminance. If so, recalibrate for the location that requires the highest light output setting.

16.3.5.11 Energy Modeling of Photosensor Control Systems

Recent software advancements permit the analysis of annual energy savings for photosensor control and offer the ability to assess and compare how well a photosensor's signal and control algorithm track daylight levels within a space [30].

Some programs estimate energy savings based on work plane illuminance, assuming the control system will operate in an ideal manner. In building energy modeling software such as eQuest (DOE2) or Energy Plus [31] [32], or in lighting software that models annual lighting energy savings, the user is often asked to input the following.

- a reference point at which the output level from the controlled lighting system will be evaluated (which should be the critical task point described above)
- the target illuminance at this point
- the controlled lighting system power

These analysis tools generally determine light output and power consumption in the dimmed zone based on the reference point illuminance. When only a portion of the electric

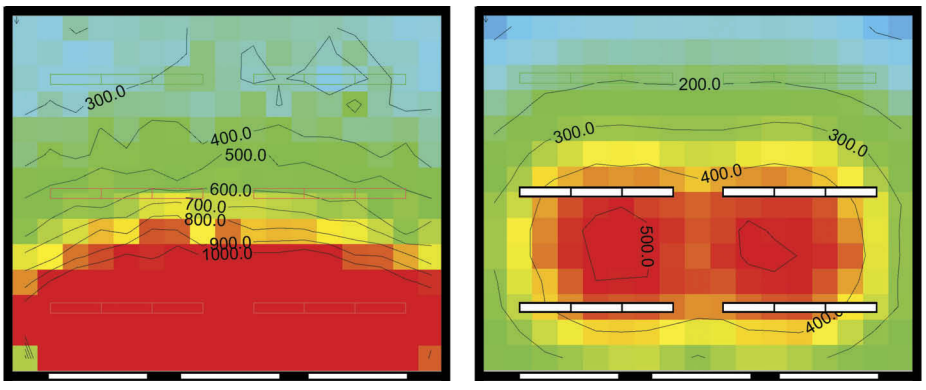


Figure 16.26 | Aligning the Controlled Zone with the Daylight Zone
The daylight distribution (left) and the electric light provided by the first two rows of luminaires provide relatively similar distributions along the edge of the controlled lighting zone and therefore are well correlated. The 400 lux contour in the left image is closely aligned with the 300 lux contour in the right image.

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Table 16.3. Photosensor Control System Feature and Options

Photosensor Features	Options/Comments
Directional Response	• Narrow – affected more by localized changes; restricts view to area beneath photosensor. Better for constant setpoint sensors. • Wide – integrates over greater area; signal is influenced by windows and sunlight patches
Color Correction	• Preferred, especially for constant setpoint control
Control Action	• Single zone switching • Multi-level switching • Single zone dimming (to minimum dimming level or off) • Multi-zone dimming
Control Algorithm	• Open-loop switching • Open-loop dimming • Closed-loop constant setpoint • Closed-loop proportional • Closed-loop switching
Calibration Process & Adjustments	• Self-calibrating – no additional devices needed • Self-calibrating with remote device • Manual with remote device • Setting adjustments require access to photosensor
Signal Response Range	• Generally listed in lux, but will vary with source direction for most sensors
Control Protocol	• 0-10 V dimming • 2-wire dimming • 3-wire dimming • DALI
Mounting	• Suspended ceiling • Drywall • Integral to luminaires
Power Supply	• Power pack • Dimming panel • Ballast • Battery • DALI loop

light received at this point is controlled by the photosensor, the target illuminance entered should be the daylight illuminance required to achieve minimum lighting power (the minimum dimming level). For example, in Figure 16.27, if 500 lux is desired and 200 lux is provided at the critical target point by an interior lighting zone with 300 lux provided by the controlled lighting zone, the analysis of the energy saved by a photosensor control system should be based on a 300 lux daylight target value at this analysis point.

In conducting either an energy study or a signal correlation study, it is important to consider the impact of operable shading devices at the daylight aperture, since the admission of direct sunlight into a space presents an extreme daylight condition that will likely result in discomfort and poor photosensor performance when bright sunlight patches fall within

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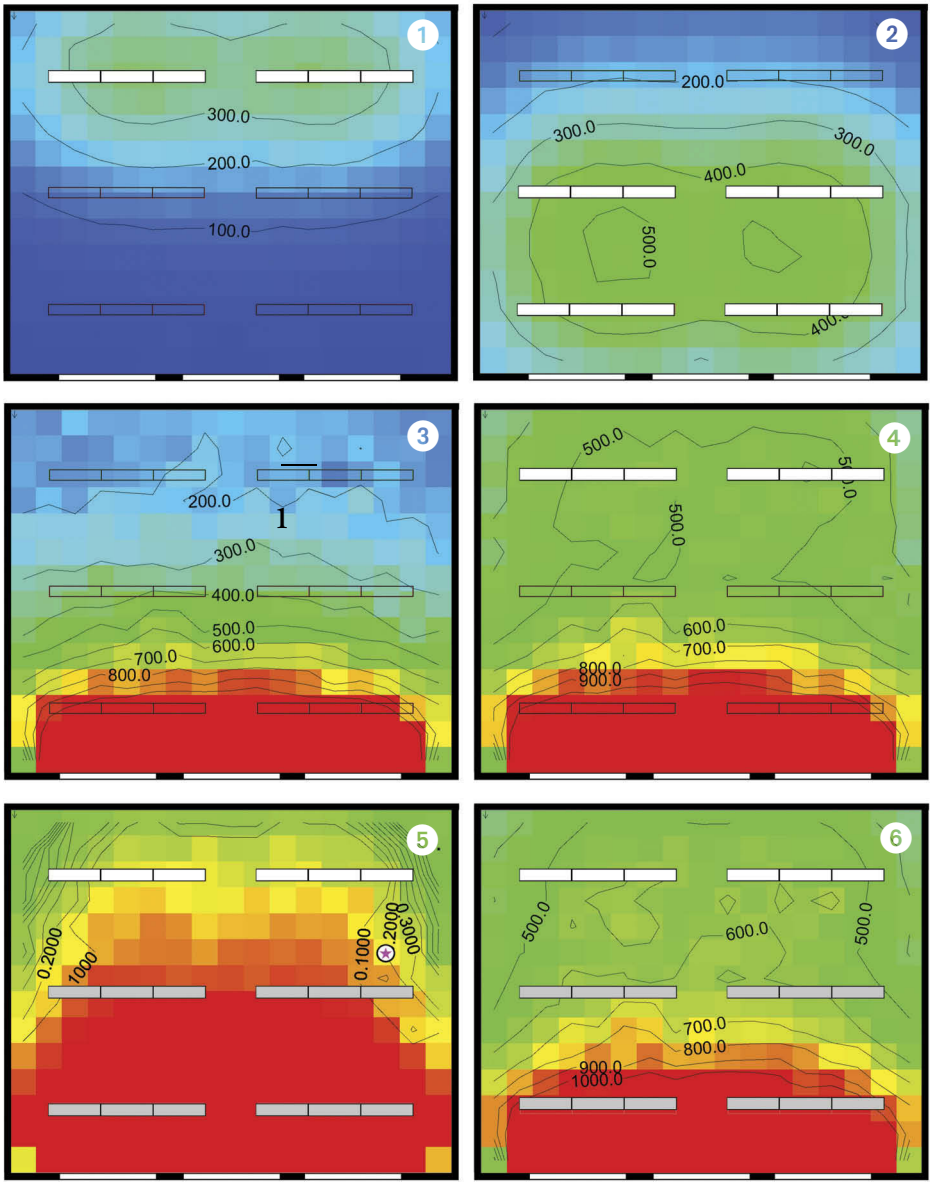


Figure 16.27 | Establishing a Critical Task Location
These images illustrate the source contributions and process for calibration of a photosensor-controlled daylight dimming system in a room with sidelighting provided by three windows. Illuminance contours are in lux (❶-❹, and ❻). ❹ shows that illuminance values are below the desired value of 500 lux on the sides of the room beyond the second row of luminaires. Line contours in ❺ indicate the dimming level required from the dimmed zone to meet 500 lux at each work plane point across the space. The critical task point has been placed at the star in ❺. ❻ shows system performance following calibration to the critical task point with the dimmed zone operating at 22% of full output.

the photosensor's field of view. If occupants are likely to apply shades or blinds under these conditions, the analysis should consider the same.

For a photosensor control system to operate properly, the signal received by the photosensor must be highly correlated to the daylight levels within a space. Some software tools provide feedback on this correlation by providing a plot of the photosensor signal versus dimming level (or daylight contribution) under a range of sky conditions. High correlations are not guaranteed when photosensors are located on the ceiling, since the illuminance being controlled is at the work plane. The sample correlation graphs shown in Figure 16.28 illustrate the nature of these variations – the tighter the fit, the better the control system will perform when properly calibrated. If S/E is identical for both electric light and daylight (the assumption under constant setpoint control), the slope of this graph will be vertical.

16.3.5.12 Commissioning

The commissioning process for a photosensor-based dimming control system typically involves calibrating the control algorithm under a representative daylight condition. Depending on the control algorithm applied, it may also require a nighttime signal. Most photo-

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sensor systems are now calibrated using a wireless handheld device. An illuminance meter is also necessary for calibration, and in some cases this meter is included in the remote device. For dimming control, daytime calibration involves placing an illuminance meter at the critical task location, then the dimmed zone output is adjusted to produce the desired illuminance at this point. Other task locations should then be checked to determine if they require a higher setting from the controlled lighting zone.

The daylight condition used for calibration should meet the following conditions:

1. The daylight condition should provide a dimmed zone setting slightly above the minimum dimming level. It may be necessary to adjust blinds or shades on the windows to achieve an appropriate daylight level.

2. The daylight condition selected should provide a relatively high S/E ratio. If horizontal blinds are applied, they should be angled to provide a high photosensor signal (which may be based on the ceiling illuminance at the photosensor) in relation to the critical point illuminances. Calibration under overcast sky conditions should be avoided with sidelighting applications since these usually provide low S/E ratios that result in underlit environments under other sky conditions.

The calibration process and means of adjustment are important product characteristics that should allow for fast and simple system calibration. Some products are self-calibrating, others are calibrated remotely using a wireless device, while some require direct access to the photosensor to manually set switches or dials. When calibration can only be performed through direct adjustment to switches or dials on the photosensor, calibration is complicated by the fact that an individual alters the photosensor signal when making these adjustments. The appropriateness of a setting can only be evaluated once the area beneath a photosensor is vacated (including removal of the ladder). Self-calibrating photosensors provide control algorithm settings based on assumptions that may not be present in all installations; performance must therefore be verified following system self-calibration. The ability to manually recalibrate (override) these systems is often provided for the case where self-calibration does not produce an adequate control setting.

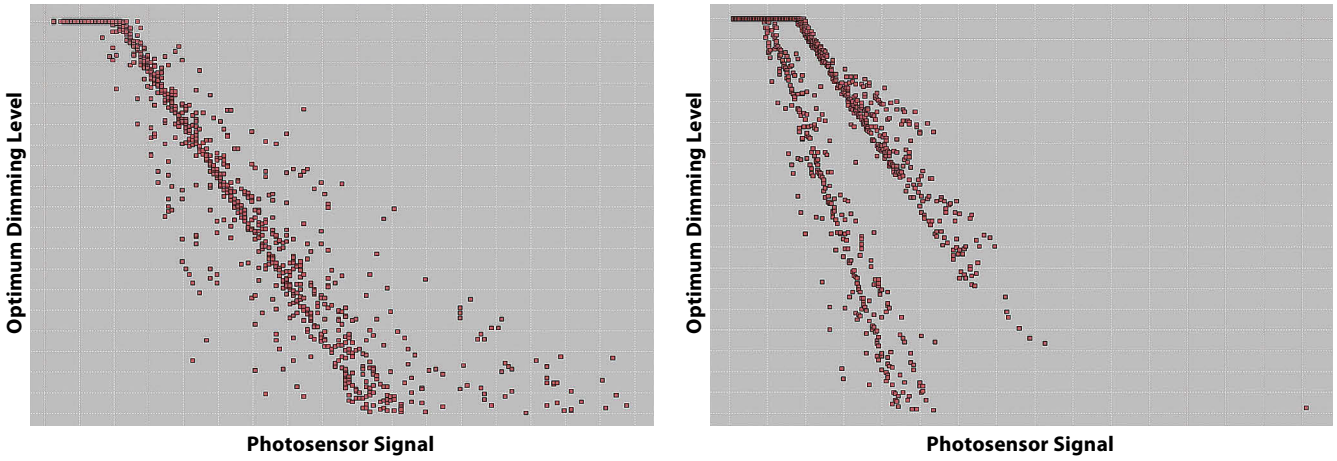


Figure 16.28 | Photosensor Signal Correlation Graphs
The relationship between photosensor signal and optimum dimming levels can be used to assess photosensor system performance across a range of daylight conditions. A tight linear collection of points is desired. The right graph illustrates significant diff erences in the photosensor signal when shades are applied compared to an unshaded window. This arrangement will result in either overdimming or underdimming, depending on the condition used for calibrating the system. To avoid overdimming (providing too little electric light), the system should be calibrated to the points with the higher signal. A better solution is one where all daylight conditions are more closely aligned. Different photosensor positions and directional sensitivities may provide a more linear dimming level-to-signal response pattern.

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In the case of a photosensor switching system, the user may need to enter switch point settings, which can then be tested by closing blinds to reduce the daylight level (with a short time delay setting applied for testing purposes).

16.4 Integration with Emergency Lighting

Emergency lighting systems (See Chapter 44| EMERGENCY, SAFETY, AND SECURITY) must operate when normal power is interrupted [33]. In many spaces, a small number of luminaires that regularly illuminate the space also serve as emergency luminaires and are powered through a separate normal/emergency panelboard. This panelboard receives power through the utility connection for general operation, but in the case of a power outage is converted to the emergency power system through an automatic transfer switch. Emergency power is provided by a generator or alternate power source. In the simplest arrangement, these luminaires are placed on 24-hour operation, which can lead to energy waste. In many spaces, it is preferred to control this equipment through local switches, dimmers, occupancy sensors and photosensors. Special hardware is required to ensure that local control devices are overridden in the case of an emergency.

With standard switches, dimmers, occupancy sensors and photosensor switching, the emergency circuit can be controlled via a separate device that is UL 924-listed for automatic load control [34]. These components operate to shunt a control device that is applied to normal/emergency lighting equipment, or switch between a normal power wire that has passed through a control device and a separate unswitched emergency line that powers emergency equipment when required. See Figures 16.29 and 16.30 for examples.

16.5 Control Protocols

A number of different communication protocols are applied in lighting control products. These include both analog and digital formats to communicate the desired output level to dimming ballasts from wall stations, photosensors, or other control equipment. Most analog approaches simply deliver a signal that communicates the desired dimming function. Digital protocols include additional features and the opportunity for two-way communication. With two-way communication, information on power consumption, operating status, and control settings can be returned to a master control device. Standard protocols permit products from different manufacturers to be interchangeable and compatible. A few proprietary protocols also exist. These were developed by manufacturers for use within their product lines and limit the ability to apply equipment from another manufacturer.

This section covers the most common control system communication protocols. It is important to understand that both the control device (which may be a wall switch, photosensor, or other device) and the ballast or other equipment must operate under the same protocol to be compatible.

16.5.1 0-10 V Control

The most common control protocol for fluorescent dimming ballasts up to now is based on an analog 0-10 V signal supplied to the ballasts through a pair of control wires that connect to each ballast, and are separate from the standard phase, neutral and ground wire. This approach is also used for LED systems that are not controlled digitally. If the control wires are run outside the electrical conduit, they can be Class 2 wiring and routed with communication wires. The magnitude of the voltage on these control wires determines the output level at which the ballast will operate the lamps. While this protocol has been widely adopted, there is no official standard to which these systems must adhere within the architectural

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lighting industry. This results in differences in output across manufacturers for ballasts receiving the same signal voltage, as shown in Figure 16.31. Note that all three ballasts in this figure begin to dim only after the voltage has dropped below approximately 8 volts.

16.5.2 Two-wire Control

This approach involves either pulse width modulation (PWM), which utilizes a high frequency squarewave to dim lamps down to approximately 5-10% of maximum output, or phase control that removes a portion of the voltage sine wave. Phase control eliminates the voltage from its zero crossing point up to approximately the midpoint of the waveform, depending on the dimming level desired. Two-wire systems utilize only a dimmed hot and a neutral wire, which is convenient for retrofit situations since it can utilize existing wiring. In most systems, a ground wire is also provided.

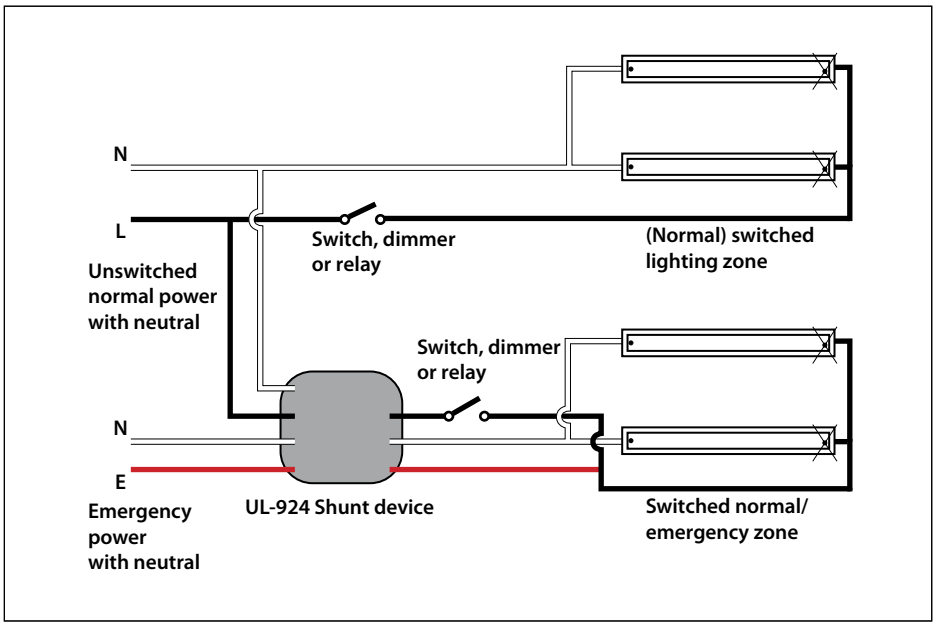


Figure 16.29 | A UL-924 Listed Device Shunts Power Around a Switch
A dimmer or relay controls only the normal/emergency circuit in this arrangement.

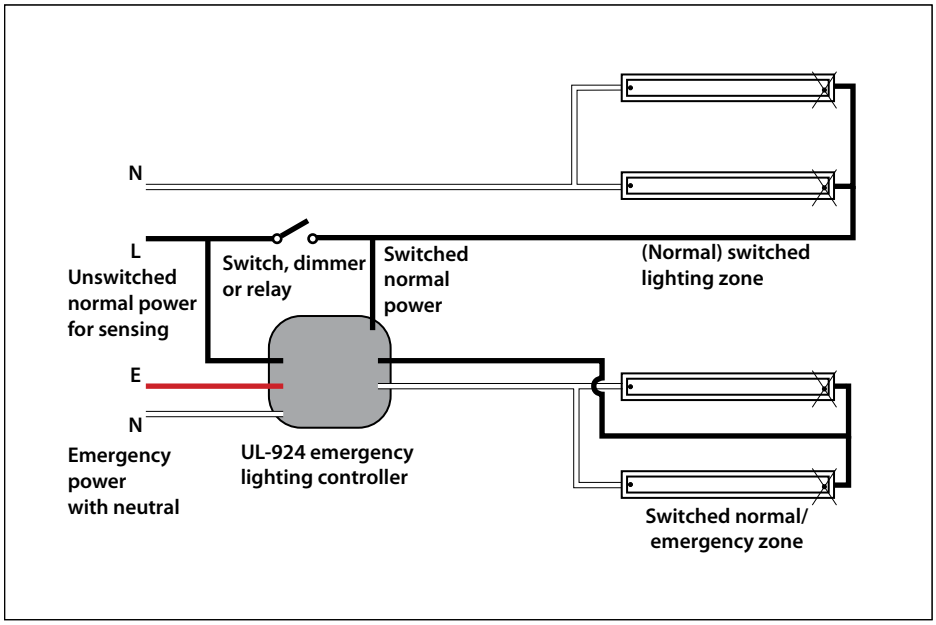


Figure 16.30 | A UL-924 Listed Device Controls Power to Normal/Emergency Luminaires
The device provides switched power to a normal/emergency circuit under normal operating conditions, and supplies emergency power when normal power is not available. This permits both the normal and normal/emergency luminaires to be controlled by the same device. The configuration for a two-wire dimming system is identical, while a three-wire dimming system requires a slight modification.

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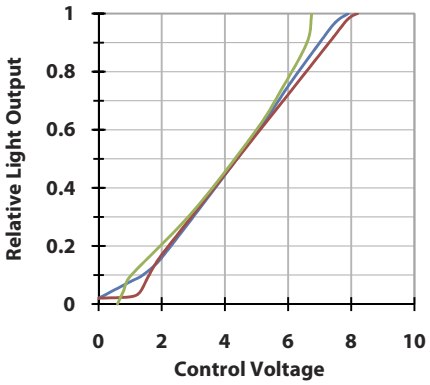


Figure 16.31 | 0-10V Dimming Curves for Three Ballasts
Output of three 0-10V fluorescent dimming ballasts at different control voltages. Dimming does not occur for each until the control voltage is below approximately 8 volts [14].

16.5.3 Three-wire Phase Control

Three-wire phase control is a proprietary three-wire system that sends a signal over a third wire which is referred to as the dimmed hot wire; with the other two wires being the standard phase wire (hot wire) and the neutral. This approach provides a wide range of control with dimming to 1% or less of full light output. Since there is minimal load on the dimmed hot wire, heat generation is minimized at the control device, allowing dimming equipment to be smaller. Dimming with this approach offers good uniformity and stability, but is generally more expensive than some of the other protocols. The need for three wires makes this approach more suitable for new construction.

16.5.4 Digital Control

The primary digital control protocol in use today is referred to as DALI (Digital Addressable Lighting Interface) [35]. With DALI, up to 64 devices (ballasts, relays, switches, zone controllers, occupancy sensors, photosensors, etc.) may be networked together on a single control bus via a pair of polarity-free control wires using a combination of daisy-chaining and branching (See Figure 16.32). These wires can be run within electrical conduit (Class 1) or as separate communication wires following Class 2 requirements. Electrical circuiting of the ballasts is independent of how they are controlled since each device (relay, ballast, switch, sensor) on the network is separately addressed to provide for individualized control. Digital control offers distributed intelligence through the microprocessor located within each device. In addition to individual control, ballasts may be assigned to one or more of 16 control groups per bus, as well as an output level in up to 16 different scenes. Control can be via individual address, group, or scene or by directive to all devices on a bus. An assortment of additional commands is also available.

Communication on a digital network is two way, with the ballasts capable of reporting lamp burnouts, and the system able to recognize faulty ballasts. Ballasts may be queried for their power level, maximum and minimum output settings, fade time, device type, and other information.

The primary benefit of digital control is the flexibility permitted in both equipment layout and configuration. Ballasts may be assigned to switches, occupancy sensors, photosensors, control groups and scenes through software or in some cases via one of the control devices without the need to rewire the equipment as space functions and layout change.

Commissioning of a building-wide DALI control system requires significant effort, since each ballast or relay must be located on the system and assigned to its respective control devices, groups and scenes using the control system's software. Control loops may be connected to a router and assigned an Internet address for centralized or schedule control. The user interface and functions provided by the digital lighting control software are important system features. For those who will operate the facility, it is essential to select a system that is easy to for facility personnel to operate, configure and understand.

Power for the DALI control circuit (the control wires) is provided by a power pack or other power source. Up to 250 mA may be provided to each control loop. In laying out a system, the current drawn by all devices placed on a single DALI loop cannot exceed the rating of the power supply for that loop.

Similar proprietary digital control protocols are also available. Some manufacturers apply digital control for communication between scene controllers, sensors, and other devices. These systems apply either Cat5 cable or twisted pair wiring.

16.5.5 BACnet

BACnet [36] is a control protocol used for building automation systems that is commonly applied on large campus networks to control equipment in multiple buildings. BACnet was developed by ASHRAE to allow communication with HVAC, lighting, fire protection,

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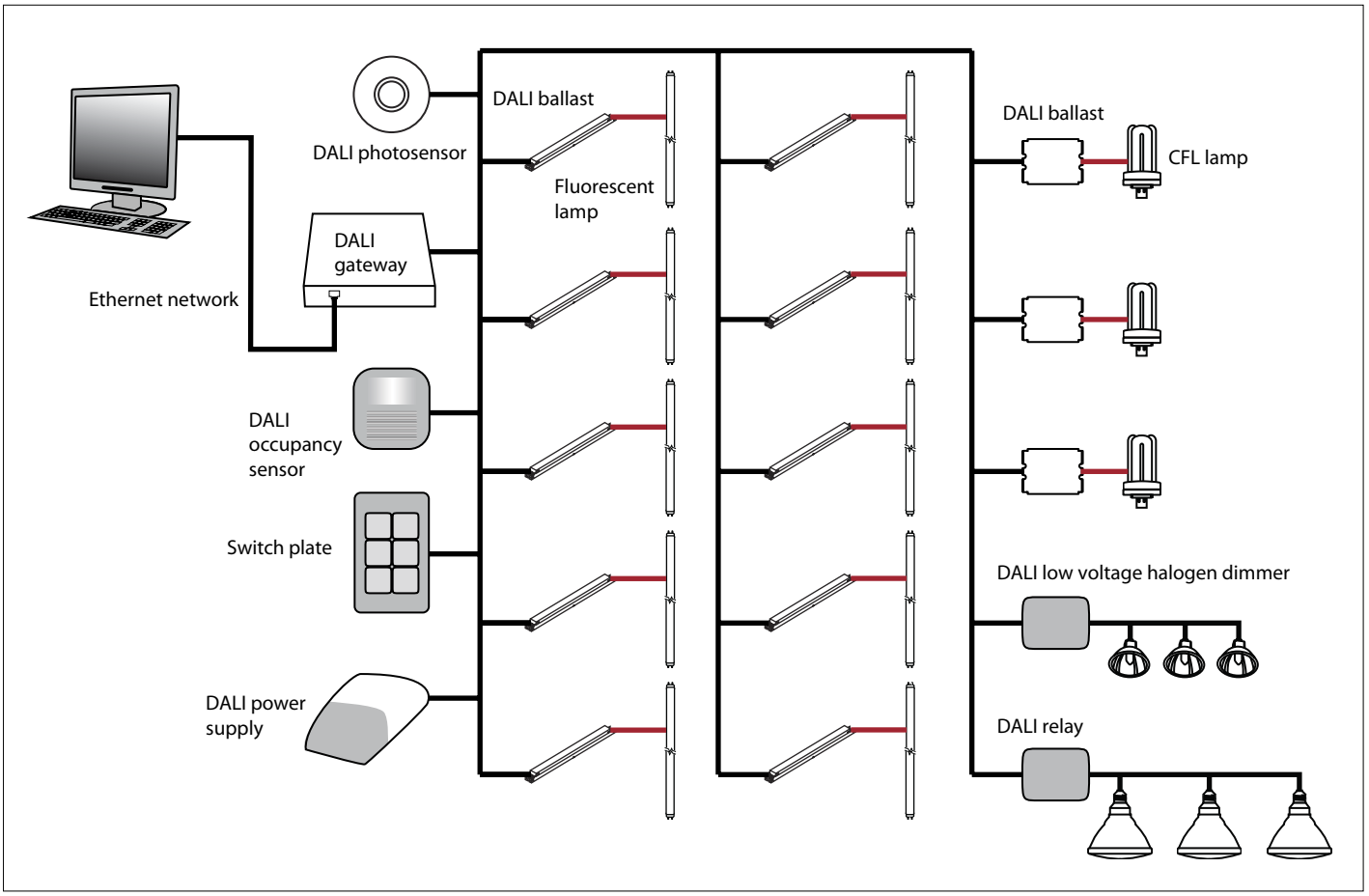


Figure 16.32 | Layout Schematic for a DALI Control System
Electric wiring is independent of lighting control.

and other building systems. Lighting panelboards and other lighting control devices from a variety of manufacturers may be linked to a BACnet system either directly or through an interface module. This module, which is often referred to as a gateway, converts BACnet commands to the control protocol used by the lighting equipment, and likewise converts data from the control system to BACnet when communicating in a reverse direction.

16.5.6 DMX512

DMX512 [37] is a control protocol that originated in the theatre industry to control stage lighting and related equipment. It is a one-way system that permits instructions to be sent from a controller to individual devices to control source output as well as motorized lighting devices. Its most common application in the architectural lighting industry is for control of RGB solid state lighting (SSL). In many installations, SSL equipment is programmed into timed sequences or shows, like in a theatrical performance. DMX operates with shielded twisted pair cable that is daisy-chained from one device to the next. A few manufacturers offer DMX control through wireless, radio frequency signals.

16.6 References

[1] Maniccia D, Rutledge B, Rea MS, Morrow W. 1999. Occupant Use of Manual Lighting Controls in Private Offices. Journal of the Illuminating Engineering Society. 28(2):42-56.

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[2] Boyce PR, Eklund NH, Simpson SN. 2000. Individual Lighting Control: Task Performance, Mood, and Illuminance. Journal of the Illuminating Engineering Society. 29(1): 131-142.

[3] Jennings JD, Rubinstein FM, DiBartolomeo D, Blanc SL. 2000. Comparison of control options in private offices in an advanced lighting controls testbed. Journal of the Illuminating Engineering Society, Summer. 39-60.

[4] Moore T, Carter DJ, Slater AI. 2002. A field study of occupant controlled lighting in Offices. Lighting Research and Technology. 34(3):191-205.

[5] Newsham GR, Veitch JA, Arsenault C, Duval C. 2004. Effect of dimming control on office worker satisfaction and performance. Proceedings of the IESNA Annual Conference (Tampa, USA). New York: IESNA

[6] Boyce PR, Veitch JA, Newsham GR, Jones CC, Heerwagen J, Myer M, Hunter CM. 2006. Lighting quality and office work: two field simulation experiments. Lighting Research and Technology. 38(3):191-223.

[7] Boyce PR, Veitch JA, Newsham GR, Jones CC, Heerwagen J, Myer M, Hunter CM. 2006. Occupant use of switching and dimming controls in offices. Lighting Research and Technology. 38(4):358-378.

[8] Galasiu AD, Newsham GR, Suvagau C, Sander DM. 2007 Energy saving lighting control systems for open-plan offices: a field study. Leukos. 4(1):7-29.

[9] Lindelöf D, Morel, N. 2006. A field investigation of the intermediate light switching by users. Energy and Buildings. 38(7):790-801.

[10] California Energy Commission. 2010. 2008 Building Energy Efficiency Standards for Residential and non-Residential Buildings. California Code of Regulations, Title 24, Part 1.

[11] ANSI/ASHRAE/USGBC/IES Standard 189.1. 2009. Standard for the Design of High Performance, Green Buildings. Atlanta/Washington. ASHRAE/USCBC.

[12] NEMA. 2010. Recommended Practice—Lamp Seasoning for Fluorescent Dimming Systems, NEMA LSD 23-2010. Rosslyn, Virginia: NEMA.

[13] NEMA. 2002. Guidelines on the Application of Dimming to High-Intensity Discharge Lamps, NEMA LSD 14-2002. Rosslyn, Virginia: NEMA.

[14] Lee ES, Clear RD, Ward GJ, Fernandes LL. 2007. Commissioning and Verification Procedures for the Automated Roller Shade System at The New York Times Headquarters, New York, New York. Lawrence Berkeley National Laboratory, Berkeley, CA; [cited on 2010 May 17]. Available at http://windows.lbl.gov/comm_perf/pdf/nyt-shade-cx-procedures.pdf.

[15] Rensselaer Polytechnic Institute. 2007. Photosensors - LRC Specifier Report. Vol 11(1). RPI.

[16] Newsham GR, Mancini S. 2006. The Potential for demand responsive lighting in non-daylit offices. Leukos. 3(2):105-120.

[17] Newsham G, Birt B. 2010. Demand-responsive Lighting – A Field Study. Leukos. 6(3):203-225.

[18] Rubinstein F, Kiliccote S. 2007. Demand Responsive Lighting: A Scoping Study. Demand Response Research Center; [cited on 2010 May 17]. Available at http://drrc.lbl.gov/pubs/62226.pdf.

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[19] Lee ES, Selkowitz, SE. 2006. The New York Times Headquarters daylighting mock-up: Monitored performance of the daylighting control system, Energy and Buildings. 38(7):914-929.

[20] NEMA. 2000. Occupancy Motion Sensors, NEMA WD 7. Rosslyn, Virginia: NEMA.

[21] Maniccia D and Tweed A. 2000. Occupancy sensor simulations and energy analysis for commercial buildings. Troy NY: Lighting Research Center.

[22] Von Neida B, Maniccia D, Tweed A. 2000. An Analysis of the Energy and Cost Savings Potential of Occupancy Sensors for Commercial Lighting Systems. IESNA 2000 Annual Conference Proceedings. New York: IESNA.

[23] Lighting Research Center. 2003. Reducing Barriers to Use of High Efficiency Lighting Systems, Final Report Submitted to US DOE. p. 95-100; [cited on 2010 May 17]. Available at http://www.lrc.rpi.edu/researchAreas/reducingBarriers/pdf/year2FinalReport.pdf.

[24] Rubinstein F, Ward G, Verdeber R. 1989. Improving the Performance of Photo-Electrically Controlled Lighting Systems. J Illum Eng Soc. 18(1):70-94.

[25] Building Technologies Program, LBNL. 1997. Tips for Daylight with Windows. University of California Regents; [cited on 2010 May 17]. Available at http://windows.lbl.gov/daylighting/designguide/download.html.

[26] Heschong Mahone Group. 1998. Skylighting Guidelines. Energy Design Resources; [[cited on 2010 May 17]. Available at http://www.energydesignresources.com/Portals/0/documents/DesignGuidelines/EDR_DesignGuidelines_Skylighting.zip.

[27] Doulosa L,Tsangrassoulisb A, Topalisa FV. 2008. The role of spectral response of photosensors in daylight responsive systems. Energy and Buildings. 40(4): 588-599.

[28] Koyle B, Papamichael K. 2009. Improved Daylighting Controls through Dual Loop Sensing. Proceedings of the 2009 IES Conference, Seattle, WA. New York: IESNA.

[29] Mistrick RG, Thongthipaya J. 1997. Analysis of Daylight Photocell Placement and View in a Small Office. J Illum Eng Soc. 26(2):150-160.

[30] Architectural Energy Corporation. 2008. Sensor Placement + Optimization Software v.4.0. Arch Energy; [cited on 2010 May 17]. Available athttp://www.archenergy.com/SPOT.

[31] US DOE. Energy Plus Energy Simulation Software; [cited on 2010 May 17]. Available at http://apps1.eere.energy.gov/buildings/energyplus/.

[32] James J. Hirsch & Associates. 2010. eQuest; [cited on 2010 May 17]. Available at http://doe2.com/equest/index.html.

[33] NFPA. 2009. NFPA 101: Life Safety Code. Quincy, MA: NFPA.

[34] Underwriters Laboratories. 2006. UL 924, the Standard for Safety of Emergency Lighting and Power Equipment. Chicago: UL.

[35] IEC. 2009. IEC 62386-Digital Addressable Lighting Interface. Geneva: IEC.

[36] ASHRAE. 2008. ANSI/ASHRAE Standard 135-2008, BACnet—A Data Communication Protocol for Building Automation and Control Networks. Atlanta: ASHRAE.

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[37] ANSI. 2008. ANSI E1.11-2008: Entertainment Technology—USITT DMX512-A—Asynchronous Serial Digital Data Transmission Standard for Controlling Lighting Equipment and Accessories. Washington: ANSI.

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17 | ENERGY MANAGEMENT

Obviously, the highest type of efficiency is that which can utilize existing material to the best advatage.
Jawaharlal Nehru, India's First Prime Minister

Lighting energy management is the process of meeting lighting quality requirements as well as space, task and user needs with low energy consumption, through energy efficient lighting system design and operation. Lighting energy use in buildings is important due to the substantial energy consumed by a lighting system over its lifetime. Averaged across all commercial buildings, lighting consumes approximately 19% of total building site energy, 25% of the primary energy, and 32% of the electrical energy [1]. In recent years, power density limits and control requirements imposed by energy codes and standards have helped to significantly reduce lighting energy consumption in new buildings.

Existing lighting systems that were installed decades ago are likely to consume significantly more energy than code compliant new construction. Fortunately, lighting energy in existing buildings can be reduced through a cost effective retrofit or complete lighting system redesign that applies energy efficient lighting equipment and control technology to supply task illuminance and lighting quality that meet current IES recommendations.

In lighting design, decisions related to nearly every lighting system component can affect energy consumption, including the choices of lamp, ballast, luminaire, luminaire layout, circuiting, control devices, and system maintenance. Since installed systems operate for decades, energy efficiency must be a major lighting design consideration. This chapter outlines many of the key opportunities for enhancing the energy efficiency of new and existing lighting systems. More specific details on available technologies, system components, and design strategies can be found in other chapters of this handbook. Reference to more detailed discussions included in other chapters are provided in the margins throughout this chapter.

17.1 Basic Strategies

Fundamental lighting energy management strategies can be classified into three primary areas: daylighting, electric lighting, and lighting control systems. Control systems can address daylight or electric lighting alone, or the integration of these sources.

17.1.1 Daylighting

The incorporation of daylight into a building's design offers significant potential for minimizing a building's electric lighting energy across a variety of applications. Daylight is abundant for a large portion of the day, provides excellent spectral quality, and is desired by most building occupants. A building's architecture, electric lighting systems, and associated lighting control systems must all be properly designed and operated to achieve savings in electric lighting energy through daylighting [2].

17.1.2 Electric Lighting

Electric lighting is required when daylight fails to meet task requirements. Lighting energy can be minimized through the use of energy efficient sources, luminaires, and system layout in combination with lighting control equipment that minimizes operating time.

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IESH/10e Daylighting and Integrated Control Systems Resources

> 7.1 Daylight
> 14 | DESIGNING DAYLIGHTING
> 16.3.5 Photosensors

IESH/10e Lighting Equipment Resources

> 7 | LIGHT SOURCES: TECHNICAL CHARACTERISTICS
> Table 13.1a Lamp Performance and Operating Characteristics: Filament and SSL
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> 8 | LUMINAIRES: FORMS AND OPTICS

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Current energy codes restrict lighting power densities (LPDs) to the point where only energy efficient equipment and systems may be applied in new designs, making solutions that "beat" these requirements with even lower LPDs challenging, but still possible. Still, energy goals should not be achieved at the expense of lighting quality. A low energy design must meet the lighting goals and recommendations for space tasks and functions and provide a comfortable, productive, and pleasing luminous environment. In work spaces, costs associated with even small changes in worker productivity that may be compromised by poor lighting quality will far outweigh any lighting energy cost savings.

IESH/10e Control Systems Resources

> 16.2.5 Occupancy Sensing and Control

> 16.3.4 Occupancy/Vacancy Sensors

> 16.2.6 Time Control

17.1.3 Lighting Controls

Since energy is equal to the product of power and time (Energy = Power x Time), lighting energy can be minimized by reducing lighting power or by limiting its operating time. Lighting controls and proper zoning of lighting equipment can help reduce operating time or, in the case of dimming or multilevel switching systems, allow the electric lighting system to be operated at reduced power levels.

Most energy codes require automatic shutoff of lighting equipment to minimize energy waste [3] [4]. Control products that meet this requirement apply some form of occupancy or time-based control. The suitability of different lighting control systems or components must be evaluated for each space or project, considering their cost, operation, and energy savings potential. For example, occupancy sensors can save significant energy (20-40%) in private offices and shared spaces that are vacant for portions of a day, but would be inappropriate for other spaces, such as a large entrance lobby to a building. Time clocks can be applied in areas that are not suitable for occupancy control to ensure that lighting is turned off when a business is closed.

17.2 New Construction

In new construction, a high level of energy efficiency is required of lighting systems based on current energy codes. In addition, green building rating systems such as LEED [5] [6] [7] [8] [9], as well as green building construction codes [10] [11], encourage or require additional efficiency measures or targets, such as the application of daylight over most of the regularly occupied interior area.

IESH/10e Daylighting Design Resources

> 14.2.4 Schematic Design: Building Form and Siting

> 14.4 Building Orientation

> 14.5 The Building Design

17.2.1 Designing for Daylighting

A major strategy for minimizing lighting energy in new buildings is the application of daylight as the primary source for interior illumination. In new building design, daylighting influences the design through siting, space layout and daylight aperture configurations. A successful design is accomplished through a coordinated effort across the entire design team from the earliest phases of the design, addressing daylight quantity and quality, as well as total building energy consumption. The key to daylight quality lies in the architectural design, space configurations, daylight aperture placement and sizing, shading devices, and light redirecting elements. See Figure 17.1 for an example of a building that contains shading elements to protect south facing windows from direct sunlight.

IESH/10e Integrated Daylighting Control Resources

> 16.3.5 Photosensors

Daylighting requires careful design due to its dynamic nature which results from both atmospheric conditions and the ever changing position of the sun. Successful designs deliver quality daylighting while controlling solar gain, HVAC loads, and sunlight penetration that may cause glare and discomfort.

Energy savings are achieved when electric lighting is dimmed or switched off during times when interior daylight levels are sufficient to satisfy space and task needs (See Figure 17.2). This is best achieved through lighting that is controlled by photosensors in daylit areas. Lighting energy savings in daylit portions of a building can range from 30-60% of the energy required when no photosensor control is applied.

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17.2.2 Electric Lighting Equipment

When a space is occupied and electric lighting is required, energy is managed through the use of energy efficient lighting equipment, proper layout of this equipment to conform to daylight and occupancy zones, and a control system that minimizes lighting energy waste. Localized task lighting is a design approach that helps to minimize lighting energy consumption, since higher levels required of specific tasks can be applied precisely where necessary, with lower ambient levels provided away from these tasks. The ambient system must meet recommended task to background luminance ratios and provide adequate illuminance for the non-critical tasks. A somewhat non-uniform, layered approach to lighting that considers the needs of different areas and surfaces within a space can enhance space appearance while saving energy compared to a uniform, general lighting system designed to the most critical visual task, which might occur infrequently and within a defined and limited area.

To design a low energy lighting system requires energy efficient equipment. However, the lamp or lamp-ballast system with the highest luminous efficacy (lumens per watt) does not always deliver the lowest installed lighting system energy that would meet the goals of a design. A less efficient source may provide better lighting control and consume less energy over its operational life while achieving the desired system performance. In some cases, lighting quality considerations may rule out specific sources due to color, controllability, size, available source lumens, candlepower requirements, or other source properties. The preferred solution is the one that meets all space lighting requirements while minimizing lighting system watts.

Specifiers and others who purchase lighting equipment must be wary of "energy saving" labels on lamps and other components. In many cases, energy saving products consume less power than the standard equipment they are designed to replace, but often at the expense of light output. These products are best applied in retrofit situations where reductions in lumen output would still meet standards and recommendations. The application of reduced output energy saving lamps or ballasts in new design provides no benefit if it requires more

IESH/10e Luminance Ratios Resources

> 12.5.2 Luminance

> 12.5.5.1 Applications and Tasks

IESH/10e Lighting Equipment Resources

> 8.4 Luminaire Performance

> 7.3.6.5 Ballasts



Figure 17.1 | Shading of South-facing Windows
The south façade of this office building applies overhangs, vertical fins and a screen to shade windows from direct sunlight and allow diffuse daylight to enter the office and lobby spaces.
» Image ©Mike Sinclair



Figure 17.2 | A Daylit Library
Daylight provided through skylights in this library permit much of the electric lighting to be switched off. Colorful fabric baffles block the view of the bright skylight apertures, while the splayed ceiling permits daylight to be distributed over a wide floor area. Shelf orientation permits daylight penetration into stack aisleways.
» Image ©Heschong Mahone Group, Inc.

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lamps or luminaires, since this may only serve to increase system cost and provide little to no energy savings. In certain applications, energy saving lamps or ballasts may be useful for tuning light output that would otherwise exceed target levels given luminaire spacing or other layout requirements. Care should be taken to ensure that energy efficiency is delivered on a system level, which requires the use of energy efficient products, as well as energy efficient design and control strategies.

Electronic ballasts are the norm for fluorescent systems and are now available for many low and medium wattage HID lamps. They offer significant energy savings through significantly lower internal losses compared to standard magnetic ballasts.

The Ballast Efficacy Factor (BEF) rating system can be used to compare ballasts that operate a particular lamp. The BEF is equal to the ballast factor divided by the ballast input watts. The product of the BEF and the lamp lumen rating is the lamp-ballast efficacy in lumens per watt provided by a particular lamp-ballast combination. It is not appropriate to compare BEFs across different lamp types, and BEF will not directly correlate to lighting system power if the required number of luminaires changes with the ballast being applied.

When selecting luminaires, the system watts required to meet the design goals are key. To provide a more general metric for comparing across luminaires, the Target Efficacy Rating (TER) was developed by NEMA [12]. This rating system replaced the previous Luminaire Efficacy Rating (LER) system [13]. TER is equal to the luminaire lumens that reach the target area under prescribed conditions for that luminaire's application class, divided by the power input to the luminaire.

In the previous system, LER was defined as the ratio of the total emitted luminaire lumens (incorporating ballast factor and thermal effects) to the system input wattage. The LER metric did not account for the efficiency at which a luminaire delivers light to a task plane when applied in a real space. For interior luminaires, TER accounts for system performance in delivering lumens to a horizontal work plane at two different room sizes and a given set of room surface reflectances. The TER uses the average of the coefficients of utilization for these two room conditions, which vary across the 16 different interior luminaire classifications. This system, like LER, includes the impact on efficiency of each system component: fixture, lamp, and ballast. TER is a simplified energy metric for comparing the relative efficacy of alternate luminaires under standardized conditions, and therefore is of limited value since it does not address lighting quality or application specific performance measures.

For exterior lighting, the TER system considers 14 different luminaire classifications and applies either roadway coefficients of utilization (the lumens delivered to a specific target area based on mounting height) or luminaire photometric efficiency, depending on the luminaire type.

17.2.3 Lighting Controls

Energy can be saved by not operating lighting equipment that is not needed. The installed lighting system establishes the maximum lighting power that can be consumed at any point in time, while the lighting control system and occupants govern the amount of light and the length of time the system operates. Occupancy and time-based automatic lighting control systems can minimize or reduce operating time, while photosensors can dim or switch off electric lighting when daylight is available (See Figure 17.3). Variable-level, occupant-based control that applies dimming, multilevel switching, or zone-based switching can provide additional savings as some users will elect to operate a lighting system at less than full load under certain conditions.

Many of today's energy codes require automatic shutoff of lighting equipment in most spaces, either through the use of an occupancy sensor or time-based control. Occupancy sensors help to minimize lighting system operation by turning lighting equipment off when spaces

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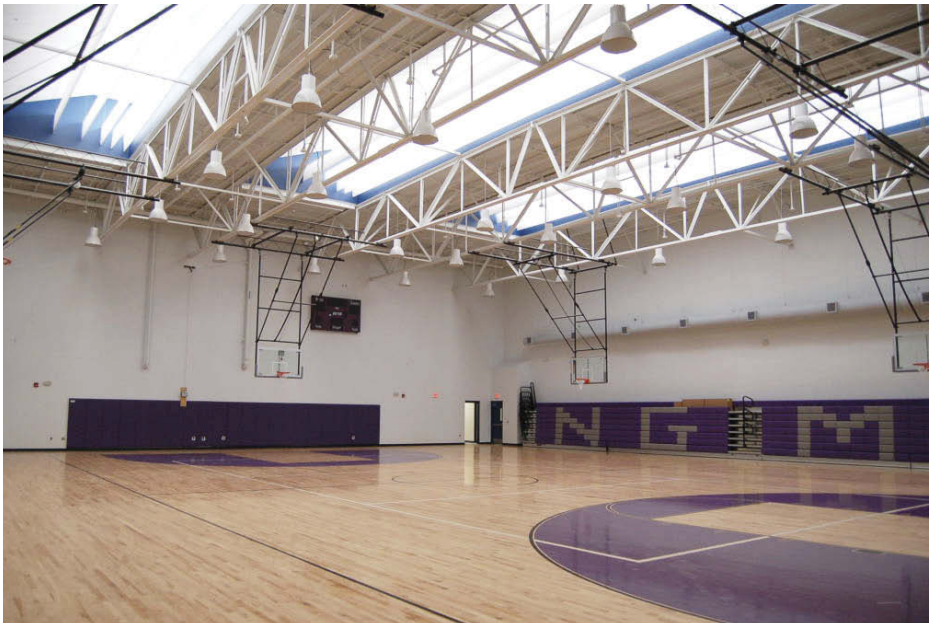


Figure 17.3 | A Daylit Gymnasium
Daylight is provided through south-facing clerestories that utilize clear glazing and fabric baffles to block direct sunlight in this gymnasium. The lighting control system has turned off the electric lighting due to the abundance of daylighting.
» Image ©Innovative Design

are vacant, while time clock control operates equipment during the time period when occupancy is expected, such as during normal business hours. The use of only time clock control in office or classroom settings will result in energy waste when spaces are unoccupied and lighting remains on. Many time-based systems conduct sweeps at preset times to turn lights off, such as at the end of the work day. A shutoff warning is generally provided to which occupants can respond with a request to override the shutoff action. In a typical application, additional sweeps at selected times throughout the evening help to de-energize lights in areas where shutoff was overridden during earlier sweeps, or where lighting may have been subsequently re-activated by janitorial staff or other individuals.

The size of lighting control zones influences energy consumption in most applications, since control zone size dictates how much power must be expended to illuminate a single work station, a circulation area, or a general task area when a large space, such as an open office area, is occupied by a single individual. Smaller zone sizes will improve energy savings. Flexibility in control can also be beneficial. Personal control of electric lighting in the form of dimming or multilevel switching has been shown to provide savings of approximately 10% [14].

For task lighting, plug load power strips with integrated occupancy sensors are available to turn off task lighting, computer monitors and other non-critical loads when a work station is vacant. These devices often contain surge protection and non-switched circuits to continuously power personal computers and other devices.

A list of available control technologies for managing lighting energy is provided in Table 17.1. Many of these technologies can be applied in new design, relighting and retrofits.

IESH/10e Lighting Controls Resources

> 16.1.3.1 Control Zones and Load Schedules
> 16.2.5 Occupancy Sensing and Control
> 16.3.4 Occupancy/Vacancy Sensors
> 16.2.6 Time Control
> 16.3.1 On/Off Switching

IESH/10e Plug Load Management Resources

> Figure 16.15 | Plug Load Controller

17.2.4 Space Design and Material Selection

Since a portion of the light arriving at any point within a space is reflected from room surfaces, the reflectance of these surfaces plays a role in the amount of light a system delivers. This is particularly important where light is directed from luminaires to room surfaces, such as with indirect or direct/indirect lighting, cove lighting, wallslot and wallwash systems. In the case of standard indirect lighting systems, light must reflect off the ceiling. Ceiling manufacturers now provide high reflectance ceiling panels that reflect as much as 90% of the incident light, compared to standard products which range between 75 and 80%.

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Table 17.1 | Lighting Control Options for Energy Management
Control options for new construction, relighting and retrofit applications.

Technology	Advantages	Limitations & Comments	Best Applications
Digital Time Switch	• Automatically turns lights off after a set time period • Replaces standard toggle switch	• Lights remain on until timer counts down even if space is unoccupied	• Storage rooms
Wall-Switch Occupancy Sensor	• Turns lights off when space is unoccupied • Replaces standard toggle switch • Bi-level occupancy sensor wall switches are also available	• Mounting position limits view across space	• Storage rooms, small private offices
Ceiling-Mounted Occupancy Sensors	• Turns lights off when a space is uoccupied • Wide coverage area • Can also be used for high/low control configuration	• Some rewiring needed unless wireless models are applied • Must comply with local fire and egress codes • Must be cablibrated/commissioned • Recalibration requires trained personnel	• Large private offices, open offices, classrooms, restrooms, gymnasiums hallways, warehouses
Photosensors	• Take advantage of natural daylight • Can be used with dimming or switching control	• Must be properly located • Must be cablibrated/commissioned • Require dimming ballasts and appropriate wiring • Recalibration requires trained personnel	• Daylight harvesting in classrooms, offices, warehouses, gymnasiums, and exterior applications
Lighting Control Panel with Integral Clock and Automatic Switch	• Provides programmable time-based circuit control • Override switch replaces toggle switch in space	• Additional space may be required in electrical closet	• Big box retail, warehouse, open offices, private offices
Remotely-Operated Circuit Breaker	• Offers time-based circuit control • Replaces manual breaker • No additional control wiring is needed	• Provides control of entire circuits only	• Big-box retail, warehouses, offices, circulation
Occupancy-Based Plug Load Control	• Controls task lighting and other workstation power loads based on occupancy • Can be easily relocated if space layout changes • Also serves as a surge protector	• Limited by number of controllable outlets • User must be instructed on use • Can be easily disabled	• Private offices, open office cubicles
Luminaire-Integrated Occupancy Sensors	• Turns luminaire off or operates luminaire at reduced output when space is unoccupied • Provides full light output upon occupancy • Requires no additional control wiring	• Must comply with local fire and egress codes	• Open office spaces, stairwells, corridors • Parking garages, parking lots, pathway lighting

Higher wall and floor reflectances also help to increase reflected light for all lighting system types. Wall reflectances are especially critical in tall or narrow spaces, where more light emitted from the luminaires and reflected from the ceiling is likely to strike the walls rather than the work plane. In tall spaces, luminaires with a concentrated downward distribution will more efficiently illuminate a horizontal plane at the floor, although attention must be paid

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to the appearance and luminance of the walls, which can appear dark under these conditions. Because the ceiling will reflect a significant amount of light to the walls, a predominantly uplight luminaire in a tall space will be relatively inefficient at delivering illuminance to the floor.

For daylighting, higher room surface reflectances, particularly on the ceiling, walls and floors adjacent to and facing a window, provide more reflected daylight to an interior space and lessen the need for electric lighting. Another important benefit of higher reflectances is that surfaces adjacent to a window will achieve a higher luminance, reducing the contrast between the window and these adjacent surfaces. This provides a more comfortable viewing condition that may reduce the tendency for occupants to apply window shading devices, and therefore deliver higher interior daylight levels that contribute to energy savings through automatic electric lighting control. See Figure 17.4.



Figure 17.4 | A Daylit Kindergarten Classroom
This classroom applies high ceiling and wall reflectances to help distribute daylight from the north-facing windows and clerestory. The white paint also reduces the contrast between the apertures and the adjacent interior surfaces. Significant energy savings is possible with a properly configured and calibrated lighting control system.
» Image ©Gelfand Partners Architects

17.2.5 Lighting System Maintenance

In the design of new systems, the owner's maintenance practices, which include relamping and luminaire cleaning, determine the light loss factors that are applied in lighting system design calculations. These in turn affect the number of lamps or luminaires required in the space. Proper maintenance can therefore help to achieve a low energy design. A lighting system that is regularly cleaned will result in less luminaire dirt depreciation and require fewer luminaires, which reduces the system's initial cost, installed lighting power, and lighting energy consumption. Similarly, group relamping can help maintain higher lamp lumen depreciation factors.

In some cases, it may be necessary to educate the owner or facility operator on the importance of good maintenance practices, and the impact these practices have on the installed lighting power and the associated initial and operating costs.

IESH/10e Light Loss Factors Resources
> 10.7 Factors Affecting Lighting Calculations

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17.3 Lighting System Upgrades

Since new lighting technology has significantly improved the energy efficiency of lighting systems in recent years, and since illuminance requirements in some spaces require less illuminance with modern tasks than was required when the older lighting systems were installed, significant reductions in lighting energy are achievable in buildings that are more than 20 years old. Modifications to a lighting system include the full range from simple component replacements (a lamp or ballast retrofit) to a complete lighting system redesign (which is often referred to as relighting). This process typically begins with an energy audit that reviews the existing systems and their energy consumption. Utility bills can confirm overall building energy use, however data from these records include a significant amount of non-lighting equipment. Pre and post upgrade energy data on feeders and branch circuits can be used to assess the actual level of lighting energy savings achieved.

IESH/10e Sources and Ballasts Resources

> 7 | LIGHT SOURCES: TECHNICAL CHARACTERISTICS

Simple retrofits may include changes to lamps, ballasts, optical materials, new luminaires, and the addition of new lighting controls. In a simple retrofit, the designer must verify the layout of the existing system provides sufficient lighting quality for the space and its tasks when fitted with the new components. Refer to the Illuminance Determination Table in the respective Handbook chapter for illuminance recommendations, and to the discussions in the general lighting design and application chapters of this Handbook (Chapter 12 | COMPONENTS OF LIGHTING DESIGN, Chapter 15 | DESIGNING ELECTRIC LIGHTING and Chapter 16 | LIGHTING CONTROLS) for additional lighting quality criteria and considerations.

If an existing system provides higher work plane illuminance than required by current standards, lighting energy savings can be achieved by lowering the illuminance. This may be accomplished through the use of lamps, ballasts, or luminaires which reduce both input power and light output, provided that lighting quality (including visual comfort, uniformity and other measures) is not adversely affected. In some cases, lamps with reduced lumen output or ballasts with low ballast factors are a simple and cost-effective solution. Some energy saving lamps, however, are incompatible with dimming equipment, which may limit the available options.

When considering a lighting system upgrade, it is helpful to rank the overall goals of a project. The general goals to consider generally will relate to one of the following.

- Energy Efficiency
- Lighting Equipment and Maintenance Costs
- Lighting Quality
- Appearance

IESH/10e Lighting System Economics Resources

> 18 | ECONOMICS

A retrofit of a poor quality existing lighting system should upgrade both its lighting quality and its energy efficiency. Therefore, it is important to study the existing system's energy performance, lighting quality, and operational costs, followed by a similar analysis for each of the retrofit options being considered. An economic analysis can determine the payback period for lighting retrofits based on the associated retrofit costs and the resulting savings in lighting energy and maintenance. Utility rebates or tax incentives may also be available to offset a portion of the costs associated with specific energy efficiency improvements.

Lighting service companies and performance contractors offer financing for many types of retrofit projects. Typical contracts require the owner to pay off the cost of the retrofit as a percentage of the energy cost savings. In this manner, retrofits can be applied with no increase in annual outlay.

Underwriters Laboratories (UL) certifies the safety of products and systems when used as directed by the manufacturer. Most luminaires have a UL certification for use with a specific type and wattage of lamp. Lighting retrofit kits that contain multiple components

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may also be UL certified. When a retrofit involves a change in lamp type, self-ballasted lamps, like a CFL or LED PAR replacement lamp, for example, may be applied as a direct replacement for a filament lamp, provided the retrofit lamp wattage does not exceed the filament lamp wattage listed on the luminaire, and provided that such use is not disallowed through markings on the lamp (such as a label indicating that a lamp is not to be used in an enclosed luminaire) [15].

Although a lamp may be permitted to be used within a particular luminaire, UL certification only indicates that an unsafe application is not likely to be created. CFL and LED sources could be subject to reduced light output and premature burnout if the lamps and other internal components are exposed to excessive heat, which may occur when they are used within recessed or enclosed luminaires. Thermal tests may be necessary to validate that operating conditions are within those recommended for a particular lamp. Consult with the luminaire manufacturer, the lamp, ballast, driver, or transformer manufacturer, and the controls manufacturer to confirm appropriateness of any planned retrofit.

In the sections that follow, a number of different retrofit options for lamps, ballasts, luminaires and lighting control systems are discussed. These are summarized in Table 17.2. For broader coverage of retrofit topics, refer to IESNA LEM-3, Guidelines for Upgrading Lighting Systems in Commercial and Institutional Spaces [16].

17.3.1 Lamps

In existing systems, a lamp retrofit may save significant energy while delivering similar or higher lighting quality. One common retrofit is the replacement of filament A lamps with an equivalent screw-based compact fluorescent or LED lamp. Federal legislation that bans certain filament lamps by 2012 will significantly increase this activity. CFLs provide light at about four times the efficacy of filament lamps, but a CFL replacement may not be appropriate due to the resulting changes in system performance. For example, an existing luminaire's optical system is designed to operate with the A lamp's size and shape. If the replacement screw-base CFL is of different size or shape, a reduction in luminaire optical efficiency results, lowering the emitted lumens and changing the luminaire's photometric distribution (where the luminaire sends light). These changes may not only affect the amount of light delivered to a task, but also the uniformity of this light, in addition to luminaire and space appearance.

IESH/10e Sources and Ballasts Resources

> 7.2 Filament Lamps

> 7.3 Fluorescent

Tests on a mockup can be performed using a single or group of luminaires within a space to assess the impacts of an alternate lamp on a luminaire's distribution by taking measurements at multiple points beneath a luminaire. In testing a single luminaire, lamps may be removed from neighboring luminaires, or measurements can be made with the test luminaire turned on and off to isolate its contribution. Comparison measurements should be conducted with new lamps of each type, so as not to bias the readings toward a retrofit lamp by testing it against an aged lamp with depreciated lumen output. When comparing an existing lamp to a retrofit lamp, it is important to also assess luminaire appearance, since differences in luminaire luminance, direct glare, and source visibility may occur at different viewing angles. If the luminaire is adjacent to a wall, the distribution pattern produced on the wall should also be evaluated. Tests of fluorescent and HID systems should allow the lamp to first be seasoned for 100 hours, and both discharge sources and LED equipment must reach thermal equilibrium within the luminaire prior to conducting any measurements, since lamp output for these sources can vary with temperature. When using CFL's in enclosed luminaires, amalgam lamps can limit temperature effects on lumen output.

When existing systems use filament lamps on a dimming system, replacement lamps must be compatible with the dimming hardware. Some CFLs are labeled as compatible with filament lamp dimming systems, however dimming equipment manufacturers should be contacted regarding the compatibility of these lamps with the dimming hardware, since the use of these lamps may void product warranties.

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In the case of filament reflector lamps, lamp retrofit options include halogen IR, self-ballasted metal halide, and LED sources. Some CFL reflector lamps are also available, but are likely to provide very wide beams that may significantly alter luminaire performance. Tests should be conducted to assess retrofit lamp performance and luminaire appearance.

A common retrofit for older linear fluorescent systems is to convert T12 lamps to T8 versions, which also requires replacement of the ballast. In most systems, the T12 lamps in use are a 34 W version powered by magnetic ballasts which have high internal losses. A conversion to T8 lamps with electronic ballasts offers significant energy savings, relatively

Table 17.2 | Energy Efficiency Retrofit and Lighting System Upgrade Options

Existing Lamps	Lamp Replacement Options
Filament - Medium Screw or Candelabra Base	• CFL with similar base and lamp shape • LED replacement lamp
Filament - Reflector	• Halogen IR reflector • Metal halide reflector with integral ballast • CFL reflector (for very few wide angle applications) • Induction reflector lamp (for very few wide angle applications) • LED PAR or MR
T12 Fluorescent T8 Fluorescent Fluorescent Lamps in Freezers	• T8 with electronic ballast • Lower wattage T8's if reduced lumen output is acceptable • LED retrofit kit
Mercury High Pressure Sodium (HPS) Standard Metal Halide (MH)	• Upgrade lamp and ballast to probe start or ceramic MH • Induction lamp retrofit
MH - Street/Area Lighting HPS - Street/Area Lighting Neon - Sign Lighting	• LED retrofit kit with proper performance
Existing Ballasts	**Ballast Replacement Options**
Fluorescent Magnetic Ballasts	• Electronic ballast with BF to deliver required task illuminance • Dimming or stepped-dim ballast with appropriate controls
MH Magnetic Ballasts	• MH electronic ballasts (limited wattages)
Existing Luminaires	**Luminaire Retrofit Options**
Filament	• Energy efficient CFL or LED luminaire with appropriate performance
Linear Fluorescent Industrial or Commercial	• Retrofit of optical components: lens, reflector, or louver • Reduce number of lamps
Any Luminaire with Low Efficiency or Degraded Performance	• Energy efficient replacement delivering suitable distribution and lighting quality
MH - Industrial	• Replace with CFL, T8 or T5 HO industrial luminaire and consider multi-level switching
Existing Controls	**Control System Upgrades**
Standard Switching or Relays	• Occupancy sensors • Multi-level controls for stepped ballasts • Dimming with wall or personal controls • Photosensors in daylit zones • Replace with digital ballasts and controls to permit rezoning and dimming

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short payback, and improved color quality. In spaces that are overlit relative to current standards, lower ballast factors may be applied or the number of lamps may be reduced (which requires rewiring of the luminaire) to deliver appropriate work plane illuminance values. If the number of lamps is reduced, this modification should not degrade luminaire appearance or distribution. With parabolic troffers, a change in lamp position will alter the lamp shielding angle and the luminaire's candlepower distribution, and both should be assessed prior to committing to such a retrofit.

17.3.2 Ballasts

IESH/10e Ballasts Resources

> 7.3.6.5 Ballasts (Fluorescent)

> 7.4.3 Ballasts (HID)

In addition to increased efficiency, conversion from fluorescent magnetic to electronic ballasts improves lighting system quality through high frequency lamp operation, improved acoustical performance, and heat reduction within the luminaire. NEMA's Premium Electronic Ballast Program identifies the most energy efficient T8 ballasts for both conventional and dimming ballasts [17].

Standard metal halide systems can be converted to pulse-start lamps and ballasts to deliver improved lighting quality and energy efficiency. These retrofit lamps offer longer lamp life and higher lumen maintenance that can decrease maintenance costs and deliver energy savings. A retrofit that applies ceramic metal halide lamps will deliver similar benefits with improved color quality.

Additional options for fluorescent and HID systems include converting to stepped ballasts to allow lamps to operate at lower output levels whenever possible. Load shedding ballasts are also available that provide reduced output levels (66% of full output) with control via a power line signal.

When analyzing potential energy savings, it is recommended that power measurements be conducted on existing circuits, since high internal luminaire temperatures generated by standard magnetic ballasts may cause fluorescent lamps to operate at less than optimum temperature conditions. This will result in ballast input power that is below catalog data. When an electronic ballast is applied in a retrofit, ballast heat is significantly reduced, and the system is likely to operate closer to the ballast manufacturer's rated input watts. The net result is that both power and energy savings may not be as great as indicated by manufacturer's catalog data.

17.3.3 Luminaires

Retrofit options for some types of luminaires include the insertion of specular or diffuse high reflectance reflectors to improve the optical efficiency of the luminaire. These reflectors may alter the photometric distribution of the luminaire. A new lens, a parabolic louver system, or a modern lens/reflector combination are options for lensed fluorescent luminaires. Retrofits involving changes to a luminaire's optical components are often combined with lamp/ballast retrofits, which may include a reduction in the number of lamps used within a luminaire. Evaluation of these retrofit options must consider how changes to the optical distribution influence both lighting quality and task illuminance, as well as room surface and luminaire appearance. Any measurements of the existing system should address that system's performance when operated with new lamps and clean luminaire surfaces.

IESH/10e Luminaires Resources

> 8 | LUMINAIRES: FORMS AND OPTICS

In some cases, the best retrofit option involves changing the entire luminaire, but retaining existing mounting locations (See Figure 17.5). This may be necessary because alternate lamping options are not available, luminaire materials have degraded over time, or because system performance is unacceptable with the existing luminaire and could be improved with a different luminaire. In still other cases, a redesign that involves a modified luminaire layout may be the best option to reduce energy and achieve the desired lighting quality for task and space conditions. Infrastructure work may be necessary to achieve proper suspension or ceiling support. Any redesign should consider alternate luminaire circuiting and control options that would deliver additional energy savings. In some situations, a complete lighting system upgrade may be nccessary to comply with existing energy codes.

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Figure 17.5 | Industrial Luminaire Retrofit Example
HID luminaires (left) were retrofit with 6-lamp fluorescent T5 luminaires (right) in this industrial application, saving close to 50% of the energy and approximately $120,000 per year. The new system provided slightly higher illuminance, improved color rendering, and higher lumen maintenance with a payback period of approximately two years.
» Images courtesy of General Electric Co.

IESH/10e Lighting Controls Resources
> 16 | LIGHTING CONTROLS
> 16.3.4 Occupancy/Vacancy Sensors
> 16.3.5 Photosensors
> 16.5 Control Protocols

17.3.4 Lighting Controls

Any retrofit should consider upgrades to the lighting controls to save additional energy. Existing controls may involve simple manual control at wall switches, or relay and time-clock devices that control large blocks of lighting at one time. In private offices, retrofit options include replacing standard wall switches with wall switch occupancy sensors. In larger spaces, occupancy sensors may be mounted to the ceiling or high on a wall. These devices are commonly linked to a power pack that contains a relay to control the lighting circuit. Wireless, battery operated occupancy sensors are also available to eliminate the need to run wiring to the sensors. Occupancy sensors have the potential to save significant energy (20-40% or more) in private offices and in a variety of shared spaces such as conference rooms, classrooms, restrooms, break areas, open office areas and others. The level of savings achieved depends on the habits of space users.

Additional control options include the application of automatic lighting control in daylit areas using either dimming ballasts or on/off control. These systems require the installation of photosensors, which are available in both wired and wireless configurations and are typically installed on the ceiling. The controlled lighting zone layout and system calibration are critical for establishing a proper lighting control response to daylight levels and for maximizing energy savings within a space. Digital control systems, such as DALI, permit the controlled lighting zone to be independent of how luminaires are circuited, which can be valuable in retrofit applications. A retrofit to a DALI control system requires ballast replacement as well as additional control wires to be connected to each ballast in the system.

When considering a retrofit that includes occupancy sensors, inexpensive data loggers make it is possible to study occupancy and lighting system operating conditions within a space over an extended period of time (days or weeks) to evaluate potential energy savings. See Figure 17.6. These loggers are mounted to the walls or ceiling and record changes in both occupancy and lighting system on/off status for later analysis. The logger software that analyzes these data provides daily occupancy and lighting system operation profiles which can be used to determine the number of hours the space is unoccupied with the lighting system in operation, and the annual energy savings likely to be achieved when occupancy sensors are installed in the space. See Figure 17.7 for an example report.

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Figure 17.6 | Examples of Loggers for Light and Occupancy Sensing
These loggers record time-stamped changes in both lighting conditions and space occupancy in existing spaces for analysis of potential energy savings through the addition of occupancy sensors.
» Left Image ©Wattstopper
» Right Image ©Sensor Switch

To realize energy savings, it is critical that control devices be properly commissioned, calibrated and maintained in a mode that optimizes energy savings. In many spaces, lighting

is required only when a space is occupied, and in the case of daylit spaces, when daylight levels are insufficient for space tasks. Time clock control should be configured to conform to space occupancy, which may change with season. Periodic follow-up checks should be conducted by the building's maintenance personnel to evaluate system performance.

The subject location was monitored from Thursday, October 25, 2007 3:50:00 PM to Wednesday, November 21, 2007 2:33:00 PM by InteliTimer Pro serial number RP0102C. Of the total elapsed time (646.72 hours), the lighting remained on with the monitored location vacant 10.18% of the time.

Based on these measurements, installing occupancy-controlled lighting controls in this location would save approximately 892.0 power-on hours per year. Assuming an energy cost of $0.08 per kWhour, and an additional 10% savings from reduced heating and cooling requirements, the potential yearly savings with a controlled load of 1,000 watts is:

Electricity saved:	$71.36
Reduced heating/cooling costs:	$7.14
Total savings:	$78.49

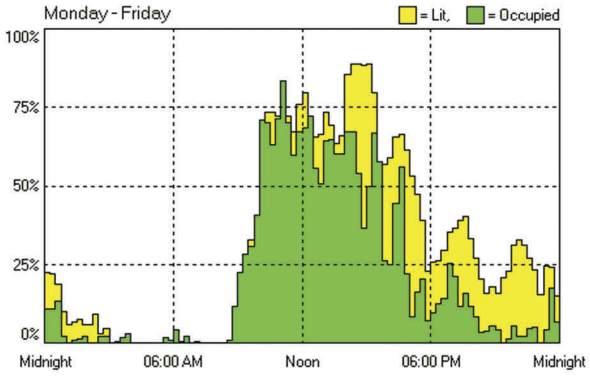
Additional savings may be possible from lighting load reductions during peak demand hours.

LIGHTING/OCCUPANCY SUMMARY

On+Occupied	86.38 hours	13.4%
On+Vacant	65.85 hours	10.2%
Off+Occupied	18.02 hours	2.8%
Off+Vacant	476.47 hours	73.7%



LIGHTING STATISTICS		OCCUPANCY STATISTICS	
Total On time:	152.23 hours	Total Occupancy time:	104.40 hours
Average On period:	1.12 hours	Average Occupancy period:	0.30 hours
Shortest On period:	0.02 hours	Shortest Occupancy period:	0.08 hours
Longest On period:	7.72 hours	Longest Occupancy period:	3.40 hours
Total On/Off cycles:	135	Total Occupancy cycles:	351
On/Off cycles per day:	5.0	Occupancy cycles per day:	13.0



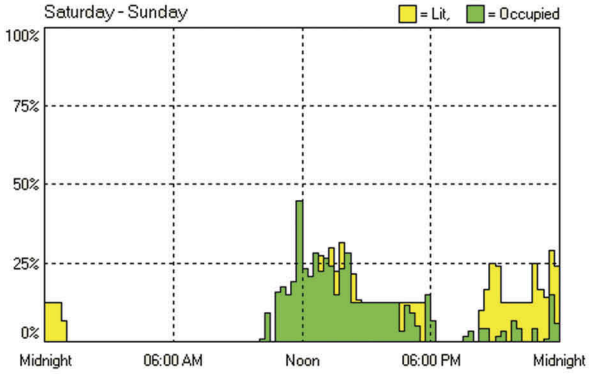


Figure 17.7 | Sample Light and Occupancy Logger Output
The results of a light logger installed in a university classroom for approximately four weeks illustrate savings opportunities with vacancy sensor control in this space. The yellow regions in the graphs represent time when the lighting systems is operating and the space is vacant. The listed cost savings are per kilowatt of connected load.

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Figure 17.8 | Low Quality LED Exit Sign Retrofit
LEDs are clearly visible in this LED retrofit exit sign. A more diffusing transmission layer is needed to provide more uniform luminance across each of the letters.



Figure 17.9 | LED Exit Sign Retrofit Kits
Red, green and white LEDs are available in screw based lamps for luminous panel exit signs. Local code office approval may be required.
» Image ©TCP, Inc.

IESH/10e Lamp Disposal and Recycling Resources

> 7.3.6 Operating and Other Characteristics (Fluorescent)

> 7.4.8.10 Operating Characteristics/Disposal and Recycling (Metal Halide)

IESH/10e Ballast Efficacy Factor Resources

> Table 7.5 | U.S. and Canadian Standards for Ballast Efficacy Factor

17.3.5 Exit Sign Upgrades

Older exit signs provide significant opportunities for energy savings and reduced maintenance through lamp or complete sign replacement. Long hours of operation (typically 24 hours per day) provide significant cost savings with reduced wattage sources. Maintenance cost savings alone can provide short payback periods due to the longer life of retrofit lamps. When considering an exit sign upgrade, it is important to investigate code issues related to source replacement. Sign visibility is critical, and is based on the uniformity and luminance of the sign's letters. Figure 17.8 illustrates an exit sign retrofit that delivers substandard uniformity. All types of older exit signs are potential candidates for retrofits or upgrades, with most replacement options applying SSL sources. See Figure 17.9 for one type of exit sign replacement lamp. SSL exit signs utilize roughly 40% of the energy of CFL signs and 15% or less of the energy of signs operated with filament lamps [18]. SSL source life is also in the 35,000-50,000 hr range, so maintenance costs should be minimal, and building safety will be improved. The presence of internal batteries to deliver emergency power or integral lighting to illuminate an exit pathway may limit the retrofit options that meet code provisions.

17.3.6 Disposal

Disposal of old lighting equipment may require special consideration. Certain lamps and ballasts must be treated as hazardous waste, such as pre-1979 fluorescent ballasts that contain PCBs, and lamps with mercury or lead solder (which includes fluorescent, MH and HPS). Consult federal, state, and local regulations regarding proper disposal of lamps and ballasts. Many of these lamps can be recycled. If luminaires are replaced, aluminum and steel parts should be recycled.

17.4 Lighting Efficiency Codes, Regulations and Standards

Lighting efficiency standards and codes are designed to ensure that energy efficient lighting systems are installed in buildings. Legislation on lighting system efficiency generally falls into one of two forms, equipment regulation and application standards.

Equipment regulation occurs when governments at the national, state or provincial level enact regulations that ban the sale or use of certain types of lighting equipment. Building design regulations apply application standards, limiting installed lighting power, placing limits on luminaire distributions (as in requiring full cutoff outdoor luminaires for certain wattages and applications), or requiring specific lighting control equipment to reduce operating time and minimize lighting energy consumption. A designer's goal is to meet or exceed the requirements of the applicable codes or standards without compromising the quality of a lighting design.

17.4.1 Applications Standards/Codes

Lighting energy codes and standards prescribe energy conscious design techniques but do not prescribe the use of specific technologies. The selection of equipment that satisfies space and task requirements in a cost effective and energy efficient manner is the responsibility of the lighting designer. Life cycle cost models can justify the economic merits of increased equipment efficiency.

The purpose of these codes and standards are to:

- Set minimum requirements for the energy efficient design of new buildings so they may be constructed, operated, and maintained in a manner that minimizes the use of energy without constraining building function or the comfort and productivity of the occupants.

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- Provide criteria for energy efficient design and methods for determining compliance with these criteria.
- Guide energy efficient design.

In Canada, each province has its own building code which includes lighting energy provisions. The national model code, the Model National Energy Code of Canada for Buildings (MNECB) [19], has been adopted in its entirety by only a few locations [20].

In Mexico, the Comision Nacional de Ahorro de Energia (CONAE) has developed building energy standards which include NOM-007-ENER-2004: Energy Efficiency for Lighting Systems in Non-Residential Buildings [21].

At press time, most U.S. states have adopted either the International Code Council's International Energy Conservation Code (IECC) or the ANSI/ASHRAE/IESNA 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings. The 2009 IECC Code permits buildings to achieve compliance by meeting the 90.1 Standard. The American Recovery and Reinvestment Act of 2009 [22] established the ANSI/ASHRAE/IESNA 90.1-2007 Standard as a minimum requirement in state energy codes in order for a state to receive federal energy assistance grants. States are also required to meet future releases of this code, following confirmation by the U.S. Department of Energy that the updated version improves building energy efficiency.

In Standard 90.1, the basic lighting requirements include minimum criteria for lighting controls as well as power limits for interior and exterior building lighting. For interior lighting power, the Standard offers a choice of three compliance methods: an energy cost budget (ECB), a prescriptive path based on building type (Building Area Method), and a prescriptive path based on the spaces within a building and their area (Space-by-Space Method).

The ECB method is the most encompassing and complex approach for assessing compliance. A whole-building energy model is used to predict energy use and must equal or beat that of a building designed using the prescriptive approach. It allows the designer to trade off lighting energy with other energy systems (such as the HVAC system). Although the method is flexible, it requires sophisticated analysis tools and can be time consuming.

The Building Area Method addresses the need for a quick and simple process for calculating the interior lighting power allowance (ILPA) for selected building types or areas within a building. This method does not address unique project requirements and is intended primarily for generic building types, core and shell buildings, or for use during the preliminary design phase. The ILPA is calculated by selecting the lighting power density for the respective building type from a table in the standard, then multiplying it by the gross building floor area represented by that building type. Different sections of a building may be assigned to different building types.

The Space-by-Space Method provides a detailed calculation procedure to determine the ILPA. The ILPA is totaled room by room and is task specific. Lighting power densities for a variety of space types are listed in a table. The ILPA for the building is the sum of the individual lighting power allowances from each of its spaces.

In all cases, a single space does not need to meet its allowance, but the total lighting power used in a building must not exceed the total building's ILPA. Similarly, the exterior lighting power allowance is the sum of individual lighting power allowances for a variety of exterior applications/areas, some of which may be traded between applications.

The IECC approach is similar to the 90.1 standard, except that it only lists a Building Area Method for determining the interior lighting power allowance. Future versions may include a Space-by-Space Method.

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17.4.2 Equipment Regulations

In both the United States and Canada, the government has played a major role in lighting energy reduction in recent years by attempting to reduce lighting energy consumption through stricter regulations on lighting system components. The primary institutions responsible for these national standards are the U.S. Department of Energy (DOE) and Natural Resources Canada (NRCan). The standards are relatively similar in these two countries so that (1) lower efficiency products are not dumped from a country with regulations to one without, (2) manufacturers can design products according to one standard instead of several, and (3) the regulatory burden is decreased.

17.4.2.1 U.S. Regulations

Over the past 20 years, a number of laws have mandated the use of efficient lighting components (lamps and ballasts): the National Appliance Energy Conservation Amendments of 1988 (NAECA) [23], the Energy Policy Acts of 1992 and 2005 (EPACT) [24] [25], and The Energy Independence and Security Act of 2007 (EISA 2007) [26].

The EPACT legislation and EISA have mandated energy efficiency standards for a number of common lamps used in the United States, such as R, PAR, and certain fluorescent lamps. As of July 1, 2010, nearly all fluorescent ballasts that are manufactured for T12 lamps in the U.S., including replacement ballasts, with the exception of some dimming and low temperature versions, must be electronic. This is the result of minimum BEF values established by DOE. For this reason, lamps and ballasts found in older lighting systems may no longer be available, and must be replaced with high efficiency models.

EISA 2007 effectively banned many of the standard forms of filament lamps by instituting minimum performance standards for these lamps that cover wattage, lumen output and life. These regulations will phase out non-compliant lamps by 2012-2014. EISA 2007 also added a number of different reflector lamps (BR, ER, and R lamps of specific wattage and size) to the efficiency requirements initially prescribed in EPACT 1992. These lamps were previously exempt from these regulations.

EPACT 1992 called for a voluntary national testing and information program for widely used luminaires that offer the potential for significant energy savings. As a result, the LER metric was developed by the National Lighting Collaborative, which was composed of NEMA (National Electrical Manufacturers Association), the American Lighting Association (ALA), and other interested organizations representing lighting designers, energy efficiency advocates, research, government, and electric utilities. LER was recently replaced by TER (see 17.2.2 Electric Lighting Equipment).

17.4.2.2 Canadian Standards

Natural Resources Canada has regulatory powers under the Energy Efficiency Act of 1992 [27], with the first Energy Efficiency Regulations were published in 1994 [28]. Federal standards do not take precedence over provincial standards, in contrast with the United States where federal standards preempt state standards on a specific product. National standards apply to products imported into Canada or shipped between provinces. Provinces may choose to adopt these standards for products sold within their borders. Canadian lamp regulations are similar to U.S. EPACT standards for filament reflector and linear fluorescent lamps. These standards took effect in 1996. Canada's regulation and phase out of filament lamps is stricter than U.S. regulations and will eliminate the sale of some lamps two years earlier than occurs in the U.S. [29]

17.4.2.3 Mexican Standards

Mexico's energy efficiency standards are developed by the Ley Federal Sobre Metrologia y Normalizacion (Federalo Standards and Metrology Laws). Energy efficiency standards are the responsibility of the Energy Secretariat, through its Comision Nacional para el Ahorro de Energia (CONAE). Many of Mexico's standards are voluntary, except for its CFL

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standard, which lists minimum efficacies [30]. The country also has a voluntary energy efficiency endorsement seal provided by the Fidelcomiso para el Ahorro de Energia Electrica (FIDE). Mexico has lighting standards for commercial buildings as well as for exterior lighting.

17.4.3 Nonregulatory Government Programs

Government agencies also promote energy efficiency and energy conservation through voluntary programs. The Energy Star Building Program administered by the U.S. Environmental Protection Agency (EPA) is a comprehensive building initiative that encourages use of energy efficient technologies for all major building systems, including lighting. A partnership agreement is signed between a luminaire manufacturer and EPA and the U.S. Department of Energy (DOE). EPA and DOE work with the luminaire manufacturer to promote superior products that qualify for the EPA/DOE Energy Star label. Products that carry the Energy Star label meet energy efficiency and quality criteria in an effort to ensure consumers do not sacrifice performance to save energy.

17.4.4 Green Building Codes and Rating Systems

The design of green and high performance buildings often involves an attempt to achieve a particular rating level on one of the green building rating systems, such as LEED, BOMA BESt [31], or Green Globes [32]. Daylighting and electric lighting (both interior and exterior) are two of the numerous system areas addressed within these rating systems. Green building standards and codes that have been approved, or are nearing the final stages of approval, include ASHRAE/IESNA 189.1, Standard for the Design of High Performance Green Buildings, and the International Green Construction Code (IgCC) from the International Code Council (ICC).

In the lighting systems area, these codes focus primarily on the implementation of daylighting and energy efficient lighting controls, since significant reductions in lighting power density may not be possible without sacrificing lighting quality. For example, the 189.1 standard contains allowable lighting power densities that are 90% of those in the 90.1 standard, while the IgCC simply requires that a building meet the values in the International Energy Conservation Code (IECC). However, in most of these green building codes and standards, daylight must meet a prescribed level across a percentage of the occupied building area, often specified using one or more set time/sky analyses, with integrated automatic lighting control applied in the daylit areas.

Daylighting code or standard compliance may take the form of either a prescriptive or performance approach. The performance approach requires extensive building energy modeling, but places less restriction on the amount of glazing area and glazing material used. Permitted glazing properties under the prescriptive path are limited in both 189.1 and the IgCC by specified maximum solar heat gain coefficients (SHGC) and limits on the fraction of exterior wall and roof area that may contain windows or skylights. An integrated design approach is essential to achieving quality daylighting and low overall building energy consumption.

IESH/10e Daylighting Metrics Resources

> 14.16.1 Performance Metrics for Daylighting

17.5 References

[1] U.S. Energy Information Administration. 2008. 2003 Commercial building energy consumption survey. < http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html>, Accessed 2010, Oct 30.

[2] Building Technology Program, Lawrence Berkeley National Laboratory. 1997. Tips for Daylighting with Windows. [cited on 2010 Apr 22]. Available at http://windows.lbl.gov/daylighting/designguide/download.html.

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[3] ASHRAE. 2007. Energy standard for buildings except low-rise residential buildings, ANSI/ASHRAE/IESNA 90.1-2007. Atlanta ASHRAE.

[4] International Code Council. 2009. International energy conservation code. Washington: International Code Council.

[5] U.S. Green Building Council. 2009. LEED 2009 for new construction and major renovations. Washington: USGBC.

[6] U.S. Green Building Council. 2009. LEED 2009 for schools new construction and major renovations . Washington: USGBC.

[7]] U.S. Green Building Council. 2009. LEED 2009 for core & shell development. Washington: USGBC.

[8] Canada Green Building Council. 2009. LEED 2009 for new construction and major renovations. Ottawa: CaGBC.

[9] Canada Green Building Council. 2009. LEED 2009 for core & shell development. Ottawa: CaGBC.

[10] ASHRAE. 2009. Standard for the design of high performance green buildings, ANSI/ASHRAE/USGBC/IESNA 189.1-2009. Atlanta: ASHRAE.

[11] International Code Council. 2009. International green construction code. Washington, International Code Council.

[12] NEMA, 2009. LE-6-2009, Procedure for determining target efficacy ratings for commercial, industrial, and residential luminaires. Rosslyn, VA: NEMA.

[13] NEMA, 2001. LE-5-2001, Procedure for determining luminaire efficacy ratings for fluorescent luminaires, Rosslyn, VA: NEMA.

[14] Galasiu AD, Newsham GR, Suvagau C, Sander DM, 2007. Energy saving lighting control systems for open-plan offices: a field study. Leukos. 4(1):7-29.

[15] Underwriters Laboratories. 2008. Questions and answers, the code authority, 2008 Issue 3; [cited on 2010 May 16]. Available at http://www.ul.com/global/documents/corporate/aboutul/publications/newsletters/thecodeauthority/tca_issue_3_2008.pdf.

[16] IESNA. 2007. Guidelines for upgrading lighting systems in commercial and institutional spaces. LEM-3-07. New York: IESNA.

[17] NEMA. 2009. Energy Efficiency for Electronic Ballasts for T8 Fluorescent Lamps. Rossly, VA: NEMA.

[18] US EPA. 2010. Save energy, money and prevent pollution with light-emitting diode (led) exit signs; [cited on 2010 Apr 22]. Available at http://www.energystar.gov/ia/business/small_business/led_exitsigns_techsheet.pdf.

[19] Canada. 1977. Model national energy code of Canada for buildings. Ottawa: National Resources Council Canada.

[20] Shui B, Evans M. 2009. Country report on building energy codes in Canada. Pacific Northwest National Laboratory; [cited on 2009 Apr 20]. Available at http://www.energycodes.gov/implement/pdfs/CountryReport_Canada.pdf.

[21] Mexico. 2004. NOM-007-ENER-2004: Energy efficiency for lighting systems in non-residential buildings. Comision Nacional de Ahorro de Energia (CONAE).

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[22] United States of America. American recovery and reinvestment act of 2009, U.S. Public Law 111-5. 17 February 2009.

[23] United States of America. National appliance energy conservation amendments of 1988. U. S. Public Law 100-357. 28 June 1988.

[24] United States of America. Energy policy act of 1992. U. S. Public Law 102-486. 24 October 1992.

[25] United States of America. Energy policy act of 2005 ,U.S. Public Law 109-58. 8 August 2005.

[26] United States of America. Energy independence and security act of 2007, U.S. Public Law 110-140. 19 December 2007.

[27] Canada. Energy efficiency act. 1992. E6.4, c.36.

[28] Canada. Energy efficiency regulations, SOR/94-651.

[29]. Regulations amending the energy efficiency regulations, P.C. 2008-1930 December 12 2008, Canada Gazette. 142(26). (SOR/2008-323)

[30] Mexico. 2008. Energy efficiency and security requirements of self-ballasted compact fluorescent lamps - Limits and test methods, NOM-017-ENER/SCFI-2008.

[31] Building Owners and Managers Association – Canada. 2009. BOMA BEst; [cited on 2009 Apr 20]. Available at http://www.bomabest.com.

[32] Green Building Initiative. 2010. ANSI/GBI 01-2010: Green building assessment protocol for commercial buildings. Portland, OR: GBI.

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18 | ECONOMICS

The highest use of capital is not to make more money, but to make money do more for the betterment of life.
Henry Ford

Economics plays a role in every lighting design decision, regardless of whether the project is large or small. Economic analysis methods permit designers and owners to evaluate alternative systems or investments on a life cycle cost basis in considering which alternative to choose. This chapter outlines basic economic analysis approaches that can be applied to lighting systems, as well as the relevant cost information that can affect the economic evaluation of a lighting system, component, or its means of operation and maintenance. It is of value to building owners, maintenance staff, manufacturers and designers for evaluating different lighting and maintenance options based on evaluations of life cycle cost.

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18.1 The Role of Economic Analyses

A lighting design must be responsive to the needs of the users and the owner, including their economic needs. In the design and construction of a project, economic concerns play a role in many decisions, and are often considered the antagonist of aesthetic and quality concerns. Early in the design process, a lighting designer establishes a list of needs and criteria (See 11.3.2.1 Programming) that are considered to be essential; then begins the complicated process of prioritizing criteria other than budget and determining which can be accommodated by the budget, or if and how the budget is to be revised. [1-4]

Rather than consider economic analyses as the antithesis of good engineering or aesthetic design, it should be viewed as a framework within which the project's needs must be addressed. Failure to provide a quality lighting condition for users can negatively impact comfort, satisfaction, and/or productivity and have financial consequences. In addition, a lighting design that fails to address the aesthetic requirements of a space may result in lower rental values, or in the case of a restaurant and certain retail applications, reduced business. A lighting design that properly addresses the users' needs and complements the architecture will address a number of important economic concerns that are by nature difficult to quantify. In general, aspects related to occupant performance, preference, and behavior are not included in a formal economic analysis of lighting system alternatives.

Economics can impact nearly every major component of a lighting design, from sources, luminaires and controls to long-term maintenance that includes cleaning and relamping. An economic evaluation is equally important for new construction as well as for retrofit projects. A comprehensive economic analysis of a proposed design will consider a variety of different economic concerns, such as:

- A comparison of alternative systems or components
- The benefits provided by a lighting system or component relative to its cost
- Evaluation of maintenance techniques and procedures
- Evaluation of energy management technologies and strategies
- Impact of lighting on other building systems and the associated costs
- The project's budget constraints

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Many of these economic concerns are straightforward to analyze. A more expensive lighting or control system may save energy or reduce maintenance costs over time to justify its higher initial cost. The question of whether the costs associated with a lighting system can be justified by the savings or benefits it provides is one of economics, and often must be considered by the design team during design development, or in defense of a design. In any economic evaluation, the lighting quality provided by different options being considered should be equal to justify a comparison based solely on initial and operating costs.

This chapter will address standard approaches to economic analyses and describe the associated system costs that generally apply to a cost/benefit analysis of lighting system design alternatives. It includes a discussion of a few low level analysis methods: simplified metrics that may provide a general economic assessment. These approaches are followed by a discussion of Life Cycle Cost Benefit Analysis (LCCBA), the recommended approach for analyzing the economics of system alternatives. First, a brief discussion follows on costs and where a lighting practitioner can turn to obtain these costs.

18.2 Estimating Costs

A lighting system can impact economics in a variety of ways. The obvious ones include the cost to purchase and install the system, as well as the annual or periodic energy and maintenance costs. Additional costs or savings may be accrued through taxes and HVAC system costs (both initial and operating). In commercial settings, issues such as worker productivity, safety, health, and employee retention, as well as customer attraction or increased sales, or increased rental income are difficult to quantify and are not typically addressed in economic comparisons. In commercial and industrial settings, worker salaries far exceed the other costs associated with construction and operation of a building , but the impact on worker productivity is too complicated to quantify, but is a critically important factor to consider. As such, an economic analysis of design alternatives will consider the costs associated with its installation and operation. With energy saving options such as alternative lighting control strategies, the question often is: Do the savings provided by a system or component justify a higher initial cost? Such a condition is relatively simple to assess through an economic analysis that considers a best estimate of all initial and operating costs, which includes energy costs. In the case of a retrofit, one option might be to maintain the existing system, in which case the initial costs for that option can be zero, or the costs associated with basic maintenance that will be performed in place of the retrofit, such as relamping. If no relamping will occur, it is important to consider that lamp and ballast replacement costs will be higher for an existing system early in the study period than for a newly installed system.

To evaluate design alternatives, the owner may wish to know how quickly higher initial costs will be recovered (a system's payback period), or the rate of return on the investment (which is analogous to the interest received on any additional investment). A detailed economic analysis can assist the building owner or a company's financial officer in determining whether it is better financially to invest in cost saving building equipment or to invest it elsewhere within the company based on a comparison of the expected returns.

In performing a cost analysis, it is important to gather representative cost data associated with the design, construction, and operation of a system. This information consists of best estimates for all cash flow related to the lighting system. In some cases, it may be appropriate to apply conservative estimates when there is uncertainty in predicting future costs. Table 18.1 provides some guidance regarding the type of information that must be gathered and sources for obtaining these data. Note that in a comparison of design alternatives, it is only necessary to assess the differences in cash flow between systems to determine which is the least expensive over the system's life, or to assess the payback period for one alternative relative to another.

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Table 18.1 | Lighting Related Costs and Sources for These Costs

Cost Category	Item	Source for Values
Initial Costs	**Equipment**	• Manufacturer's representatives • Previous projects • Electrical distributor or contractor • RSMeans [5,6]
	Labor	• Previous projects • Electrical distributor or contractor • RSMeans [5,6] • Previous projects
	HVAC Equipment & Labor	• Mechanical system designer
Annual Costs	**Energy Charges**	• Lamp or ballast wattages • Electrical rates from utilities • Operating hours (considering impact of lighting controls) • Mechanical system designer for differences in HVAC Energy
	Demand Charges	• Lamp or ballast wattages • Utility rates • Mechanical system designer for differences in HVAC peak demand
	Lamp or ballast replacement costs	• Local distributors/suppliers of lighting products • Manufacturer's data for life expectancy • Operating schedules
	Labor for lamp or ballast replacement	• Labor rates for maintenance staff, including benefits • Time required to replace lamp or ballast or • Lighting services company charge
	Lamp disposal costs	• Lamp recycling or disposal companies
	Luminaire cleaning costs	• Labor rates for maintenance staff, including benefits • Time required per luminaire • Cleaning material costs or • Lighting services company charges
Other Costs	**Utility rebates**	• Local utility provider
	Tax impacts	• Local, state, and federal tax laws for tax credits, depreciation and other expense deductions
	Insurance	• Insurance company
	Disposal Costs	
	Salvage costs	• Waste disposal companies
	Recycling costs	• Recyclers
	Residual value	• Companies specializing in demolition or resale of used building products

As previously noted, these analyses cannot account for productivity and therefore should be judged accordingly. If lighting system option A exhibits a lower cost value than option B, but option A is know to create more glare, or exhibits light distributions that create dark ceilings and upper walls, then option A is rightly an inappropriate choice.

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18.3 Simple Payback

Simple payback is a general, first-level method commonly applied in comparing design alternatives. The simple payback period is an approximation to the amount of time required to pay off an investment. It is the incremental initial cost of a system divided by the additional annual cash flow (financial benefit) it provides

$$PP = \frac{I}{A} \tag{18.1}$$

Where:

PP = simple payback period (years)
A = incremental annual cash flow (annual savings)
I = incremental investment

Simple payback does not consider the time value of money, which considers that a given monetary amount is worth more today than at some point in the future. Therefore, the use of the simple payback method is appropriate only when payback occurs quickly (within a couple years) and not well into the system life of the systems. Simple payback is not an IES recommended practice to evaluate alternative lighting systems because a low cost system or retrofit may not prove to be the best system financially when a longer time period is considered. The use of Life Cycle Cost Benefit Analysis is a more rigorous second level method (See 18.6 Life Cycle Cost Benefit Analysis (LCCBA) and 18.7 Discounted Payback and Rate of Return).

18.4 Simple Rate of Return

The simple rate of return (ROR), which is often referred to as simple return on investment (ROI), is the reciprocal of the simple payback period. It is the annual benefit provided by an investment divided by the initial cost of that investment.

$$ROR = \frac{A}{I} \times 100\% \tag{18.2}$$

Where:

ROR = simple rate of return
A = incremental annual cash flow
I = incremental investment

ROR, as defined here, does not consider the time value of money. A more rigorous second-level discounted rate of return is defined in 18.7 | Discounted Payback and Rate of Return.

18.5 Cost of Light

The cost of light is a general lighting cost analysis metric that considers the costs incurred over the life of a lamp in relation to the cumulative lumen-hours it will produce over its lifetime. This metric is only valid for comparing lamps that produce the same general light distribution , are interchangeable within luminaires, and have no resulting impact on a luminaire's optical efficiency. The cost of light in dollars per million lumen-hours is expressed by the following equation:

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$$U_{lamp} = \frac{1000}{\phi_{lamp}}\left[\frac{1000(C_{lamp} + C_{labor})}{L_{lamp}} + P_{lamp}\,C_{energy}\right] \quad (18.3)$$

Where:

U_{lamp} = unit cost of light for a lamp in $/lm-hr
ϕ_{lamp} = mean lamp lumens
C_{lamp} = lamp price ($)
C_{labor} = labor cost to replace one lamp ($)
L_{lamp} = average rate lamp life (hrs)
P_{lamp} = mean input power per lamp (including ballast losses)
C_{energy} = energy cost ($/kwh, including any demand charges)

18.6 Life Cycle Cost Benefit Analysis (LCCBA)

Life cycle cost benefit analysis (LCCBA) is a robust economic analysis method capable of addressing all quantifiable costs in a project, is widely endorsed and required on government projects, and is the economic analysis method recommended by IESNA [3]. This method compares systems or hardware alternatives under consideration by analyzing their differential costs. This generally requires all known costs over the life of the system to be evaluated. [3] [4] [7] [8]

18.6.1 The Time Value of Money

The time value of money is considered in the LCCBA approach. Under this approach, payments and receipts in the future are valued less than current transactions. All costs that are incurred over the life of the system must be converted to their equivalent value at a single point in time, generally the current value of a currency, or its "present worth." Once all costs are converted to present worth, systems can be compared to determine which is least expensive over the life of the system.

To convert future expenses to present worth, it is necessary to select a rate for the time value of money. This value is a percentage rate that represents the opportunity cost to an owner, which is the interest rate an owner would expect to make on an investment of similar risk, or the firm's cost of capital. This rate will differ depending on how inflation is handled in the analysis. Inflation can either be included or ignored in the analysis, but this will change the proper rate to apply for the time value of money. If included in the analysis, costs will increase each year throughout the analysis period, and different types of costs, such as labor, equipment and energy, may increase at different rates. If inflation is ignored, all costs are expected to escalate with the general rate of inflation, and the rate used for the time value of money is adjusted to account for this. In such an analysis, if an annual cost such as energy will increase at a higher or lower rate, the difference between its escalation rate and the general rate can still be included in the analysis.

Market interest rates generally consider that inflation will occur, so if a market interest rate is being used, inflation rates should be considered for all costs. An interest rate for the time value of money that accounts for inflation, permitting general inflation to be ignored, can be determined from an equivalent market rate through the following equation.

$$i = \left[\frac{1 + i_m}{1 + r}\right] - 1 \quad (18.4)$$

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Where:

i = interest rate to convert future costs to current dollars that permits inflation to be ignored
i_m = market-based interest rate (accounting for inflation)
r = rate of inflation

18.6.2 General Assumptions

In applying LCCBA or any other economic analysis method, all systems are assumed to fulfill the functional requirements of the design equally. They are of the same general quality, and impact productivity in a work environment and other performance measures such as sales in a retail environment similarly. In many retrofit situations, lighting quality is improved, in which case the results of an economic analysis can be further strengthened.

18.6.3 Considering Systems with Unequal Lives

To compute the total life cycle cost of each system, it is necessary to perform an analysis over the expected life of the system. If a present worth analysis is being conducted to compare the costs of systems with different lives, the systems must be evaluated over the same number of years. If the systems being compared have different life spans, then a time period that is the least common multiple of these time periods should be applied to the analysis. With this approach, the initial costs of a system are incurred at the beginning of each new life cycle.

An alternate approach is to determine the present worth of each system over their respective lifetimes, then convert these present worth values which include both initial and annual costs to a total uniform annual cost over the life of that system using Eq. 18.8. The system with the lower total annual cost is the less expensive system.

18.6.4 Converting Costs to Present Worth

The total present worth of each system considers all costs that are expected over the life of the system. To determine the lowest cost system over their lifetime, it is only necessary to consider the cost differences between the systems. If a particular cost, such as the labor for system installation, is the same for all systems being analyzed, then this cost does not need to be considered. If, however, the analysis is being conducted to determine the relative magnitude of the costs associated with alternate systems, then full and accurate costs are required for all expense categories.

The process of determining the total present worth of a system involves first determining all costs that are to be considered. A list of items to consider in the analysis of a lighting system is provided in Table 18.2. These costs are converted to present worth using the appropriate equation from Table 18.3. One approach is to list the costs incurred in each year of the analysis, total them by year, then convert each of these values to present worth. Table 18.4 lists present worth conversion factors derived from Eq. 18.5 to use in converting future costs or income to present worth for interest rates up to 15% and time periods through 20 years. Two examples are provided in 18.8 Present Worth Example Problems.

If a cost is repeated each year over the system life, an optional approach is to convert the repeated annual cost directly to present worth using either Eq. 18.6 or 18.7. Note that some costs, such as group relamping costs, may not be incurred in every year. These should be converted to present worth individually. Costs that occur sometime during a particular operating year should be considered to occur at the end of that year in assessing the number of years to consider for the present worth conversion factor.

Once a total present worth value is determined, these costs can be converted to an equivalent annual cost using (18.8). The initial costs are then distributed across all of the years of the analysis.

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Table 18.2 | LCCBA Worksheet

Worksheet for the analysis of lighting system present worth values from initial and annual costs.

	Relevant Cost Items	System Cost Comparisons			
	Worksheet Instructions are outlined by line number on facing page.				
1	System Life = _____ years				
2	Interest Rate = _____ %				
3	**A. Initial Costs**	**System 1**	**System 2**	**System 3**	**System 4**
4	Lighting system—Equipment				
5	Lighting system—Labor				
6	HVAC system - Cooling				
7	HVAC system - Heating				
8	Utility rebates				
9	Other first costs:_____				
10	Initial taxes:				
11	Total intitial costs :				
12	**B. Annual Costs**				
13	Luminaire energy (_____annual kWh @ $_____/kwh)				
14	Demand charges (_____KW @ $____/KW x 12 mos.)				
15	Air-conditioning energy costs				
16	Heating energy costs				
17	Lamp replacement costs				
18	Ballast replacement costs				
19	Luminaire cleaning costs				
20	Annual property tax cost				
21	Other annual costs:_____				
22	Total of annual costs:				
23	Present worth factor for annual costs (A→P)	X	X	X	X
24	Present worth of annual costs:				
25	Taxes - depreciation (per annum for ____ yrs)				
26	Present worth factor for taxes (A→P)	X	X	X	X
27	Present worth for taxes:				
28	Residual (salvage) value at end of economic life				
29	Present worth factor for salvage costs (F→P)	X	X	X	X
30	Present worth of salvage costs:				
31	**C. Total Net Present Worth (sum of lines 11, 24, 27 and 30):**				

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18.6.5 The LCCBA Worksheet

The simplified LCCBA worksheet provided in Table 18.2 lists lighting system and other related costs that are typically addressed in a lighting system economic analysis. Not all costs may be considered in every analysis. Remember that only those costs which are different need to be included to assess which system is less costly over the life of the system. Detailed notes are provided to explain the data entered on each line of the worksheet.

18.6.5.1 Line-by-line notes for Table 18.2 | LCCBA Worksheet:
Line 1: Establish the anticipated life in years of the lighting systems (identical for all systems).

Line 2: Determine an interest rate associated with borrowing money, alternative investments, or simply the escalation for the life of the lighting system.

Line 4: Estimate the material costs for the lighting system, remembering to include any differences in wiring costs.

Line 5: Estimate the labor costs to install the system.

Line 6: A lighting system introduces heat into the building which must be removed by the HVAC system in spaces that are cooled. If the lighting system choice alters the size of the HVAC equipment, the appropriate differential costs should be entered here. Note: If a daylighting system is being analyzed, the HVAC loads and equipment sizes may be affected. The project mechanical consultant should be consulted for this information. 1 ton of cooling can remove the heat provided by approximately 3.5 kW of lighting. Cooling equipment pricing is approximately $1500-$2500 per ton.

Line 7: Energy efficient lighting systems may increase the heating load for a building due to reduced internal gains. If the size of heating equipment differs between lighting systems being compared, enter the differential cost of the systems here. The project mechanical consultant should be consulted for this information. 1 kW of heat is equal to 3.4 kBtu/h, which corresponds to about $60-$100 for the incremental heating equipment costs if the equipment size changes.

Line 8: Electric utilities may offer incentives for end users who retrofit or install energy efficient lighting equipment in their buildings. Enter financial incentives to be received as a negative number.

Line 9: Include any other differential costs, such as design fees or tax credits here.

Line 10: Enter any taxes that are not already included in the price of the equipment.

Line 11: Sum the total initial costs of the systems. This is the present worth of the initial costs.

Line 13: Determine the annual energy consumption (kwh) for each system, considering the building occupancy schedule and the impact of control systems, such as occupancy and dimming controls. Multiply the energy consumption by the utility charge for energy ($/kwh). Note that rates may vary by time of day and season.

Line 14: Monthly demand charges may be incurred if the lighting system is operating during the peak demand period. Estimate the impact on the monthly demand reading for the system and apply the electric utility's demand charge, if demand metering is to occur.

Line 15: Annual cooling costs should be obtained from a detailed energy load study conducted by the mechanical consultant since these are based on aspects such as the system efficiency, fuel type, and economizer applications. [13] These values may be particularly important in studying alternative daylight delivery systems.

Line 16: Annual heating costs should be obtained from a detailed energy load study conducted by the mechanical consultant since these are based on aspects such as the system efficiency, fuel type, and economizer applications. [13] These values may be particularly important in studying alternative daylight delivery systems.

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Line 17: Lamp replacement costs will depend on the lamp life, operating schedule, and lamp replacement strategy. Both material and labor costs should be included. A rough approximation considers the number of lamps to be replaced per year based on operating hours and lamp life. Note that non-uniform annual costs are likely to occur with group relamping. The impact of this effect can only be evaluated through non-uniform annual costs.

Line 18: Ballasts generally have relatively long lives. Ballast replacement costs are unlikely in the early years of a system, but may eventually reach a steady-state condition where the number of ballasts replaced is equal to the number of ballasts divided by the ballast life. Both material and labor costs should be included.

Line 19: Luminaire cleaning may be conducted on a regular basis, or may be conducted only when lamps are changed. In the latter case, these costs may be included in the lamp replacement costs. Consider both material and labor costs. For use in this spreadsheet, approximate these costs based on an average cost per year.

Line 20: Enter the expected impact on annual property taxes here.

Line 21: Enter any additional annual costs here.

Line 22: Sum all of the annual costs here to obtain the approximate cost of the system on an annual basis.

Line 23: Calculate the present worth factor for each system to convert annual costs over the life of the system to its equivalent total present worth using Equation 18.6.

Line 24: Multiply the present worth factor (line 23) by the total annual costs (line 22).

Line 25: Tax laws permit equipment to be depreciated over a set number of years on tax returns. In the U.S., lighting equipment that is incorporated into furniture can be depreciated over 7 years rather than the standard 39 year period. In additionaaddition, a commercial building tax deduction is available in the form of accelerated depreciation for energy efficient lighting equipment through 2013. Input the annual tax savings to the owner and the time period as a negative number.

Line 26: Calculate the present worth factors for each system to convert the annual tax savings to an equivalent total present worth for the listed depreciation period using Equation 18.6.

Line 27: Multiply the present worth factor (line 26) by the annual tax savings (line 25) to obtain the equivalent present worth of these savings.

Line 28: The amount the system will be worth or the cost to the owner to dispose at the end of its economic life. This value is negative if money is received and positive if a cost is incurred to dispose of the system.

Line 29: Calculate the present worth factor to convert salvage value at the end of system liflife to its equivalent total present worth using Equation 18.5.

Line 30: Multiply the present worth factor (line 29) by the salvage value (line 28).

Line 31: Sum lines 11, 24, 27 and 30 to determine the total present worth of the systems. The lower value is the less expensive option over the life of these systems.

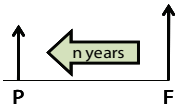
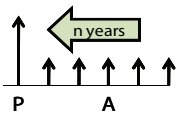
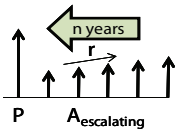
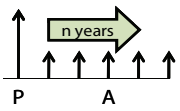
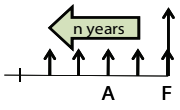
18.6.5.2 General Assumptions for Table 18.2 | LCCBA Worksheet:
1) The systems are assumed to provide equal benefits and lighting quality in all areas not assessed by this worksheet.

2) The systems being compared have identical system lives.

3) The interest rate used to determine the present worth factors accounts for inflation. Individual escalation rates could be applied to each of the costs in section B if they are each converted individually to present worth using Equation 18.5.

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Table 18.3 | Equations Relating Present Worth, Future Worth and Annual Costs
(i is the opportunity cost or interest rate; r is the inflation rate, in decimal format: 0.01=1%)

To Compute	Given	Equation		Graphic
Present Worth (P)	F	$P = F \times \frac{1}{(1+i)^y}$	(25.5)	
	A	$P = A \times \frac{(1+i)^y - 1}{i(1+i)^y}$	(25.6)	
	A , r	$P = A \times \frac{(1+r)\left[(1+i)^y - (1+r)^y\right]}{(i-r)(1+i)^y}$	(25.7)	
Annual Cost (A)	P	$A = P \times \frac{i(1+i)^y}{(1+i)^y - 1}$	(25.8)	
	F	$A = F \times \frac{i}{(1+i)^y - 1}$	(25.9)	

18.7 Discounted Payback and Rate of Return

If the cumulative present worth of all costs through any year of the analysis is considered, it is possible to determine a discounted payback period for a system that has a higher initial but lower operating costs. It is also possible to determine a discounted rate of return (DROR) that considers the time value of money. The DROR is the rate for the time value of money that creates identical total system present worth values over the life of the systems.

18.8 Present Worth Example Problems

This section contains two examples, showing how present worth is considered in the economic analysis of actual lighting system decisions.

18.8.1 Present Worth Example 1

Consider an existing lighting system that is spot relamped. The system consists of 100 lamps which cost $3 each. The lamp life is 10,000 hrs and the lamps are burned for 2,500 hrs per year. The option being considered is a change to group relamping every three years (to occur at 75% of rated life). The cost to spot relamp is $10 of labor per lamp, whereas the cost to group relamp is $4 per lamp. Which is the more economical approach considering an interest rate of 10%? This analysis will consider the number of spot relampings that will occur between group relampings based on a lamp mortality curve.

Solution: Table 18.5 lists the costs incurred initially and in each year of the study period, which is considered as one relamping cycle. These costs are converted to present worth using the appropriate multipliers from Table 18.4, and then totaled.

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Table 18.4 | Present Worth Multipliers

Multipliers for converting costs that occur in a future year to present worth given the interest rate.

Interest Rate	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0.5	.995	.990	.985	.980	.975	.971	.966	.961	.956	.951	.947	.942	.937	.933	.928	.923	.919	.914	.910	.905
1.0	.990	.980	.971	.961	.951	.942	.933	.923	.914	.905	.896	.887	.879	.870	.861	.853	.844	.836	.828	.820
1.5	.985	.971	.956	.942	.928	.915	.901	.888	.875	.862	.849	.836	.824	.812	.800	.788	.776	.765	.754	.742
2.0	.980	.961	.942	.924	.906	.888	.871	.853	.837	.820	.804	.788	.773	.758	.743	.728	.714	.700	.686	.673
2.5	.976	.952	.929	.906	.884	.862	.841	.821	.801	.781	.762	.744	.725	.708	.690	.674	.657	.641	.626	.610
3.0	.971	.943	.915	.888	.863	.837	.813	.789	.766	.744	.722	.701	.681	.661	.642	.623	.605	.587	.570	.554
3.5	.966	.934	.902	.871	.842	.814	.786	.759	.734	.709	.685	.662	.639	.618	.597	.577	.557	.538	.520	.503
4.0	.962	.925	.889	.855	.822	.790	.760	.731	.703	.676	.650	.625	.601	.577	.555	.534	.513	.494	.475	.456
4.5	.957	.916	.876	.839	.802	.768	.735	.703	.673	.644	.616	.590	.564	.540	.517	.494	.473	.453	.433	.415
5.0	.952	.907	.864	.823	.784	.746	.711	.677	.645	.614	.585	.557	.530	.505	.481	.458	.436	.416	.396	.377
5.5	.948	.898	.852	.807	.765	.725	.687	.652	.618	.585	.555	.526	.499	.473	.448	.425	.402	.381	.362	.343
6.0	.943	.890	.840	.792	.747	.705	.665	.627	.592	.558	.527	.497	.469	.442	.417	.394	.371	.350	.331	.312
6.5	.939	.882	.828	.777	.730	.685	.644	.604	.567	.533	.500	.470	.441	.414	.389	.365	.343	.322	.302	.284
7.0	.935	.873	.816	.763	.713	.666	.623	.582	.544	.508	.475	.444	.415	.388	.362	.339	.317	.296	.277	.258
7.5	.930	.865	.805	.749	.697	.648	.603	.561	.522	.485	.451	.420	.391	.363	.338	.314	.292	.272	.253	.235
8.0	.926	.857	.794	.735	.681	.630	.583	.540	.500	.463	.429	.397	.368	.340	.315	.292	.270	.250	.232	.215
8.5	.922	.849	.783	.722	.665	.613	.565	.521	.480	.442	.408	.376	.346	.319	.294	.271	.250	.230	.212	.196
9.0	.917	.842	.772	.708	.650	.596	.547	.502	.460	.422	.388	.356	.326	.299	.275	.252	.231	.212	.194	.178
9.5	.913	.834	.762	.696	.635	.580	.530	.484	.442	.404	.369	.337	.307	.281	.256	.234	.214	.195	.178	.163
10.0	.909	.826	.751	.683	.621	.564	.513	.467	.424	.386	.350	.319	.290	.263	.239	.218	.198	.180	.164	.149
10.5	.905	.819	.741	.671	.607	.549	.497	.450	.407	.368	.333	.302	.273	.247	.224	.202	.183	.166	.150	.136
11.0	.901	.812	.731	.659	.593	.535	.482	.434	.391	.352	.317	.286	.258	.232	.209	.188	.170	.153	.138	.124
11.5	.897	.804	.721	.647	.580	.520	.467	.419	.375	.337	.302	.271	.243	.218	.195	.175	.157	.141	.126	.113
12.0	.893	.797	.712	.636	.567	.507	.452	.404	.361	.322	.287	.257	.229	.205	.183	.163	.146	.130	.116	.104
12.5	.889	.790	.702	.624	.555	.493	.438	.390	.346	.308	.274	.243	.216	.192	.171	.152	.135	.120	.107	.095
13.0	.885	.783	.693	.613	.543	.480	.425	.376	.333	.295	.261	.231	.204	.181	.160	.141	.125	.111	.098	.087
13.5	.881	.776	.684	.603	.531	.468	.412	.363	.320	.282	.248	.219	.193	.170	.150	.132	.116	.102	.090	.079
14.0	.877	.769	.675	.592	.519	.456	.400	.351	.308	.270	.237	.208	.182	.160	.140	.123	.108	.095	.083	.073
14.5	.873	.763	.666	.582	.508	.444	.388	.338	.296	.258	.225	.197	.172	.150	.131	.115	.100	.087	.076	.067
15.0	.870	.756	.658	.572	.497	.432	.376	.327	.284	.247	.215	.187	.163	.141	.123	.107	.093	.081	.070	.061

Table 18.5 | Present Worth Analysis for Example 1

The Relamping costs for the two systems in Example 1 are converted to their equivalent present worth values then totaled. The initial costs for the group relamping option are considered to already be at present worth.

		OPTION 1 - Spot Relamping				OPTION 2 - Spot + Group Relamping			
Year	PW Factor	# of Lamps Replaced	Relamping Type	Annual Cost	PW	# of Lamps Replaced	Relamping Type	Annual Cost	PW
Initial	1.000			$0		100	Group	$700	$700
1	0.909	25	Spot	$325	$295	0		$0	$0
2	0.826	25	Spot	$325	$269	0		$0	$0
3	0.751	25	Spot	$325	$244	7	Spot	$91	$68
TOTAL		75		$975	**$808**	107		$791	**$768**

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The difference between the two options in this example is much greater when actual costs are totaled, but this does not address the time value of money. Since costs in future years are discounted in a present worth analysis, the system with more of its costs deferred to the future benefits from a present worth analysis. When the time value of money is considered, Option 2 still is the least expensive, but the difference between the two systems is much less. Note that regardless of how many full relamping cycles are considered, the ratio of the two costs will not change, since identical costs are repeated in future years.

18.8.2 Present Worth Example 2

This example considers two options for design that applies recessed downlights. One applies CFL Lamps and the other LED sources. Details on these systems are provided below. All values are hypothetical and are provided solely for use in this example.

General Details:

- 20 year operational life with 10 hr/day operation, 365 days/year.
- Energy cost: $0.10/kwh
- Installation labor rate: $60/hr
- Maintentance labor rate: $30/hr

System #1:

- (54) 18 W CFL recessed downlights at $350 each
- 12000 hr lamp life
- 20 input watts

System #2:

- (48) LED recessed downlights at $450 each
- 50000 hr lamp life
- 12 input watts

System #1 Cost Calculations:

- Initial installed cost:
  54 luminaires × ($350/luminaire + 0.75 hr labor × $60/hr) = $21,330
- Annual energy cost:
  54 luminaires × 20 W × 10 hr/day × 365 days/yr / 1000 W/kwh × $0.10/kwh = $394/yr
- Annual relamping cost:
  (3,650 hrs/yr) /12,000 hr/lamp × ($8/lamp + 0.2 hr labor × $30/hr) = $123
- Annual cleaning cost:
  54 luminaires × $0.1 hrs labor /luminaire × $30/hr = $162

System #2 Cost Calculations:

- Initial cost:
  48 luminaires × ($450/luminaire + 0.75 hr labor × $60/hr) = $23,760
- Annual energy cost:
  48 luminaires × 12 W × 10 hr/day × 365 days/yr / 1000 W/kwh × $0.10/kwh = $210
- Group relamping cost:
  48 luminaires × ($30/LED module + 0.2 hrs/lumininaire × $30/hr) = $1,728 (years 1 and 4)
- Annual cleaning cost:
  48 luminaires × $0.1 hrs labor /luminaire × $30/hr = $144

Table 18.6 illustrates the calculation of both simple payback and discounted payback using a 4% interest rate that does not require inflation to be considered. System 2 is the more expensive system initially, but incurs lower annual costs. The bolded values indicate times when the cumulative costs associated with System 2 are less expensive than the same costs for System 1. Simple payback for System 2 occurs when the cumulative total of all payments for that system is less than those for System 1. This occurs at about the 7 year

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Table 18.6 | Present Worth Analysis for Example 2

System 2 costs more initially, but is less expensive to operate and maintain. The bold values in the Total of Payments and Total PW columns indicate the year in which these cummulative totals become less expensive for System 2.

		System 1							
Year	PW Factor	Energy Cost	Maint. Cost	Annual Cost	Annual Cost PW	Total of Payments	Total PW (i=4%)		Total PW (i=11%)
Initial	1.000			21330	21330	21330	21330		21330
1	0.962	394	162	556	535	21886	21865		21831
2	0.925	394	162	556	514	22442	22379		22282
3	0.889	394	162	556	494	22998	22873		22689
4	0.855	394	417	811	693	23809	23566		23223
5	0.822	394	417	811	667	24620	24233		23704
6	0.790	394	417	811	641	25431	24874		24138
7	0.760	394	417	811	616	26242	25490		24528
8	0.731	394	417	811	593	27053	26083		24880
9	0.703	394	417	811	570	27864	26652		25197
10	0.676	394	417	811	548	28675	27200		25483
11	0.650	394	417	811	527	29486	27727		25740
12	0.625	394	417	811	507	30297	28234		25972
13	0.601	394	417	811	487	31108	28721		26181
14	0.577	394	417	811	468	31919	29189		26369
15	0.555	394	417	811	450	32730	29639		26539
16	0.534	394	417	811	433	33541	30072		26691
17	0.513	394	417	811	416	34352	30489		26829
18	0.494	394	417	811	400	35163	30889		26953
19	0.475	394	417	811	385	35974	31274		27065
20	0.456	394	417	811	370	36785	31644		27165

		System 2							
Year	PW Factor	Energy Cost	Maint. Cost	Annual Cost	Annual Cost PW	Total of Payments	Total PW (i=4%)	Savings in PW	Total PW (i=11%)
Initial	1.000			23760	23760	23760	23760	-23,760	23760
1	0.952	210	144	354	337	24114	24097	-2,233	24097
2	0.916	210	144	354	324	24468	24421	-2,043	24401
3	0.881	210	144	354	312	24822	24733	-1,860	24675
4	0.847	210	144	354	300	25176	25033	-1,467	24921
5	0.814	210	144	354	288	25530	25321	-1,088	25143
6	0.783	210	144	354	277	25884	25598	-724	25343
7	0.753	210	144	354	266	**26238**	25864	-374	25523
8	0.724	210	144	354	256	**26592**	26121	-38	25686
9	0.696	210	144	354	246	**26946**	**26367**	**285**	25832
10	0.669	210	144	354	237	**27300**	**26604**	**596**	25964
11	0.643	210	144	354	228	**27654**	**26832**	**895**	26083
12	0.619	210	144	354	219	**28008**	**27051**	**1,183**	26190
13	0.595	210	144	354	211	**28362**	**27261**	**1,459**	26286
14	0.572	210	1872	2082	1191	**30444**	**28452**	**737**	26797
15	0.550	210	144	354	195	**30798**	**28647**	**993**	26875
16	0.529	210	144	354	187	**31152**	**28834**	**1,238**	26945
17	0.508	210	144	354	180	**31506**	**29014**	**1,475**	27009
18	0.489	210	144	354	173	**31860**	**29187**	**1,702**	27066
19	0.470	210	144	354	166	**32214**	**29354**	**1,920**	27117
20	0.452	210	144	354	160	**32568**	**29514**	**2,131**	**27164**

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point (6.99 years). Discounted payback, which considers the time value of money, occurs when the cumulative present worth of all payments is less than the same payments for System 1. This occurs at approximately 8.12 years. Over the 20 year system life, in today's dollars, System 2 is $2,044 less expensive than System 1. Averaged over the life of the system, the discounted Rate of Return (ROR) is equal to the interest rate that provides identical 20-year present worth values. The rightmost column shows this occurs at an interest rate of 11%, which is the ROR.

18.9 Economic Analysis Software

In general, it is quite easy to perform a lighting system economic analysis in a spreadsheet. Costs should be categorized as one of the following

- Initial costs, which are already at present worth.
- Annual costs that are unchanged over the system's lifetime.
- Intermittent costs that occur at recurring intervals throughout the system's life, but change from year to year.
- Salvage costs that occur at the end of the system's life.

The latter three are converted to an equivalent present worth using the appropriate multipliers.

A number of different economic analysis tools are available to perform these functions [9-12]. Some of these are standalone programs, while others are modules attached to another lighting analysis program.

18.10 Summary

The consideration of economics in the design and selection of lighting equipment and lighting systems will help to provide maximum long term benefit to a building owner by providing a quality lighting solution at lower net cost. Remember that the types of economic analysis described in this chapter are intended for the evaluation of systems that offer equivalent lighting quality, otherwise the additional cost or savings between two systems reflects the costs incurred or savings gained in moving to a higher or lower level of lighting quality. Keep in mind that differences in lighting quality are likely to have financial implications beyond what is reflected in most economic analyses.

18.11 References

[1] IES Design Practice Committee. 1980. Life cycle cost analysis of electric lighting systems. Light Des Appl. 10(5):43-48.

[2] DeLaney WB. 1973. How much does a lighting system really cost? Light Des Appl. 3(1):22-28.

[3] IES. Lighting Economics Committee. 1996. Recommended practice for the economic analysis of lighting, IES RP-31-1996. New York: IESNA.

[4] White JA, Case KE, Pratt DB. 2010. Principles of engineering economic analysis, 5th Ed., Hoboken: John Wiley & Sons.

[5] Waier PR, Babbitt C, Baker T, Balboni B. 2010. RS Means building construction cost data 2010. Kingston, MA: RS Means.

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[6] Chiang J, Babbitt C, Baker T, Balboni B. 2010. RS means building construction cost data 2010. Kingston, MA: RS Means.

[7] Fuller SK, Peterson SR. 1996. Life cycle costing manual for the federal energy management program: NIST handbook 135, 1995 edition. Gaithersburg: Natl Inst of Stds and Tech; [cited 2010 Jan 20]. Available at http://www.nist.gov/customcf/get_pdf.cfm?pub_id=907459.

[8] ASTM Committee E06.81 on Building Economics, ASTM E917 - 05e1 Standard practice for measuring life-cycle costs of buildings and building systems. West Conshohocken: ASTM.

[9] Fetters JL, 1998. The handbook of lighting surveys and audits, Boca Raton: CRC Press. 51-60 p.

[10] Acuity Brands Lighting. 2010. Economic viewer 2.0 software.;[cited 2010 Jan 20]. Available at http://www.acuitybrandslighting.com/lightware/Software/Economic_Viewer/.

[11] Cooper Lighting. 2010. Luxicon software; [cited 2010 Jan 20]. Available at http://www.cooperlighting.com/content/design/etools.cfm.

[12] General Electric Co. 2010. Value light software; [cited 2010 Jan 20]. Available at http://www.gelighting.com/na/business_lighting/education_resources/tools_software/.

[13] Owen MS, Ed. 2009. 2009 ASHRAE handbook: Fundamentals. Atlanta, GA: ASHRAE.

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19 | SUSTAINABILITY

The future belongs to those who understand that doing more with less is compassionate, prosperous and enduring and thus more intelligent, even competitive.
Paul Hawken, environmentalist, entrepreneur, journalist, and author

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19.2 Elements of Sustainable Lighting Design 19.2
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19.6 References 19.12

Applying sustainable approaches to building design has gained wide acceptance in recent years in response to concerns about climate change, depletion of the world's natural resources, pollution, and concerns about human health and well-being. The United Nations World Commission on Environment and Development, in 1987, declared that "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[1] In the lighting profession, the IES and International Association of Lighting Designers (IALD) have defined sustainable lighting design as "meeting the qualitative needs of the visual environment with the least impact on the natural environment." [2] [3] Sustainable design attempts to balance our current needs with that of future generations by using natural resources wisely and protecting the natural environment.

Lighting is a major component of sustainable building design, due to its potential impact on the environment and on society. The electricity used to power lighting systems consumes 25% of commercial building primary energy [4]. Electricity production in the United States is largely based on fossil fuel burning power plants, which release carbon dioxide, mercury, sulfur dioxide and nitrous oxides that contribute to global warming and acid rain. Hazardous materials such as mercury and lead solder are used in the production of certain lamps. The manufacture of lighting equipment also consumes natural resources and energy; most lamp and luminaire components consist of steel, aluminum, copper, other metals, glass, and plastic [5].

Lighting also impacts the quality of the visual environment. Lighting affects human health, comfort and performance in building interiors, where many people spend the majority of their waking hours. Understanding how design decisions affect both occupants and the natural environment is necessary to achieve more sustainable design solutions.

Sustainable design begins with a set of goals that are developed at the initial project programming stage. These include lighting performance, energy performance and environmental impacts of a design that span from the materials used in the manufacture of the lighting products, to the installation and operation of the lighting system, and finally to disposal of these components at end of life.

19.1 Basic Concepts

Sustainable design considers a building's economic , societal, and environmental impacts, which McDonough has labeled as economy, equity and ecology [4]. Products should be designed and utilized to have a positive impact on nature and society, while creating economic value. McDonough's "cradle to cradle" concept suggests that products should be designed so that upon end of useful life their materials can be converted into new products, such as occurs with recycled steel, glass, and aluminum. If a product is made of a synthetic material, that material should be one that can be recycled. Metals and glass are the primary ingredients in most lighting products, so many of these products can both apply recycled

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content and be recycled when decommissioned. This approach is preferred to over a "cradle to grave" approach where a product is sent to the landfill, and its replacement must be created from scratch using the basic raw materials. This can consume greater amounts of energy and more of the earth's available resources than would occur using recycled materials. The recycling of lamps containing mercury helps to recover that mercury for use in new products and keep it out of landfills and the environment.

With lighting, a major focus of sustainability is the energy required to operate a lighting system over its lifetime, which can be significant. Reduced energy consumption can be accomplished through the use of daylight and energy efficient lamps, luminaires, layouts and lighting control systems. Some lighting system components, such as poles for exterior lighting and luminaire housing materials, have no end use energy impact and can be evaluated like most other building materials.

19.2 Elements of Sustainable Lighting Design

Sustainable building design considers the impact of all building materials and systems on both the occupants and the environment. Emphasis is placed on the quality of the interior environment, energy consumption, and environmental influences of all related activities – from raw material extraction to the eventual retirement and disposal of the system, as well as on the embodied energy of the equipment being used, and on the release of harmful materials to the environment.

Sustainable lighting can be addressed in a variety of areas: system and component design, system operation, quality of the visual environment, and disposal. A number of key considerations are listed below.

1. Apply quality daylighting as the primary source of light at appropriate levels. This will reduce reliance on electric lighting, save lighting energy, and extend in-service lamp life when luminaires are switched off during daylight hours.

2. Enhance work environments by connecting occupants to the exterior through daylight and view apertures.

3. Minimize electric lighting energy consumption through energy efficient equipment, integrated building design [7] and energy saving lighting controls. Apply the correct amount of electric lighting only where and when it is needed to conserve energy and reduce electrical demand based on time of day, occupancy and available levels of daylight. Flexible personal control of lighting equipment can save additional energy when reduced levels are selected by occupants [8] [9] [10].

4. Provide a pleasing and comfortable visual environment that enhances occupant performance, health and general well-being.

5. Employ systems and equipment that offer flexibility (which may include system reconfiguration), durability, and ease of maintenance. These features ensure the system will be in place for many years, adding to the sustainability of the design by avoiding the need to change equipment as space functions change.

6. Specify equipment made with environmentally responsible materials that minimize chemical and material waste and environmental pollution

7. Consider options that reduce packaging material and transportation requirements.

8. Provide for proper commissioning, and document system operation, maintenance, commissioning and lamp recycling procedures in a lighting systems operation and maintenance manual.

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9. Minimize light pollution and light trespass by applying outdoor lighting according to the environmental zone at the building site and by stepping back or eliminating lighting at a given curfew.

10. Specify that all lighting products be appropriately recycled or disposed at end of useful life.

Sustainability should be considered at all phases of the lighting design process, beginning at the project programming stage. Sustainability is often dictated by the project client who desires a building that meets a given level of sustainability as qualified through a green building rating system. Even without such a requirement, many of the elements of sustainable design represent good design practice and should be considered. More details on each these design elements that can contribute to sustainability are described in the following sections.

19.2.1 Daylighting

Since daylight availability corresponds to the standard work day and most building occupancy schedules, lighting energy can be minimized through the application of daylighting to partially or fully illuminate building interiors. In addition to saving energy, daylight can enhance the quality and appeal of a space through its dynamic nature, higher luminances, and excellent color quality. Occupant well-being is improved through connections to the exterior environment provided by view windows and daylight apertures. See Figure 19.1. To achieve a quality daylit environment, direct sunlight and glare through daylight apertures must be controlled. Daylighting designs that meet occupant and space needs with net energy savings (considering both lighting and HVAC energy) demand an integrated design approach by the project team, since daylighting affects multiple building systems and design decisions (see 14.2 Daylighting Design Process). Building siting and layout, selection of glazing material, aperture sizing and placement, and sunlight control are critical to overall system performance and energy savings potential. Excessive glazing can lead to glare and high heating and cooling loads. Automatic control of daylight is necessary to ensure energy savings are achieved.



Figure 19.1 | A Daylit Office
Workers in this open office area are provided with daylight and a view. Note that no electric lighting is operating. The skylight well contains baffles to block direct sunlight and provides daylight to wash an interior wall on a lower level.
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19.2.2 Electric Lighting

A sustainable electric lighting system requires energy efficient equipment, a well-planned layout, and in some cases flexible or automatic lighting control. Current building energy codes restrict lighting power densities and require specific lighting control features to guarantee that base levels of energy efficiency are achieved. Additional energy can be saved by designing systems with even lower installed lighting power, or by controlling the system to reduce system operating power or hours of operation. Quality lighting must be maintained under all conditions.

In the design of electric lighting, a layered lighting approach helps to achieve energy savings. Under such an approach, required task levels may only be provided over the immediate task area with general ambient lighting at a lower level to maintain visual comfort and performance while enhancing space appearance. See Figure 19.2 and 15.1 Electric Lighting Systems. Sustainable designs must be both functional and pleasing in addition to addressing energy and environmental concerns. Designs and equipment that permit easy reconfiguration are desirable in spaces that may be rearranged periodically. If the lighting design is lacking in any way, including aesthetics, a space may not be used to its fullest intent, or the lighting system is likely to be removed and replaced, both of which are an inefficient use of resources.

19.2.2.1 Equipment Considerations

To address sustainability in the selection of lighting equipment, the following aspects of the lighting equipment should be considered.

- energy efficiency
- lighting quality relative to task visibility, visual comfort and aesthetics
- controllability
- recycled and recyclable materials
- embodied energy
- hazardous waste or by-products (through manufacturing, use, or disposal)
- required maintenance

Figure 19.2 |Task Lighting
Task lighting within an office cubicle supplies the desired work surface illuminance, while ambient lighting provides lower general levels of illuminance across the space, which saves energy. Indirect lighting helps to increase the overall perception of space brightness. The left side of this workstation applies an undercabinet task light that also helps to balance luminance ratios within the work station, while the right side contains a flexible LED desktop luminaire.
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- life/durability
- packaging and transportation requirements

19.2.2.2 Lamps

Section 13.11 Sustainability provides an overview of the sustainability issues pertaining to lamps. Figures 13.1a and 13.1b provide information on lamp efficacy and lamp life, both of which are related to sustainability. Lamp efficacy, while it contributes to energy efficiency, does not always predict the most energy efficient lighting system. General comments on each of the primary source types are provided below.

Filament

The lamps in this family are among the least efficacious and their use should be minimized. Both luminous efficacy and lamp life are low. Their use for general ambient lighting should be avoided, but may be appropriate for some accent lighting and in limited historic settings. The most efficient forms apply halogen infrared (IR) technology. Filament lamps have relatively low embodied energy and no hazardous waste.

Fluorescent lamps

Fluorescent lamps, even though they contain mercury, couple energy efficiency with long life to contribute to a more sustainable design. Mercury content of fluorescent lamps has been significantly reduced over the past 25 years as shown in Figure 19.3 [11]. All varieties of fluorescent lamps should be recycled to avoid placing mercury into landfills or incinerators. CFLs are an energy efficient replacement for general service filament lamps in many applications. Fluorescent lamps reduce mercury emissions to the atmosphere relative to less efficient filament lamps when powered by an oil- or coal-sourced utility [13].

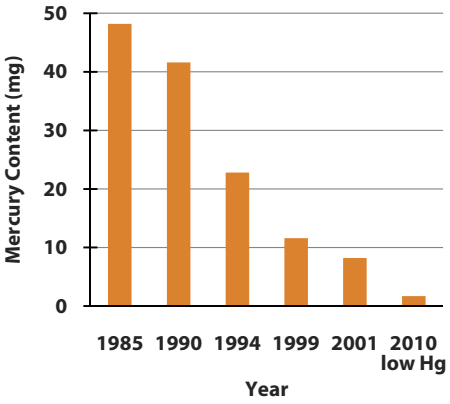


Figure 19.3 | Average Mercury Content of Four-foot Fluorescent Lamps
Mercury content of fluorescent lamps has been significantly reduced over the past few decades. Some four-foot lamps in 2010 have mercury content under 2mg [12], but an industry average is not available.

HID

Many HID lamps contain mercury and lead-based solder and therefore should be recycled. Some HPS lamps are now available with no mercury or lead. HID lamps can be a sustainable design option since the application of high output lamps may reduce the number of luminaires required, provided relevant quality criteria are met, especially those related to glare. HID lamps have relatively long lives, particularly in relation to filament lamps. Ceramic metal halide lamps offer excellent color quality and high efficacy, and can be used to replace filament lamps in a variety of applications, including those requiring reflector lamps. In some applications, such as industrial and high bay applications, fluorescent lamps have replaced HID lamps due to their longer life and more flexible control options.

Solid State

Solid State Lighting (SSL), if properly applied, can have very long lamp life, as in the case with most LEDs, that reduces the need for replacement. This, in itself, can be considered a sustainable feature. LEDs also offer small size, good energy efficiency (which is continuously improving and expected to exceed that of all other known electric sources [14]). LEDs can compete with both halogen and CFL downlight equipment in terms of energy and photometric performance. They offer exceptional directional control and the opportunity for dimming or multilevel switching. In exterior lighting, multilevel switching is possible using occupancy sensors to reduce energy in parking areas when these areas are unoccupied. The requirement for drivers and heat sinks must be considered in evaluating LED systems.

As of this writing, LEDs are powered by low voltage DC current, which makes them excellent candidates for application with photovoltaic systems. Wiring distances, however, can create a challenge with DC systems since current flow is much higher at low voltages, which contributes to increased wire losses and voltage drop. When lighting is powered by site-generated photovoltaic systems, the savings in primary energy are greater than simply the load removed from the grid due to inefficiencies in power generation and distribution. The national average for the ratio of source to site power is roughly 3.4, which means that it takes more than three times as much energy to be consumed at a power plant to operate a given load within a building.

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19.2.2.3 Ballasts

Fluorescent ballasts should be electronic to minimize ballast losses. Dimming ballasts provide the opportunity to achieve energy savings when the occupant desires reduced space brightness, or when daylight is available. Digitally addressable dimming ballasts offer highly flexible control options, and the ability to monitor energy consumption, institute load shedding, and be informed of equipment failures. Some fluorescent ballasts are designed to provide stepped dimming or peak load reduction.

For HID luminaires, magnetic HID ballasts use significant quantities of copper and iron in their windings, requiring more raw material to be mined and processed. Electronic ballasts are now available for a number of low wattage HID lamps, offering energy savings and requiring less raw material to manufacture. Stepped-dimming ballasts permit HID lighting levels to be lowered, with resulting energy savings.

19.2.2.4 Luminaires

In selecting luminaires, the ability to deliver high quality, low glare lighting with low environmental impact is critical. Along with quality, high system energy efficiency is key, and results from a combination of both lamp efficacy and luminaire optical performance. Other attributes such as materials used, durability, life, maintenance, and adaptability to changes in space use or layout further determine the ultimate sustainability of a particular product or design. Components of luminaires generally consist of steel, aluminum, plastic and glass, most of which is recyclable. Both the recycled content and the ability to recycle components at end of life affect the sustainability of a product. When used as a common reflector material, aluminum is often anodized, which is a relatively environmentally responsible process since it generates no hazardous waste and does not complicate the recycling process. Painting of metal parts is typically performed with powder coatings that emit little to no volatile organic compounds (VOCs).

19.2.2.5 Controls

Controls, including local, scene, timer-based, occupancy-based, photosensor, and personal controls are key energy saving features of electric lighting systems (See 16 | LIGHTING CONTROLS for details on each of these systems). Once a lighting system is installed, the control system and occupant behavior largely determine energy consumption. To function properly, automated lighting control systems must be properly selected, designed and commissioned. For best results, commissioning of scene, occupancy and photosensor systems should occur after spaces are furnished. A plan for how a system will be commissioned and operated should be addressed during the design process. A third-party commissioning agent is typically responsible for this work. This person is often involved in planning and review throughout the building design process, to ensure that the owner's needs are continuously addressed through an integrated design process [15].

Since lighting needs and preferences vary by individual, personal or occupant controls are recommended in most work areas. These may take the form of low wattage task lighting with local control or an adjustable overhead system in a private office. The ability to dim or switch to achieve different lighting levels will save energy for occupants who prefer less than full system output. The establishment of appropriate lighting scenes in spaces with scene control enhances system flexibility and performance while contributing to energy savings.

Smart zoning limits the portion of a lighting system that must be operated based on occupancy or daylight conditions. Flexible control settings permit lighting in daylighted areas to be adjusted to appropriate levels through either dimming or switching to provide energy savings, even when no automatic photosensor control system is installed. Occupancy sensors can be used to save lighting energy in a wide variety of spaces, including work spaces, classrooms, conference rooms, break rooms, supply and print rooms, resetrooms, corridors, stairways and outdoor spaces. Automatic-off technologies should turn lighting off when not needed or when the space is unoccupied. In some of the spaces, reduction to a lower illuminance is preferred to complete system shutoff. Consult codes to verify which types of control are permitted in different spaces.

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Systems that minimize operating time may also contribute to longer in-service equipment life, reducing waste and conserving resources through less frequent component replacement.

19.2.2.6 System Maintenance

Regular luminaire maintenance in the form of cleaning and relamping helps to minimize installed lighting power through the application of higher light loss factors in design calculations (see 10.7.1.2 Recoverable Light Loss Factors). At the design stage, knowing that good maintenance practices will be in place can result in fewer luminaires being required to maintain target illuminance values, lowering installed lighting power levels which leads to reduced energy consumption.

19.2.2.7 Room Surface Materials

Sustainable building designs often attempt to minimize the use of paints and apply materials in their natural state. Typically the reflectance of these materials is lower than what is recommended for efficient lighting system design. Lower reflectances result in greater energy costs through reduced daylight levels and greater installed lighting system power. A life cycle cost analysis should be performed to determine the net effects of applying unpainted versus painted surfaces.

19.2.2.8 Packaging and Transportation

Sustainability can also be addressed in the environmental costs associated with packaging and transporting a particular product from its manufacturing site to the location where it will be installed. Packaging materials can be minimized, utilize recycled materials, and be reusable or biodegradable to improve sustainability. The specification of smaller, lighter weight products can also reduce the energy required to transport these items. Similarly, purchasing products from local manufacturers that make use of locally supplied components will reduce transportation energy.

19.3 Light Pollution and Trespass

Light pollution involves light that is directed skyward, hindering or eliminating the view of the starlit sky on clear nights (see Figure 19.4). Light trespass, on the other hand involves light that leaves a site and strikes a neighboring property, which may be considered a

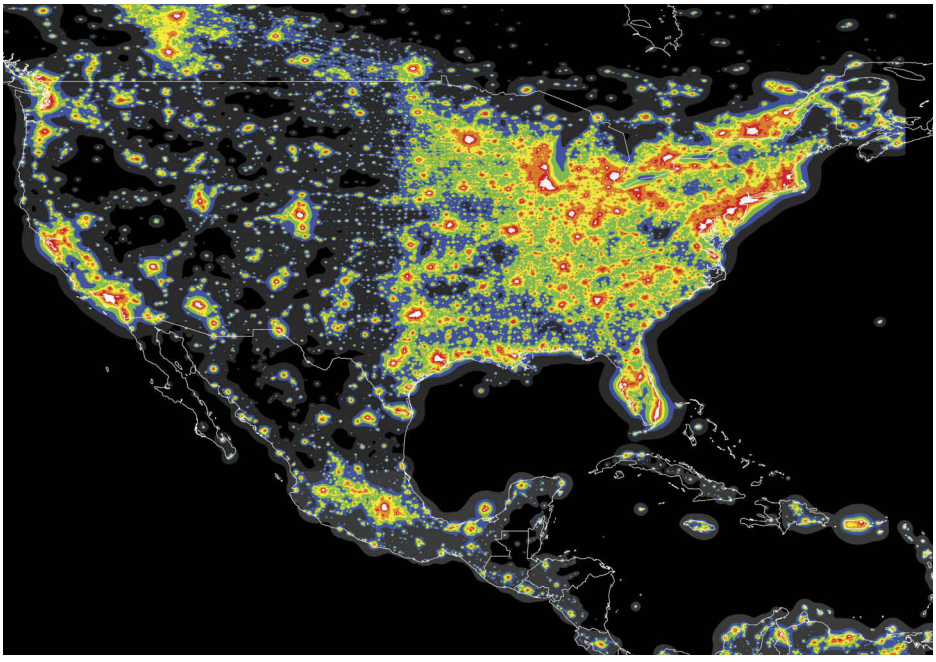


Figure 19. 4 | Light Pollution Map
This map shows calculated levels of sky luminance across Mexico, the United States and Canada [16]. High population areas produce higher levels of light pollution.
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nuisance. Sky glow and light trespass both represent poor lighting design since they waste energy by directing light to areas other than the intended target.

In exterior lighting for buildings, signage, landscape and hardscape, light pollution and trespass can be limited by minimizing the use of light to what is essential for safety, with decorative lighting limited to selective accents rather than wide area floodlighting (which can enhance aesthetic appeal as well as energy efficiency), by directing light downward and through careful optical control. At the time of this handbook's printing, the IES and the International Dark Sky Association are working toward development of a Model Lighting Ordinance (MLO) that provides municipalities with suggested language and guidelines for use in formulating local ordinances. Lumens emitted in the upward zones of the BUG rating system may be limited based on the environmental zone in this or similar outdoor lighting ordinances (see 8.2.2.6 Outdoor Environmental Classification).

Light trespass can be avoided by selecting luminaires with appropriate optical control and by applying a layout that directs light primarily toward the intended targets. Shielding attachments can help eliminate spill light onto neighboring properties and toward the sky. Both well-designed optical systems and timers that turn lights off at a predetermined time can help limit both light trespass and light pollution. Illuminance levels should be as close as possible to IES recommended values, avoiding excess wherever possible to minimize energy consumption. See Figure 19.5 for a gas station canopy example. Bi-level switching of luminaires in outdoor areas is available with some equipment to help limit light pollution and save energy by reducing illuminance when areas are not occupied.

In some situations, lighting must be controlled to avoid detrimental effects on wildlife [17]. Sea turtles lay their eggs on the beach. When the turtles hatch and emerge during the night they are attracted to the sea, which is typically brighter than the land. Neighboring streetlights and houselights can cause the turtles to travel inland, where they are likely to perish. Exterior lighting is also known to disrupt the flight of nocturnal migratory birds, who may be attracted to structures such as lighthouses and radio towers. Continuously operating lights, particularly red have been shown to be most problematic. The birds can become disoriented and crash into the structure or its support devices. Other creatures known to be attracted to light include certain insects, and specific species of bats and fish. Lamps with UV radiation have a higher attraction rate than HPS, while low pressure sodium offers little in the way of attraction. Studies on nocturnal mammals have shown reduced movement and feeding under full moonlight for a number of species, most likely to reduce predation



Figure 19.5 | A Fuel Service Station
This lighting system was designed to strict light pollution criteria. Illuminance at the pumps is approximately 10 fc and most of the light is concentrated under the canopy. The local exterior lighting ordinance focusses on providing dark skies by limiting emitted lumens based on canopy area. Spill light from the drop lens luminaires and canopy provide low level lighting for adjacent pavement areas, but may contribute to light trespass onto neighboring properties. The canopy serves as a cutoff optic for these luminaires to prevent direct light from leaving the canopy area above horizontal. Recessed, flat lens luminaires would further control spill light and light trespass in a canopy application. The sign uses colored luminous letters on a black background to minimize the emitted lumens.
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risk. Further research is needed in many of these areas to better understand the effects of modern lighting equipment, including more modern sources such as LEDs.

19.4 Assessing Sustainability

Individual products can be assessed with regard to sustainability in a number of ways. The primary approach involves a technique known as Life Cycle Assessment (LCA) [18] [19]. LCA evaluates a product's cumulative impact on the environment throughout its lifetime or another time period, which is addressed through the following four life cycle stages:

- Raw materials and their acquisition
- Manufacturing and transportation
- Installation, maintenance and operation
- Disposal and recycling

At each of these stages, inputs of energy and raw materials are considered, along with outputs that include the desired product along with atmospheric emissions, waterborne and solid wastes, and other by-products (see Figure 19.6). These emissions are characterized according to their potential to cause several environmental impacts such as global warming, ozone depletion, and acidification, among others. A LCA is applied to compare alternative solutions or products to determine which offers the least environmental impact.

A number of different software tools [20] [21] are available to address LCA for building materials, products and projects; however none currently contains detailed information on lighting systems or equipment. Hence, the ability to conduct a full LCA on a lighting

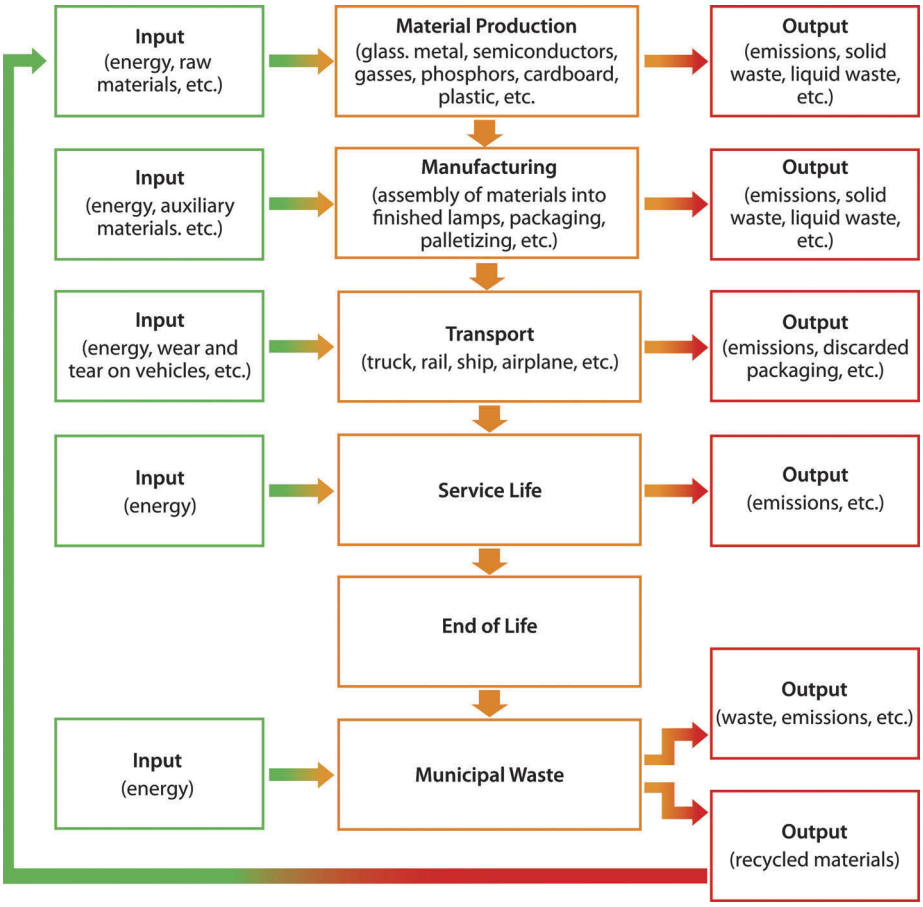


Figure 19.6 | Life Cycle Analysis (LCA) Input and Output
LCA considers the social, environmental and economic impacts of the production, operation, and disposal of the materials used in a system or product. This flowchart addresses the different aspects of a product's life cycle that can be addressed in LCA.

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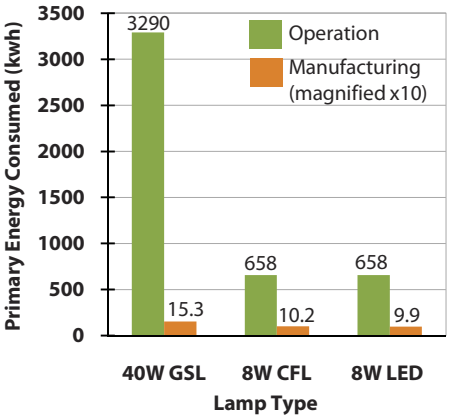


Figure 19.7 | Primary Energy Consumption: Lamp Use versus Lamp Manufacturing
The primary energy required to manufacture and operate three lamp types (including ballast losses) over a 25,000 hr period is shown for a 40W filament General Service Lamp (GSL), an 8-watt CFL and an 8-watt LED lamp. Operating energy is 60 times more than manufacturing energy even for low-wattage lamps and 200 times more for the filament source. Energy required to manufacture the ballasts, drivers and heat sinks are included. The short life of the GSL (1000 h) requires more frequent relamping for this lamp over the life of the study. [22]

Table 19.1 | Sustainability Categories Used in Green Building Rating Systems (2010)

LEED (USGBC, CanGBC)
• Sustainable sites
• Water efficiency
• Energy and atmosphere
• Materials and resources
• Indoor environmental quality
• Innovation and design process
BOMA BESt / Green Globes
• Integrated design process
• Site
• Energy
• Water
• Resources
• Environmental management
• Indoor environment

system is not practical for a lighting designer. Manufacturers are more likely to have access to the information required to assess alternate product or material decisions and some have conducted such analyses in refining their products to make them more sustainable.

In many situations, simplified measures that address only a subset of the quantities considered in a full LCA are applied. One example is embodied energy – the total energy required to make, install, and dispose of a product. Assessment of lamps has shown that operating energy is likely to be many times the energy required to produce a product [22], which explains the importance that energy consumption plays in quantifying the sustainability of building lighting systems (see Figure 19.7). A similar metric is carbon footprint, which consists of CO_2 emissions of a product or system throughout its life cycle. Carbon footprint is applied not only to products, but may be applied to larger entities such as a complete facility, or even to an entire country. Energy consumption is directly linked to carbon footprint, which largely comprises carbon dioxide (CO_2) emissions from electricity generation.

19.5 Sustainable Building Design Rating Systems, Codes and Standards

Since its release in 1998, the Leadership in Energy and Environmental Design (LEED®) Green Building Rating System [23], developed by the U.S. Green Building Council (USGBC) has transformed building design practice. Many buildings have received LEED certification and achieved a green building rating. Many owners, large institutions and end users now demand some level of green building design even when buildings are not submitted for formal recognition or rating. The Canada Green Building Council (CaGBC) operates a similar system in Canada [24]. The more popular Canadian green building certification system is Green Globes, which is operated in the U.S. by the Green Building Initiative (GBI) [25]. Both LEED and Green Globes offer certification credentials for building professionals. BOMA BESt from the Building Owners and Managers Association Canada is a similar system for existing buildings to which the Canadian government subscribes (earlier versions were named Go Green and Go Green Plus) [26]. The UK's Building Research Establishment Environmental Assessment Method (BREEAM) [27] is widely used outside North America, and was established a few years prior to LEED.

These green building rating systems typically award points to a project based on the inclusion or presence of different sustainable design and site features. The number of total points amassed determines the level of certification achieved. Both LEED and BOMA BESt/Green Globes offer four award levels. In the Green Globes system, they are one to four globes, while LEED classifies the four levels as certified, silver, gold and platinum. Within these systems, points are currently awarded within the categories shown in Table 19.1.

The USGBC developed different LEED rating systems for different project types. A list of the different rating systems based on building type is provided below. All of these contain provisions related to lighting.

- New Construction (NC)
- Existing Buildings – Operations and Maintenance
- Commercial Interiors
- Core and Shell
- Schools
- Retail
- Healthcare
- Homes
- Neighborhood Development

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Table 19.2 | 2009 LEED-NC Credit Opportunities Related to Lighting Systems

Credit*		Points	Requirements
IEQ 6.1	Controllability of Systems - Lighting	1	• Task lighting/individual control for 90% of occupants • Flexible controls in shared spaces
IEQ 8.1	Daylight and Views - Daylight	1 (1-2 SC) 2	• Daylight coverage - 75% of regularly occupied spaces • Daylight coverage - 90% of regularly occupied spaces
IEQ 8.2	Daylight and Views - Views	1	• Direct line of sight to outdoors via vision glazing from 90% of regularly occupied area
SS 8	Light Pollution Redution	1	• Limit interior light transmitted to the exterior from 11pm to 5am • Exterior - light only those areas required for for safety and comfort, limit direct light above horizontal • Exterior - limit illuminance at property line.
EA Prereq 1	Fundamental Commissioning of Building Energy Systems	-	• Required
EA Prereq 2	Minimum Energy Performance	-	• Energy costs are 10% lower than baseline building
EA 1	Optimize Energy Performance	1 to 19	• Points are based on energy savings relative to a baseline building and apply to all building systems that consume energy
EA 3	Enhanced Commissioning	2	• Early involvement of commissioning agent

* IEQ = Indoor Environmental Quality, SS = Sustainable Site, EA = Energy and Atmosphere

For LEED NC, a total of 40 points are needed to achieve the lowest LEED certification level, in addition to meeting specified prerequisite requirements. The credits currently available in 2009 LEED-NC [23] that relate to lighting systems are listed in Table 19.2. These are likely to change with each revision of the rating system.

In addition to building rating systems, green building construction standards are now available or are nearing completion. These documents are written in code language to be adopted by local municipalities. ANSI/ASHRAE/USGBC/IES Standard 189.1[28] was released in January 2010 and the International Green Construction Code (IgCC) [29] is currently under development and intended for release in 2012. These codes contain requirements for lighting power densities, automatic lighting controls (interior and exterior), daylight coverage across occupied spaces, lamp recycling, light pollution, and system commissioning. Standard 189.1 contains mandatory provisions as well as both a prescriptive and performance-based approach to address compliance with provisions of the code. The prescriptive approach involves meeting relatively simple performance requirements or metrics, whereas the performance approach involves more detailed daylight simulation and energy modeling.

The IgCC in its current draft has several project electives as well as jurisdictional electives. Project electives allow designers flexibility in meeting compliance on a project by project basis, while jurisdictional electives are meant to be set by an authority having jurisdiction for all projects in a state or territory. Standard 189.1 is one of the jurisdictional electives for the IgCC.

The U.S. Environmental Protection Agency provides an Energy Star label for buildings whose documented energy performance places them in the top 25% of the existing building stock of a similar type [29]. The rating system used to evaluate performance is the source Energy Use Intensity (EUI), measured in source energy per unit of building floor area per year (kBtu/ft^2/yr). The system accounts for differences in occupancy and operating conditions, regional weather data, fuel sources, and other details across different buildings. The

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existing building data set is taken from the Commercial Building Energy Consumption Survey (CBECS), a national building survey that occurs every four years. An Energy Star label applies to a specific year of operation, with renewal based on documented performance in future years relative to the most current evaluation of similar building stock.

19.6 References

[1] U.N. 1987. World Commission on Environment and Development: Our common future. [cited on 2010 Jun 4]. Available at http://www.un-documents.net/wced-ocf.htm.

[2] Loeffler M. 2002. Sustainable design-getting the green light, Archit Light. 17(1):27-29.

[3] IES Sustainable Lighting Committee. 2010. DG22 -Design guide for sustainable lighting: an introduction to the environmental impacts of lighting. New York: IESNA.

[4] McDonough W and Braungart M. 2002. Cradle to cradle: remaking the way we make things. New York: North Point Press.

[5] D&R International, Ltd. 2009. Buildings energy data book. U.S. Department of Energy; [cited on 2010 Oct 16]. Available at http://buildingsdatabook.eren.doe.gov/docs%5CDataBooks%5C2009_BEDB_Updated.pdf.

[6] European Lamp Companies Federation. 2010. About lamps and lighting: material composition. [cited on 2010 Jun 15]. Available at http://www.elcfed.org/2_lighting_composition.html.

[7] IES. 2009. IES position statement, integrated building design (PS-01-09). New York: IESNA.

[8] Maniccia D, Rutledge B, Rea MS, Morrow W. 1999. Occupant Use of Manual Lighting Controls in Private Offices. J Illum Eng Soc. 28(2):42-56.

[9] Boyce PR, Eklund NH, Simpson SN. 2000. Individual lighting control: task performance, mood, and illuminance. J Illum Eng Soc. 29(1):131-142.

[10] Newsham GR, Mancini S, Veitch JA, Marchand R\G, Lei W, Charles KE, Arsenault CD. 2009. Control strategies for lighting and ventilation in offices: effects on energy and occupants, Intelligent Buildings International. 1(2):101-121.

[11] NEMA. 2005. Fluorescent and other mercury-containing lamps and the environment. [cited on 2010 Jun 4]. Available at http://www.nema.org/gov/env_conscious_design/lamps/upload/Lamp%20Brochure%20Final%203%2005.DOC.

[12] Philips. 2010. Alto lamp technology - T8 collection. [cited on 2010 Jun 4]. Available at http://www.lighting.philips.com/us_en/browseliterature/download/ 5569_altot8.pdf.

[13] Gydesen A and Maimann D. 1991. Life cycle analysis of integral compact fluorescent lamps versus incandescent lamps. Proceedings of Right Light 1991, Stockholm.

[14] Navigant Consulting, Inc. 2010. Energy savings potential of solid-state lighting in general illumination applications 2010 to 2030. [cited on 2010 Jun 20]. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ ssl_energy-savings-report_10-30.pdf.

[15] The Building Commissioning Association. 2008. Best practices in commissioning existing buildings. [cited on 2010 Jun 30]. Available at http://www.bcxa.org/downloads/bca-ebcx-best-practices.pdf.

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[16] Cinzano P, Falchi F, Elvidge CD. 2001. The first world atlas of the artificial night sky brightness. Monthly Notices of the Royal Astronomical Society. 328:689-707.

[17] Rich C, Longcore T (Ed.). 2006. Ecological consequences of artificial night lighting. Washington, DC: Island Press.

[18] ISO. 2006. ISO 14040:2006 Environmental Management: Life Cycle Assessment-Principles and Framework. [cited on 2010 Jun 30]. Available at http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=37456ISO.

[19] ISO. 2006. ISO 14044:2006 Environmental management: life cycle assessment-requirements and guidelines. [cited on 2010 Jun 30]. Available at http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=37456ISO.

[20] NIST-BFRL. 2010. BEES (Building for Environmental and Economic Sustainability) software. NIST; [cited on 2010 Jun 4]. Available at http://www.nist.gov/el/economics/BEESSoftware.cfm.

[21] Athena Institute. 2010. ATHENA impact estimator for buildings. [cited on 2010 Jun4]. Available at http://www.athenasmi.org/tools/impactEstimator.

[22] OSRAM Opto Semiconductors GmbH, and Siemens Corporate Technology. 2009. Life Cycle Assessment of Illuminants: A Comparison of Light Bulbs, Compact Fluorescent Lamps and LED Lamps. OSRAM.

[23] USGBC. 2009. LEED reference guide for green building design and construction. Washington: USGBC.

[24] Canada Green Building Council. 2009. LEED Canada reference guide for green building design and construction. Ottawa: Canada Green Building Council.

[25] ECD Jones Lang LaSalle. 2010. Green Globes. [cited on 2010 Jun 4]. Available at http://www.greenglobes.com/.

[26] BOMA of Canada. 2010. BOMA BEst. [cited on 2010 Jun 4]. Available at http://www.bomabest.com.

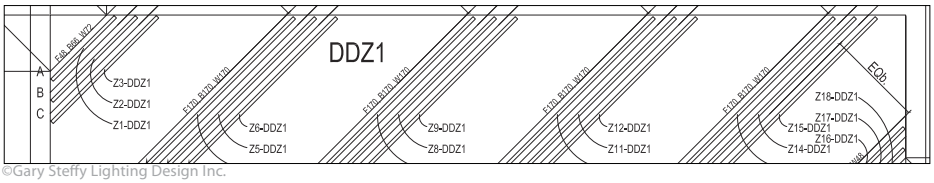
[27] Building Research Establishment. 2010. BREEAM: the environmental assessment method for buildings around the world. [cited on 2010 Jun 4]. Available at http://www.breeam.org.

[28] ASHRAE and USGBC. 2009. Standard for the design of high-performance green buildings except low-rise residential, ANSI/ASHRAE/USGBC/IES Standard 189.1. Atlanta: ASHRAE.

[29] International Code Council. 2010. International green construction code, public version 1.0. Country Club Hills, IL: ICC.

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20 | CONTRACT DOCUMENTS

The whole difference between construction and creation is exactly this: that a thing constructed can only be loved after it is constructed; but a thing created is loved before it exists.
Charles Dickens

Quality of documentation ultimately determines the quality and success of the finished lighting design. Documenting a design for purposes of construction requires careful preparation of plans, details, and specifications. Contract documents (CDs) that are clear, concise, and unambivalent are the objective. This chapter identifies the main components involved in contract documents for lighting. These are typically used as part of the package of project documents delivered to contractors for bidding and then subsequently used for procurement and installation. The design efforts outlined in the previous chapters culminate here.

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20.1 Responsibilities

The team member acting as the lighting designer is charged with documenting the lighting design. As noted previously, that team member may have other project responsibilities such as that of architect, interior designer, or electrical engineer. What follows is guidance for documenting a lighting design. Team members responsible for architecture, interiors, and electrical engineering have other tasks not necessarily outlined here, but which support or are related to lighting design documentation. Those other tasks include, for example, development of elevations, sections, details, mounting and support requirements, integration with other systems and devices, life-safety lighting, circuiting, and detailed control device and equipment layouts and specifications related to lighting. Tasks and responsibilities should be addressed in fee proposals and project scopes and clarified well before lighting design commences. Specific scope or jurisdictional requirements, including code compliance, will dictate which of the design team members is responsible for the development, review, and delivery of some or all of the documentation. See Table 11.1 | Example Lighting Scope and Deliverables. Coordination of responsibilities, documentation preparation, and scheduling of work efforts is necessary prior to project commencement. A project organizational chart typically puts the lighting design role in perspective with other design and engineering roles. [1]

Contract documents as presented here do not identify all of the specific details necessary to address the variety of project types typically encountered. For example, new construction documentation need not address the vagaries of existing conditions or conditions that may be found once demolition occurs on renovation or restoration projects. The designer must coordinate the documentation effort with the project type as determined by the licensed or registered professional in charge.

Procedures outlined here are intended to advance the practice of lighting design by whichever team member fills the role of lighting designer. The focus in this handbook is on what must and should be done rather than what traditionally has been done and accepted as lighting design.

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20.2 Documentation

The lighting design role of the team member charged with that effort involves preparation of documentation that describes, specifies, and illustrates the lighting solution. This documentation may be referenced or subsumed partially or entirely by other disciplines, such as architecture, engineering, landscape architecture, or interior design, or may stand as independent material. Regardless, the integrity of the documents is crucial to everyone's understanding of the lighting design. Everyone being the participants in the design, engineering, procurement, and installation, including architect, interior designer, electrical engineer, lighting consultant, owner, energy engineer, sustainability consultant, lighting representative, lighting manufacturer, contractor, and distributor. Documents should leave no doubt that altering any component in any way may be detrimental to any, many, or all of the programming requirements and may have a domino effect on other disciplines' designs and documentation.

Lighting contract documents should include drawings and specifications, cutsheets, and initial preset schedules. If any of these documents are not of sufficient integrity, the end result may be disappointing because of any or all of these results: 1) inappropriate substitutions, 2) procurement of incorrect equipment, 3) overlooked equipment; 4) incongruous layouts, 5) misaiming, 6) scrambled controls, 7) unfulfilled energy savings, and 8) dissatisfied clients.

Another component of lighting documentation involves review of at least key documents prepared by team members serving other roles. For example, daylighting, electric lighting integration into electrical plan set, lighting-related sections, elevations, and details should be checked for conformance to the lighting design intent.

What follows is indicative of the documentation necessary to convey the lighting design and outline requirements and expectations of the contractor.

20.3 Drawings

Plans are the most common drawings that are part of the lighting documentation. Additionally, architectural elevations, sections, and details may be necessary. Plans endeavor to illustrate the layout of lighting equipment, identify luminaire types, establish control zoning, and indicate control devices. Architectural elevations, sections, and details elaborate specific items for which the plan and specification do not provide clarity of intent.

20.3.1 Lighting Plans

Ultimately, lighting plans must document all lighting on the project. Debates may arise about the interpretation of reflected ceiling plans (RCPs) and what lighting information is to appear on the RCPs. Nevertheless, the plans must convey to the team, client, jurisdictional authorities, and the contractor all of the lighting equipment that is to be installed. These plans are also the basis for the client's as-built set of documents identifying all lighting equipment to be maintained. So it is, then, that not only lighting equipment in and on the ceiling must be shown, but the lighting in and on walls, in and on millwork and other built-in and freestanding elements, and in and on floors also must be shown. The team must resolve on which plans these different types of luminaires are to be shown and how these plans are to be labeled. EL sheets, using National CAD Standard "E" for "Electrical" and "L" for "Lighting", is a means of conveying all lighting equipment on a single set of plans. [2]

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Given their influence and reliance on architectural configurations, daylighting elements are part of the inherent architecture and so are detailed on architectural plans and in architectural specifications. This includes daylight apertures, glazing, shading, and surface configurations and reflectances. These architectural daylighting components should be evident on the architectural backgrounds used for the lighting plans and are inevitably used as reference locations for development of electric lighting layouts and control zoning.

EL sheets or the work represented on them may be subsumed into architectural and electrical sheets. For example, the electrical engineer may show control zoning information on electrical sheets along with circuiting. Reiterating, the division of work and what information is shown where must be established early in the design process. Also reiterating, the outline here attempts to identify all of the documentation necessary to illustrate the lighting design in its entirety and is not proposing which disciplines show which portion of the work on which documents.

Lighting plans should convey luminaires, their types, locations, and control zones. Table 20.1 identifies the plan drawing components for typical 2D implementation. National CAD Standards and ANSI-IES standard symbol sets offer basic symbols. However, additional degrees of visual information are appropriate in a time when accurate deployment of lighting is crucial to its efficient and effective operation. [3] [4] Symbols across disciplines require coordination early in design to avoid, for example, luminaire symbols matching mechanical device symbols. Figures 20.1a, 20.1b, 20.1c, and 20.1d introduce a visually informative luminaire symbol set for 2D planning primarily for interior lighting. Figures 20.2a and 20.2b introduce a set for exterior lighting. Figure 20.3 introduces controls symbols. This detail in layout designation can also serve as a quality-control check and confirmation on design intent during documentation as luminaires are seen against final architectural and landscape backgrounds. CAD allows for ready implementation of these visually informative symbols. A more literal representation of the luminaire in plan helps distinguish one variety from another. Since the installers in the field are likely to reference just plans, the more concise the information that can be conveyed on the plan the better. As additional lighting technology and techniques advance, additional embellishments and symbols can be employed to distinguish these variations. The print copy of the lighting plan might be done with the lighting information printed in normal black while background information is halftoned as exemplified in Figure 20.4.

Symbols for 3-dimensional CAD should be scaled 3D representations of their real-world counterparts. Luminaire vendors offer Building Information Modelling (BIM) symbols of their respective and various luminaires. While this minimizes the designer's time on developing 3D models of specific selections, it can inadvertently identify forms, shapes, and dimensions not entirely representative of all of the brands specified. At the project's outset where 3D CAD is required, a generic set of 3D luminaire models should be established which encompasses rough styling of the luminaire families and provides anticipated maximum sizes. As the project progresses, these luminaire models should be refined. After several such projects, a robust library of luminaire models will then be available. Models should represent 3-dimensional characteristics of likely luminaire candidates, covering the range of the number of acceptable versions. Complete and rather accurate modeling is needed if clash-detection, fit, and renderings are to be employed. Table 20.2 outlines some characteristics typically embodied by and embedded in 3D luminaire models which are commonly used in BIM or 3D CAD building models. The more detailed this information becomes, the higher the risk of error if this same information is to be reported in luminaire specifications, since this demands that the information be tracked and accurately transcribed in more than one location. For this information to reside solely in the 3D model risks that contractors will not reference specifications, which is where more complete information is placed regarding luminaires installation, aiming, lamping, finish, orientation, and the like. Further, few field

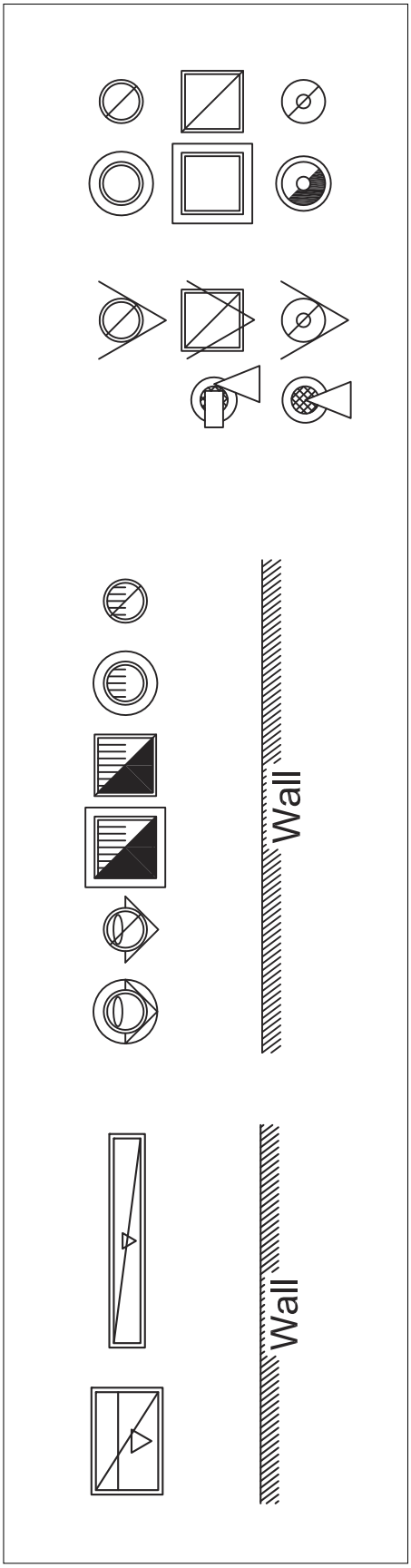
Table 20.1 | Plan Drawing Components

Component	Representation
Luminaire	Basic function • accent • downlight • pendant • wallwash
	Shape
	Size
	Symbol • 2D for 2D cad • 3D for 3D cad
Type	Designation • unique alphanumeric tag
Location	Position • hard dimension • *obvious dimension*
	Hosting surface • ceilings • floors • furnishings • walls
Control	Zone • unique alphanumeric tag • looping

Obvious dimension as used here is a reference to an apparent specific location, such as the center of a 2'x2' tile where a downlight is located. Typically, a hard dimension is not applied as the exact location is obvious.

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Figure 20.1a | Downlight, Accent, and Wallwash Luminaires 2D Symbol Set



Downlights

- draw symbol to match size and shape
- adjust scale and line weight as necessary for visibility on plan
- diagonal line (from lower left to upper right) to denote recessed
- add outer line representing housing enclosure for surface mounts (illustrated on bottom three)
- with diagonal fill to denote emergency lighting

Adjustable accents

- draw symbol to match size and shape
- adjust scale and line weight as necessary for visibility on plan
- use arrowhead to indicate aiming direction for recessed adjustable luminaires
- diagonal line (from lower left to upper right) to denote recessed
- use Isosceles triangle orienting short leg in direction of light throw for monopoints
- monopoint on far left shown with transformer/driver housing which may affect installation/aiming orientation
- with diagonal fill to denote emergency lighting

Wallwashers

- draw symbol to match size and shape
- adjust scale and line weight as necessary for visibility on plan
- use arrow or hatching (open area oriented to wall surface being washed) to indicate orientation
- diagonal line (from lower left to upper right) to denote recessed
- add outer line representing housing enclosure for surface mounts (illustrated in 2nd, 4th, and 6th from top of series)
- with diagonal fill to denote emergency lighting

Linear or rectilinear wallwashers

- draw symbol to match size and shape
- adjust scale and line weight as necessary for visibility on plan
- use pointer to indicate aiming direction
- diagonal line (from lower left to upper right) to denote recessed"
- add outer line representing housing enclosure for surface mounts (not shown)
- use line work to represent identifiable baffle or reflector scoop
- with diagonal fill to denote emergency lighting (not shown)

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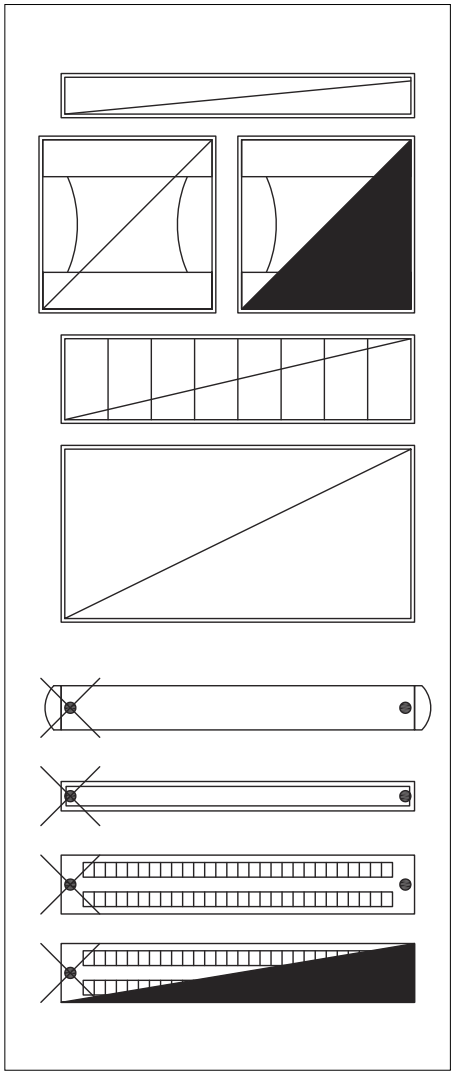


Figure 20.1b | Ambient Luminaires 2D Symbol Set

Linear or large area luminaires

- draw symbol to match size and shape
- adjust scale and line weight as necessary for visibility on plan
- diagonal line (from lower left to upper right) to denote recessed
- add outer line representing housing enclosure for surface mounts
- use line work to represent identifiable luminaire characteristics (e.g., side baskets, parabolic or blade baffles or louvers, lens or door configuration, etc.)
- with diagonal fill to denote emergency lighting

Linear suspended luminaires

- draw symbol to match size and shape
- adjust scale and line weight if necessary for visibility on plan
- solid circles indicate suspension point locations, match layout to correspond with design intent
- "X" used to indicate power feed location(s)
- use line work to represent identifiable luminaire characteristics (e.g., baffles or louvers, lens or door configuration, end caps, etc.)
- with diagonal fill to denote emergency lighting

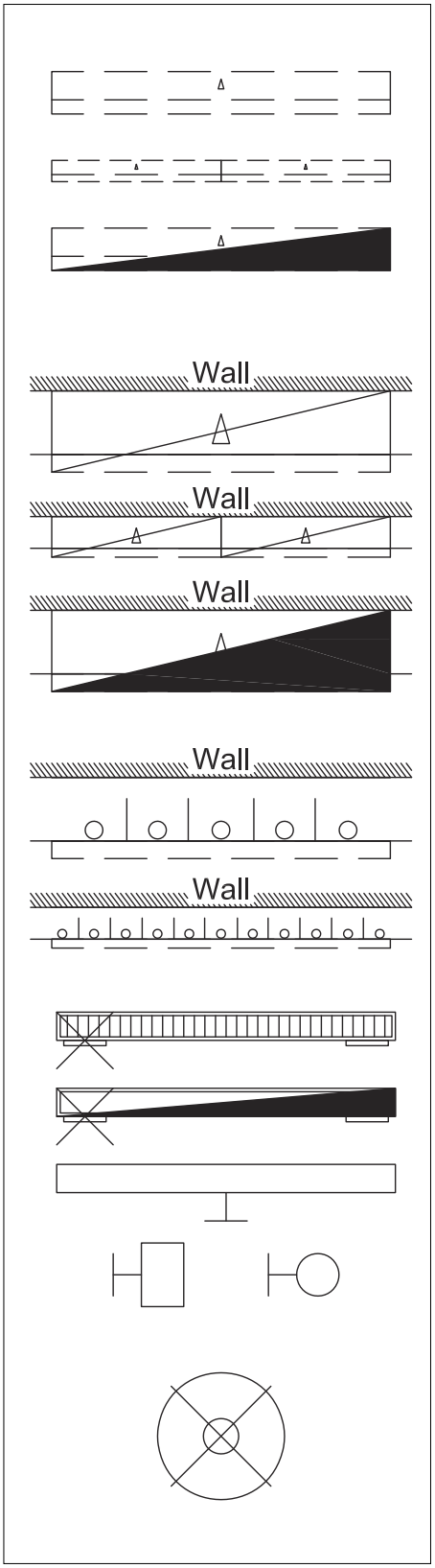
installers have access to or wish to encumber themselves with the equipment and skills necessary to view and interpret the 3D computer models in the field. Clearly a challenge that goes well beyond lighting and must be left to the architects, clients, and contractors to coordinate and resolve.

Luminaire layouts include dimensioned or dimensionally-obvious locations and type designations. Where luminaires are in non-modular construction, such as drywall, plaster, wood, stone, grade, and ground planes, their locations should be dimensioned. Otherwise, the contractor or installer might be inclined to scale drawings which, generally, increases risk of error. Where luminaires are in modular construction, such as standardized lay-in grid ceilings, luminaire locations are dimensionally obvious unless they are not centered in the ceiling module, in which case dimensions are necessary. Figure 20.4 illustrates lighting diagrammed in drywall and lay-in ceiling conditions.

Coordination efforts are made by the architect and engineer either of whom may fill the role of lighting designer. The lighting plan is typically overlaid onto the architectural RCP and lighting is then coordinated with exit signs, signage, standalone exit lighting, sprinklers, speakers, expansion joints, mechanical diffusers, smoke detectors, occupancy sensors, security devices such as glass-break detectors and other intruder-detectors,

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Figure 20.1c | Cove, Slot, Wallmount, Pendant Luminaires 2D Symbol Set



Cove (indirect lighting detail)

- draw symbol to match size and shape of individual units
- repeat units as necessary to convey design intent for layout (butted end-to-end as shown to limit/avoid socket shadows; butted front-corner-to-front-corner for inside curves and back-corner-to-back-corner for outside curves)
- adjust scale and line weight if necessary for visual clarity with dashed lines to indicate luminaire is above the visible ceiling
- use pointers to indicate orientation for asymmetric luminaires
- with diagonal fill to denote emergency lighting

Wallslot (wall grazing) from linear source (fluorescent, linear LED)

- draw symbol to match size and shape of individual units
- repeat units as necessary to convey design intent for layout
- adjust scale and line weight if necessary for visual clarity with dashed lines to indicate that portion of the luminaire which is above the visible ceiling (typically the offset for lamp position)
- use pointers to indicate orientation toward wall being grazed
- with diagonal fill to denote emergency lighting

Wallslot (wall grazing) from point source (CMH, halogenIR$_{LV}$, LED)

- draw symbol to match size and shape of individual units, showing individual lamps and baffles
- repeat units as necessary to convey design intent for layout
- adjust scale and line weight if necessary for visual clarity with dashed lines to indicate that portion of the luminaire which is above the visible ceiling
- use line work to indicate baffles if used between lamps
- with diagonal fill to denote emergency lighting (not shown)

Wall mounted luminaires

- draw symbol to match size and shape
- adjust scale and line weight if necessary for visibility on plan
- small boxes and/or arms represent mounting point/bracket locations, match layout to correspond with design intent
- "X" used to indicate power feed location(s) when necessary
- use line work to represent identifiable luminaire characteristics, such as baffles or louvers, lens or door configuration, and end caps
- with diagonal fill to denote emergency lighting

Pendant luminaires

- draw symbol to match size and shape
- adjust scale and line weight if necessary for visibility on plan
- use line work to represent identifiable luminaire characteristics., such as concentric-ring louvers, lensing, lamp shields
- with diagonal fill to denote emergency lighting (not shown)

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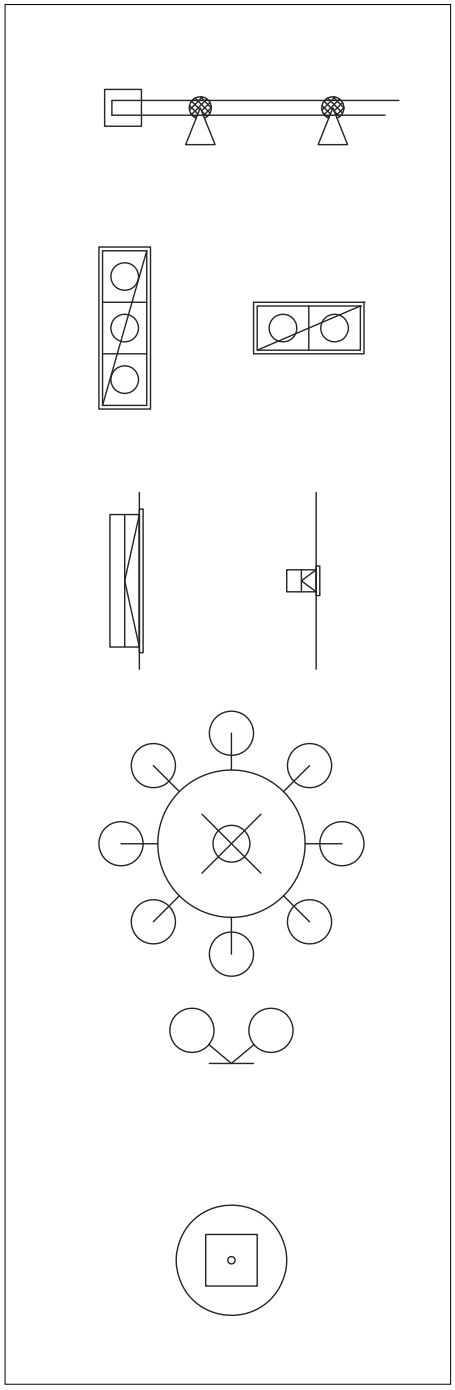


Figure 20.1d | Assorted and Miscellaneous Luminaires 2D Symbol Set

Track
- draw symbol, including power feed location, to match size and shape
- adjust scale and line weight as necessary for visibility on plan
- use Isosceles triangle orienting short leg in direction of light throw for track luminaires

Multi-lamp accents
- draw symbol to match size and shape
- adjust scale and line weight as necessary for visibility on plan
- use directional arrowhead to indicate aiming direction of each lamp, if known (not shown)
- diagonal line (from lower left to upper right) to denote recessed

In-wall luminaires (steplights, indirect uplights, flush sconces, indicators, nightlights)
- draw symbol to match size and shape
- adjust scale and line weight as necessary for visibility on plan

Traditional chandelier and pendant luminaires
- draw symbol to match size and shape
- adjust scale and line weight as necessary for visibility on plan
- use additional line work to represent identifiable luminaire characteristics, such as scalloped globes, bowl configurations, lamping layouts within bowls, shades, and bracket dimensionality

Traditional wall bracket luminaires
- draw symbol to match size and shape
- adjust scale and line weight as necessary for visibility on plan
- use additional line work to represent identifiable luminaire characteristics, such as scalloped globes, number of globes, shades, and bracket dimensionality

Traditional torchiere luminaires
- draw symbol to match size and shape
- adjust scale and line weight as necessary for visibility on plan
- use additional line work to represent identifiable luminaire characteristics, such as bowl configurations, lamping layouts within bowls, shades, bracket dimensionality, and feet

surveillance devices such as cameras, wireless service devices, remote control detectors such as those required for some lighting control setups, projectors, access panels, and the like. However, in most situations, the lighting layout will probably take precedence over layouts of other systems since lighting is typically planned for both its functional performance and its visual effects—any luminaire off-center of artwork or feature walls or distinguished architectural features or furniture layouts or floor and ceiling configurations typically creates an obvious and undesirable asymmetric visual effect and may also exhibit functional deficiencies. Even where other systems appear to deem priority, a review of technologies and long-term affects is warranted. Lighting systems are likely in

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place for decades before upgrade or replacement. Other technologies such as cameras or AV equipment may be outdated and more likely replaced in a few years. Changing layouts and effects of a permanent system such as lighting to accommodate more ephemeral systems may not be a viable long-term solution.

20.3.2 Elevations

The architect, landscape architect, and interior designer generate elevations illustrating devices, furnishings, architectural details, and other dimensional objects. These should include lighting equipment such as wall sconces, steplights, lighted handrails, chandeliers, pendants, and control devices. In combination with plans, these elevations clarify vertical and horizontal locations and are used for coordination with ceiling heights, door swings, door and window jambs or casework, and coves and soffits. Elevations also help the team understand, coordinate, and collect all manner of objects and devices for a neat and orderly appearance and improved operational convenience. Lighting control devices might be ganged with or at least symmetrically spaced with respect to other devices such as environmental controls, volume controls, call buttons, security pads, and the like. Lighting control devices need to be spaced in accordance with respective vendor's requirements for heat dissipation or functionality. If the architect, landscape architect, or interior designer is not designing the lighting, then appropriate dimensional information for luminaire locations is required from the lighting designer.

Table 20.2 | 3D Luminaire Components

Parameter	Distinction

Physical	Luminaire
	• type (designation)
	• length
	• width
	• height
	• geometric configuration
	  • behind surface
	  • projected from surface

	Attachment projection • suspension length from ceiling • projection length from surface
Electrical	Electrical data • input watts • voltage
	Luminaire data • ballast • ballast factor • finish • lamping
Specifics	Ordering information • vendor(s) catalogic • finish • accessories
Links	Additional information • to photometry • to cutsheet(s) • to specification(s)

20.3.3 Sections and Details

For additional clarity, the architect, landscape architect, and interior designer generate sections and details. Where appropriate to meet programming requirements, lighting is included in coves, slots, niches, shelving, and millwork details. To assure proper luminaire positioning and orientation, lighting details show critical dimensions, positions, and orientations to meet the anticipated performance requirements for the project, exemplified in Figure 20.5. Although the conceptual detail illustrated in Figure 20.5 may be included as part of the lighting specification for convenient contractor reference, many times these details are subsumed into architectural details on architectural sheets so that all trades have access to accurate detail information.

20.3.4 Luminaire Schedules

Luminaire schedules are an artifact of a bygone era. By their very nature, luminaire schedules are brief and typically embedded on drawing sheets. Schedules are prone to conveying insufficient information. These offer little or no guidance on key installation parameters like overall-suspension-lengths-relative-to-given-ceiling heights, field-dimension-confirmations by contractor of architectural details accommodating lighting, and coordination efforts between the contractor and other related trades. The simplicity of a schedule implies substitutions are of little consequence. A lighting specification that details salient features, dimensions, operational characteristics, ballast, and control and installation requirements along with substitution procedures is a necessity. Lighting now must meet LPD, energy, whole-building-performance, and code requirements in addition to a host of other analytic and aesthetic criteria established during the design process. There is very little allowance for the vagaries of "or equals" as determined by other-than-the-designers to address all of these aspects.

Additionally, if schedules are used in conjunction with the more detailed requirements of specifications, the former present a risk management issue: two locations in the contract documents that must bear identical information and, therefore, must be updated simultaneously whenever a revision to one is made.

On small projects, a simple schedule that does not identify luminaire or lamp catalog number may be warranted for team and jurisdictional reference. One such example is shown in Figure 20.4. Otherwise specifications are a superior means of conveying all salient information on the equipment required and its installation.

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20.4 Specifications

Lighting specifications cover a comprehensive list of requirements related to lamps, ballasts, drivers, transformers, luminaires, procurement, specific equipment from specific vendors, installation, operations and maintenance manuals, warranties, and turn-over of the finished installation. Such a volume of information is much too onerous to distill into a luminaire schedule or drawing. Specifications follow industry formats, most notably those espoused by the Construction Specifications Institute (CSI) and Construction Specifications Canada in MasterFormat® [5]. Although the format was significantly overhauled in 2004, some project managers and clients subscribe to the 1995 version, support and licensing for which were discontinued by CSI on December 31, 2009. The electrical division, in which lighting is a subdivision, was numbered 16 for the 1995 format edition and 26 for the 2004 and subsequent format editions. Depending on the depth and breadth of project electrical work, the lighting specification typically encompasses 26 50 00. Table 20.3 identifies the formal numbering and associated lighting subdivisions. Specific references in the lighting specification should be made to other supporting and relevant specification sections, such as those for gas lighting or those related to complementary components and systems integration such as integrated ceiling assemblies, luminous ceilings, illuminated panel signs, illuminated handrails when these types of sytems are employed.

There are a number of specification types, but for purposes of this discussion two basic types are considered: performance and prescriptive. Performance specifications cite the qualitative and quantitative performance parameters of a given luminaire that are determined necessary during design, but allowing others to determine which products meet these performance parameters. This specification typically defines luminaire shape and profile, dimensions, material, construction, finish, optical media and performance, lamp type, wattage, ballast, transformer, or driver type, control aspects, lamp compartment access, suspension means, and so on. The designer must take care to not incorporate performance or function details that are proprietary or covered by patents or copyrights. Any parameters not specifically addressed are at the discretion of the contractor and may result in surprise and disappointment. Even where all parameters that the designer considers important are addressed, if their specific features are not fully detailed, results may be unexpected. For example, if a traditional chandelier is to have chain suspension, but the type, size, thickness, and finish of chain links are not identified, the chain on the supplied luminaire may look too small or delicate relative to the scale of the luminaire lantern with a finish uncoordinated with the interior scheme.

Prescriptive specifications identify the specific product or products by brand and model for a given luminaire that are determined necessary during a design. These specifications allow little or no flexibility on brand and model deviation. Prescriptive specifications may also include citation of performance details for clarity of intent and to identify distinguishing features with the specified brands and models. Here, if only one brand and model are listed, the cost-to-owner may be suspect. Although careful attention to pricing during design can limit these concerns, the vagaries of the purchasing chain ultimately determine costs. The designer is obligated to thoroughly assess the luminaire options available, otherwise single- or multiple-name prescriptive specifications may be indefensible. Knowledge of brands and models is a must.

The type of specification used will depend on the type of project, the client, and the degree to which performance variances are acceptable on any, many, or all parameters. The type of specification must be determined early in the design process. The benefits and drawbacks should be reviewed with the team and client. A desire to use performance specifications may be driven by expectations of greater competition and low first cost. However, life-cycle costs, long-term performance, durability, and occupant satisfaction should be paramount.

Regardless of the type of specification, the format involves three parts: general; products; and execution. Table 20.4 outlines sections typically found within these three parts of the

Table 20.3 | MasterFormat® Lighting[a]

Division	Subject
26 51 00	Interior Lighting
26 52 00	Emergency Lighting
26 53 00	Exit Signs
26 54 00	Classified Location Lighting
26 55 00	Special Purpose Lighting • Outline Lighting • Underwater Lighting • Hazard Warning Lighting • Obstruction Lighting • Helipad Lighting • Security Lighting • Display Lighting • Theatrical Lighting • Detention Lighting • Healthcare Lighting • Broadcast Lighting
26 56 00	Exterior Lighting • Lighting Poles and Standards • Parking Lighting • Roadway Lighting • Area Lighting • Landscape Lighting • Site Lighting • Walkway Lighting • Flood Lighting • Exterior Athletic Lighting

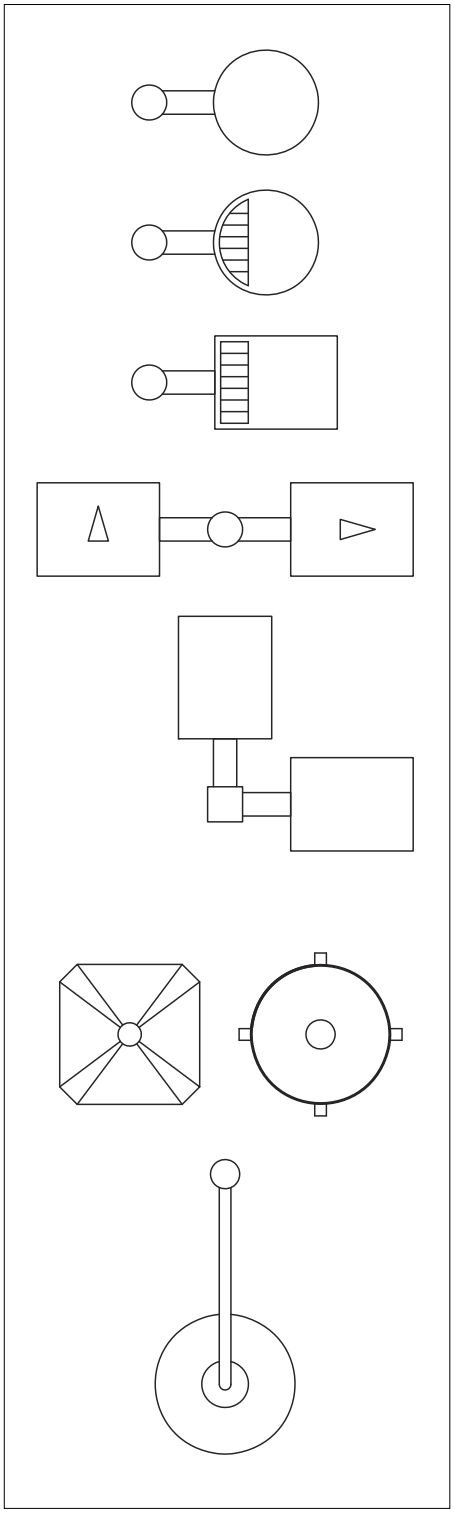
a. Adapted from MasterFormat® 2011 Update [6] with permission.

The Groups, Subgroups and Divisions used in this textbook are from MasterFormat® 2011, published by The Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC), and are used with permission from CSI. For those interested in a more in-depth explanation of MasterFormat® 2011 and its use in the construction industry visit www.csinet.org/masterformat or contact:

The Construction Specifications Institute
110 South Union Street, Suite 100
Alexandria, VA 22314
800-689-2900: 703-684-0300
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Figure 20.2a | Exterior Area-light Luminaires 2D Symbol Set



Area, roadway, parking post lights

- draw symbol to match size and shape of individual units, pole, and arms/brackets
- repeat units as necessary to convey design intent for layout of multi-head luminaires
- adjust scale and line weight if necessary for visual clarity
- adjust arm length(s) and head shape to denote cobra head units and/or long-arm units
- use pointers to indicate orientation when contrary to typical
- with hatching to denote house-side shielding

Pedestrian post lights

- draw symbol to match size and shape
- adjust scale and line weight if necessary for visibility on plan
- use pointers to indicate orientation when contrary to typical (not shown)
- use line work to represent identifiable luminaire characteristics, such as lantern with peaked top, globe basket, and lamp shields or refractors

specification and respective content matter. Detailed lighting specification information is available through texts and online resources. [7] [8] [9] What follows is an overview of some topics and a few key aspects related to the effects of procurement and installation on the technical and aesthetic proficiency of the lighting system. For convenience, parenthetical references are made to the specification section numbers outlined in Table 20.4, but actual section numbering is at the designer's discretion. Section 2.12 in Part II is titled

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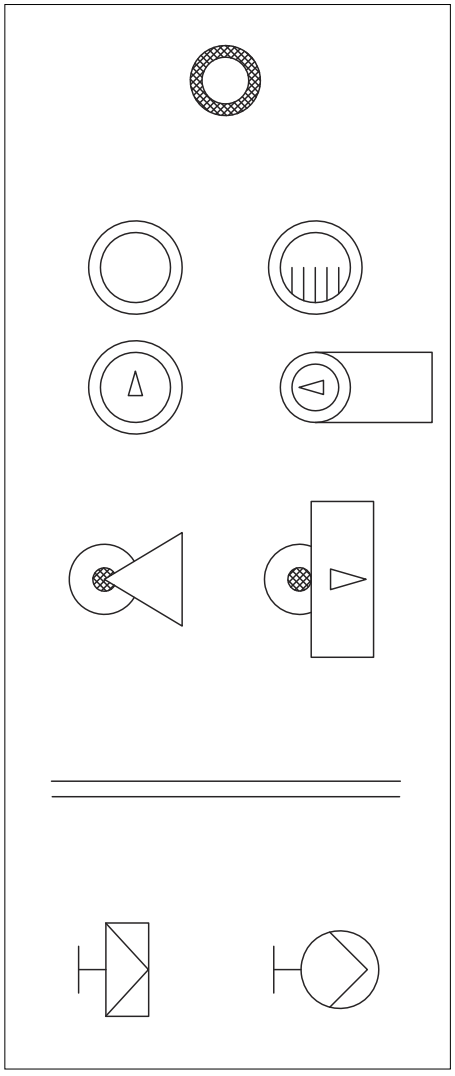


Figure 20.2b | Exterior Local-light and Accent Luminaires 2D Symbol Set

Bollards
- draw symbol to match size and shape
- adjust scale and line weight as necessary for visibility on plan
- use pointers to indicate orientation if unit is asymmetric

In-grade uplights
- draw symbol to match size and shape
- adjust scale and line weight as necessary for visibility on plan
- use pointers for accents or hatching for wallwashers (with open area oriented to surface being washed) to indicate orientation

Above-grade uplights
- draw symbol to match size and shape
- adjust scale and line weight as necessary for visibility on plan
- use pointers for orientation as needed or hatching for wallwashers (with open area oriented to surface being washed [not shown]) to indicate orientation

Handrail-integrated lights
- draw symbol to match size and shape
- adjust scale and line weight as necessary for visibility on plan
- close ends at each end of handrail run

Wallmount cutoff area lights
- draw symbol to match size and shape
- adjust scale and line weight as necessary for visibility on plan
- use arrowhead to indicate major throw orientation

Luminaire Specification Schedule, but this is a detailed fully-descriptive specification section not to be confused with the less-informative spreadsheet commonly called "Luminaire Schedule" and placed on drawing sheets.

20.4.1 Description (Specification Section 1.01)

At the outset, the need for UL/CSA/NOM tested, listed, and labeled equipment must be clear. One specification entry addressing this aspect might read:

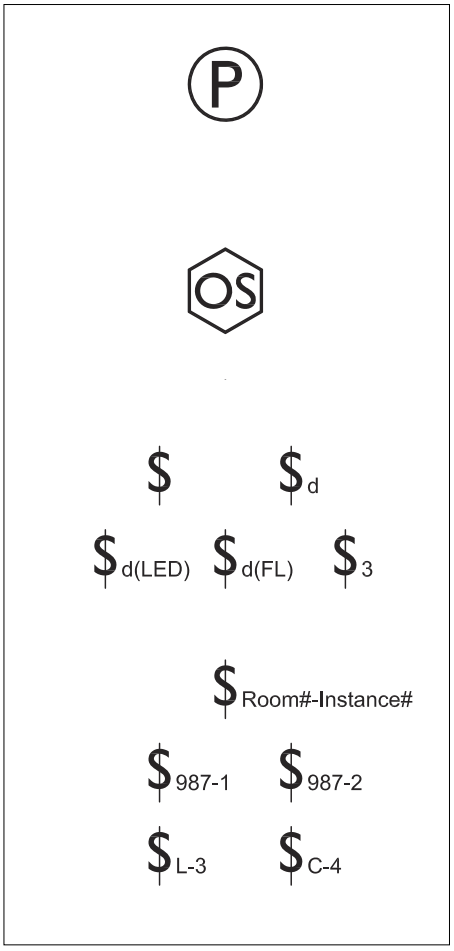
> 1. All equipment and parts specified herein shall bear the "U.L. Approved" label (or other NRTL label) indicating compliance with UL requirements or as otherwise allowed in Section 1.04.G [1.04.G is a citation in the "References" Section of the specification regarding listing and labeling requirements]. All luminaires shall be UL/NRTL [or CSA or NOM] listed and labeled for installation in fireproof or non-fireproof construction, dry, damp, or wet locations as required.

20.4.2 Submittals - General (Specification Section 1.06)

Submittals are a process whereby the contractor secures shop drawings from the vendors selected to provide lighting equipment and submits these to the design team for review and disposition with respect to the contract documents. These submittals identify equipment appearance and performance hopefully in accordance with the specification.

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Figure 20.3 | Lighting Controls Symbol Set



Photocell

- draw symbol to legible scale
- provide engineered layout or float symbol in proximity of use with explanatory note on drawing indicating design intent for engineering
- loop control to respectively controlled luminaire zone(s) or indicate luminaire control intent with note

Occupancy Sensor

- draw symbol to legible scale
- provide engineered layout or float symbol in proximity of use with explanatory note on drawing indicating design intent for engineering
- loop control to respectively controlled luminaire zone(s) or indicate luminaire control intent with note

Dimmers and Switches

- draw symbol to legible scale
- provide engineered layout or float symbol in proximity of use with explanatory note on drawing indicating design intent for engineering and architectural detailing of elevations
- loop control to respectively controlled luminaire zone(s) or indicate luminaire control intent with note
- add information, such as 3- or 4-way switching or loads to be dimmed, for clarity

Dimmers and Switches and Keypads and Preset Controls

- draw symbol to legible scale
- assign room number to symbol
- assign instance number to symbol where more than one control is used in a room or area
- provide engineered layout or float symbol in proximity of use with explanatory note on drawing indicating design intent for engineering and architectural detailing of elevations
- indicate control function in specification and with preset schedules were applicable
- information, such as 3- or 4-way switching or loads to be dimmed, number of buttons, override functions, and finish along with controls vendors catalog numbers are conveyed in specification

For some equipment so specified, this may also include vendors' proposed equipment layouts to address, for example, sensors or panels or modules required as part of the vendor's equipment package. Substitution submittals involve design assessment. This may be an inconsequential effort or may require significant time by many team members. For example, if a proposed substitution exhibits just a 5% efficiency variance, on a large project this may ultimately influence LPD compliance, power distribution systems, mechanical systems and architectural RCPs. The time and fees involved in evaluating these effects are large, should be covered by the substitution proposer, and must be agreed to in advance and in a transparent-to-the-team-and-client fashion. Such a process is detailed below in item 4. Several specification entries addressing submittals might read:

1. The Contractor shall be responsible for supplying equipment product data, and as indicated in the specification, partial or complete working samples of the specified equipment in a timely fashion for design team approval, prior to releasing orders on equipment. Contractor shall be responsible for coordinating all aspects of order placement, deposits, shop drawing procurement, order release, order follow-up, delivery tracking, etc. with Distributor in a timely fashion. Some luminaires may require at least 12 to 16 weeks of lead time or more - the Contractor is responsible for allowing sufficient time for the order-and-deposit process, shop drawing procurement, submittal, and review process. Substitutions will not be accepted on the basis of the contractor's obligation to make any deadlines, contractual or otherwise, agreed by the contractor toward the completion of this project. Lamp submittals are as important and necessary as luminaire submittals and must be supplied by the Contractor to assure correct lamp wattage, color and efficacy.

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2. All submittals shall be generated by respective factories with their seals or other authentication marks and each submittal sheet shall be clearly labeled with respective luminaire type, complete catalog number relevant to submitted luminaire, date of submittal generation and name, phone number, and email address of submittal author in order to track provenance of information. The Architect may contact respective factory submittal source.

3. The lighting equipment specified herein has been carefully chosen for its ability to meet the luminous environment requirements of this project. Calculations (with {insert software name here} or other such software) were typically made to determine luminances, luminance ratios, and/or horizontal and vertical illuminances and uniformities. In some instances, virtual reality "images" were generated with lighting calculation software to assist the Design Team and/or the Client in assessing the lighting quality of the spaces or areas. Equipment and/or manufacturers which have been shown to comply with the established criteria, including ASHRAE/IES 90.1 or California Title 24 or other such energy code as applicable by ordinance, code, Federal law, or mandate, and/or intended LEED or other green-building certification, is specified herein. Substitutions in all likelihood will be unable to meet all or some of the salient criteria as the specified equipment.

4. Where permitted, substitution submittals shall consist of a physical description, detailed dimensioned drawing and complete photometric and electric data of the proposed lamp, ballast, driver, or transformer as required, and luminaire. Working samples of lamp and luminaire substitutions must also be supplied at time of substitution request for visual check of finish, operating and photometric characteristics, and functional and aesthetic design. Photometric reports must list the actual candela values of the luminaire's distribution with specified or similar lamp in at least five horizontal planes with elevation angles in increments not greater than 5° from nadir to zenith. If additional data is required to account for asymmetric distributions, then this shall also be supplied. Candela curves, lux or footcandle and lumen tables and iso-lux-or-footcandle contours are not acceptable. The Contractor shall be responsible for negotiation with the Client, Lighting Designer, Architect, and Electrical Engineer prior to substitution submittal to assure fees are available to: redesign project based on proposed substitutions; or review by Lighting Designer, Architect, and Electrical Engineer of all photometric, sample, design and calculation documentation and virtual reality renderings (provided by Contractor) for proposed substitutions. All substitutions must be identified and approved prior to bid date; and all contractor negotiations re: additional fees for redesign work due to substitutions must occur prior to bid date. A Substitution Request Form (on the following page) shall be completed, submitted, and postmarked along with all relevant documentation required on the Substitution Request Form two weeks prior to bid date. No substitutions will be considered without compliance with this paragraph. Contractor's bid value and/or schedule commitments shall not be based on substitutions in expectation of design team approval, nor on Contractor estimated value of specified equipment. If submitted substitution fails to comply with any specification requirements or is rejected for any or no reason whatsoever, Contractor will furnish specified equipment at no additional cost or delay to the Owner.

5. The Contractor shall be responsible for obtaining from his supplying lighting manufacturers, for each luminaire, a recommended maintenance manual including:

- Vendor and local representative's contact information
- Tools required
- Instructions
- Types of cleaners to be used
- Replacement parts identification lists
- Equipment product data (high-quality reproducible copies)
- Warranty documentation

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Type	What	Description	Catalog Number	Input Watts
FCD1	CFL Downlight	18W DTT lensed, 7" aperture	See 26 51 00 Specification	19.0
FCW1	Fluorescent Wallwash	42W triple-tube lensed, 6" aperture	See 26 51 00 Specification	46.0
FTC1	Fluorescent Cove	1-lamp F28T5/F14T5 asymmetric cove light, continuous row (48')	See 26 51 00 Specification	402.0

GENERAL NOTES

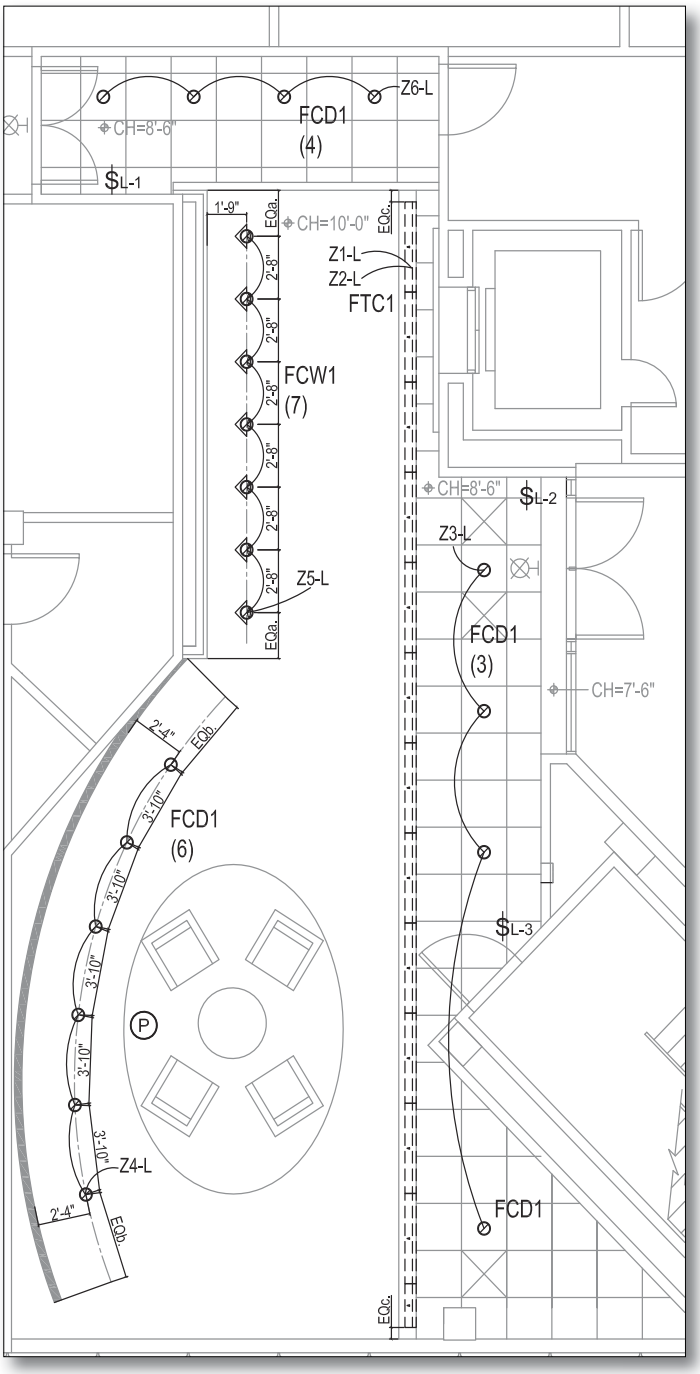
1. All lighting shall be installed in accordance with the NEC and all local codes.
2. Coordinate all final luminaire locations with Architect prior to any installation work.
3. This lighting plan addresses normal power architectural lighting. Controls Systems Specification and egress/emergency lighting shall be developed by registered professionals as identified by the Owner.
4. Reference Lighting Specification Section 26 51 00.

Figure 20.4 | Lighting Plan Excerpts

Excerpt above from a lighting plan exemplifies a luminaire schedule. Sometimes catalog information from the respective acceptable vendors is also cited under "Catalog Number." Use of "or equal" is not recommended as this leaves interpretation of "equal" up to individuals without explicit knowledge of all pertinent lighting programmed criteria and wherewithal to perform and/or assess necessary calculations and renders.

Excerpt at right from a lighting plan illustrates a portion of a lighting plan with luminaire locations, types, dimensions as necessary, and control looping and zones identified. A skylight over the seating area is fitted with a photocell which then controls the six FCD1 luminaires on Z4-L. North orientation is to the right. The specification or a controls schedule is used to outline functionality of keypads.

» Lighting Plan ©Gary Steffy Lighting Design Inc. Architectural Plan ©David Masko Architect. Courtesy Nemer Property Group



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20.4.3 Luminaire Specification Schedule (Specification Section 2.12)

This specification section is not to be confused with a simple luminaire schedule. Procuring the correct lighting equipment is fundamental to an installation's success in meeting the design criteria. So it is that a complete description of the physical size, geometry, fit, finish, optics, lamps, ballasts, drivers, transformers, mounting, voltage, connected load, accessories, and other salient features is provided for clarity to those in the procurement and installation chain, including the contractor, distributor, lighting representative, and factory. This is done for each luminaire type on the project.

Lifting specification templates from vendors' catalogs is not recommended unless this material is carefully reviewed and purged of proprietary features, unless a prescriptive, single-name specification is desired. Even then, however, the template must be reviewed to assure there are no conflicts with the designer's standard of care or with any other lighting equipment or strategies on the project. Templates should also be reviewed for loopholes or simply loose or nonexistent detail on the salient features of the equipment.

Any special features or requirements are also noted in the description of each luminaire. For prescriptive specifications, a cutsheet from at least one of the listed vendors for each luminaire type is typically shown for instant recognition of generally what's involved. An example description is shown in Figure 20.6. A few special features cited in this example are related to how the wallwash lens is to be installed and the care with which the contractor installs the housing to assure proper orientation of the wallwash optic. Table 8.6 Factors in the Evaluation and Specification of Luminaires offers a checklist of items that are worthy of specification consideration.

The specification is the place to indicate special relationships between different luminaire types. For example, a wall bracket may exhibit a lantern, globe, or bowl that matches those used in a pendant or chandelier. Such is noted in the specification to ensure this detail is not overlooked and the family remains intact. More mundane, but important aspects that are noted in the luminaire specification include power feed positions and suspension points on linear pendants, for example, and, where occurring in close proximity, the need for these items to be oriented similarly and aligned for a neat appearance.

Custom luminaires or modifications require additional specification information, including a sketch or drawing illustrating the intended appearance and scale (see Figures 15.19c and 15.19d). Any samples or mockups required during shop drawing submittals are outlined in the specification. This typically involves review of casting patterns, glass and acrylic samples, metal finish samples and, where designs are unique, full-luminaire mockups. These mockups also provide an opportunity for obtaining actual photometric reports for the custom luminaire to confirm performance and calculations during submittals against those made during the design phase.

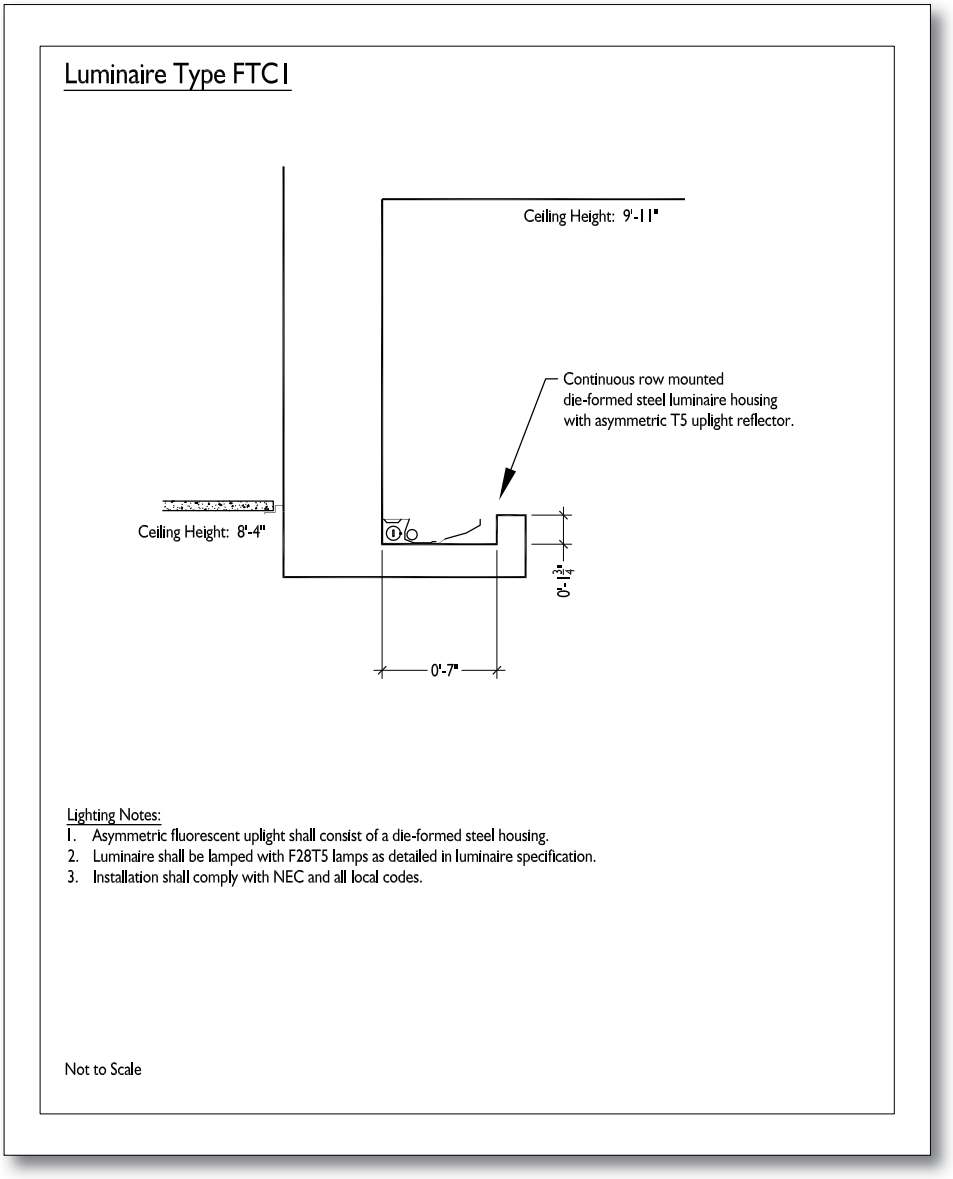
20.4.4 Installation (Specification Section 3.01)

The integrity of the lighting installation is established by the degrees of attention given to various aspects of installation including coordination between various lighting equipment vendors, such as controls and luminaires, care of visible aspects, such as leveling of luminaires, and lamp seasoning. All affect the photometric, lighting effect, and appearance qualities of the lighting system. In the specification section on references (1.04) NECA/IESNA jointly-developed installation standards are cited (see Table 20.4). Several lighting specification entries addressing installation might read:

1. Install lighting equipment, including but not limited to luminaires, controls, auxiliary devices and the integration of same in strict conformance with all manufacturers' recommendations and instructions the securing of which shall be the responsibility of the Contractor.

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Figure 20.5 | Lighting Detail
Luminaire type FTC1 shown on the lighting plan in Figure 20.4 is intended to be housed in an architectural cove. For best lighting efficiency, an asymmetric luminaire is selected. Salient dimensions and orientation related to the luminaire are depicted in this simple sketch for the architect's development of the architectural cove detail.
» Graphic ©Gary Steffy Lighting Design Inc.



2. Luminaires shall be integrated with controls in accordance with respective luminaire manufacturers' and controls manufacturers' recommendations and instructions and to provide a complete, trouble-free operation without compromising safety, code and UL/CSA/NOM requirements.

3. Contractor shall be responsible for sealing all outdoor luminaires for wet locations (i.e. all knock-outs, all pipe and wire entrances, etc.) as is standard industry practice to prevent water from entering luminaires.

4. The Contractor shall coordinate the lighting system installation with the relevant trades so as to eliminate interferences with hangers, mechanical ducts, sprinklers, pipes, steel, etc.

5. For installation in suspended ceilings, ensure that the luminaires are supported such that there is no resultant bowing or deflection of the ceiling system greater than 1/360 of the length of the total span of the ceiling member.

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6. Mounting heights and configuration of the luminaires shall be as specified in the Luminaire Schedule portion of the Specification or indicated on the drawings, and where conflicts exist, as approved by the Architect.

7. All luminaires shall be installed plumb and true and level as viewed from all directions unless specifically identified otherwise in the Luminaire Schedule portion (Section 2.12) of this Specification. Luminaires shall remain plumb and true without continual adjustment or visibly obvious means beyond what is shown on luminaire submittal drawings.

8. Suspended luminaires shall be installed plumb and true and level unless specifically identified otherwise in the Luminaire Schedule portion (Section 2.12) of this Specification and at a height from finished floor as specified on the drawings, details and Luminaire Schedule. In cases where this is impractical, refer to the Architect for a decision. All appurtenances shall be consistently organized for a neat, uniform appearance.

9. Luminaire finishes which are disturbed in any way during construction shall be touched up or refinished in a manner satisfactory to the Architect.

10. Reflector cones, louvers, baffles, lenses, trims and other decorative elements shall be installed after completion of ceiling tile installation, plastering, painting and general cleanup.

11. Whenever a luminaire or its hanger canopy is installed directly to a surface mounted junction box, a finishing ring painted to match the ceiling, shall be used to conceal the junction box.

12. All lamps shall be seasoned for a minimum of 12 hours and a maximum of 100 hours in full-on mode without dimming. All lamps used for convenience lighting during construction shall be replaced with identical New lamps, which shall then be seasoned as described above, immediately prior to the date of substantial completion as determined by the Architect.

13. All accessories shall be properly installed and adjusted by Contractor in accordance with specification and installation instructions. Any spare items shall be clearly labeled (indicate type of accessory and associated luminaire types).

20.4.5 Testing and Adjustment (Specification Section 3.02)

Photometric performance of adjustable luminaires is of no benefit unless these luminaires are aimed, focused, and locked. The effort to achieve this involves the contractor as well as the team member serving in the role of lighting designer. Several specification entries addressing testing and adjustment might read:

1. As required, all adjustable luminaires shall be aimed, focused, locked, etc., by the Contractor under the observation of the Architect. As aiming and adjusting is completed, locking setscrews and bolts and nuts shall be tightened securely by the Contractor.

2. All ladders, scaffolds, lifts, etc. required for aiming and adjusting luminaires shall be furnished by the Contractor.

3. The Contractor shall be responsible for notifying the Architect of appropriate time for staking any outdoor luminaire locations which are called out as “to be field located” on drawings and Luminaire Schedule, and shall supply equipment and personnel for staking at the direction of the Architect.

4. Where possible, units shall be focused during the normal working day. However, where daylight interferes with seeing lighting effects, aiming shall be accomplished at night.

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Table 20.4 | Key Specification Sections

Section		Topic	Typical Content
Part I GENERAL	1.01	**Description**	• Name and location of project for which specification is generated • General caveats and/or requirements (e.g., equipment shall be UL/NRTL listed/labeled) • Notice of means for identifying revisions (underlining and strikeouts) • Notice that cutsheets are copyrighted and are for procurement of specified equipment only
	1.02	**Related Documents**	• Notice that all work shall comply with terms of project's contract documents
	1.03	**Work Included**	• Outlines work required of the contractor
	1.04	**References**	• Citation of relevant related safety, operational, and performance references and codes, such as • American National Standards Institute (ANSI) • Canadian Standards Association (CSA) • Illuminating Engineering Society (IES) • National Electrical Contractors Associaton (NECA) • National Electrical Manufacturers Associaton (NEMA) • National Fire Protection Association (NFPA) • Norma Oficial Mexicana (NOM) • Underwriters Laboratories Standards (UL)
	1.05	**Quality Assurance**	• Workmanship requirements • Requirements for unit pricing and proposed vendor citations in bid
	1.06	**Submittals - General**	• Requirements for submittal drawings • Requirements for substitutions, if permitted
	1.07	**Submittals - Samples**	• Requirements for submittal samples
	1.08	**Delivery - Storage - Handling**	• Requirements for taking delivery, storing, and handling lighting equipment
Part II PRODUCTS	2.01	**Lamps - General**	• Outlines general operational and performance requirements of lamps
	2.02	**Lamps - Neon/Cold Cathode**	• Outlines operational and performance requirements specific of neon/cold cathode lamps
	2.03	**Ballasts - Fluorescent**	• Outlines operational, performance, and warranty requirements for fluorescent ballasts
	2.04	**Ballasts - HID**	• Outlines operational, performance, and warranty requirements for HID ballasts
	2.05	**Drivers - LED**	• Outlines operational, performance, and warranty requirements for LED drivers
	2.06	**Transformers - Low Voltage**	• Outlines operational, performance, and warranty requirements for low-voltage-lamp transformers
	2.07	**Transformers - Neon/Cold Cathode**	• Outlines operational, performance, and warranty requirements for neon/cold cathode transformers
	2.08	**Luminaires - General**	• Outlines general operational, fit, and performance requirements of luminaires
	2.09	**Luminaire Reflectors and Trims**	• Outlines general operational, fit, and performance requirements of reflectors and trims
	2.10	**Luminaire Lenses**	• Outlines general operational, fit, and performance requirements of lenses
	2.11	**Vendor Support**	• Outlines requirements for vendors' warranty, proficiency, and support
	2.12	**Luminaire Specification Schedule**	• Identifies and describes specific requirements for each luminaire, including vendor(s) catalogic
Part III EXECUTION	3.01	**Installation**	• Outlines requirements for installation (e.g., coordination/integration, plumb/level, lamp seasoning)
	3.02	**Testing and Adjustment**	• Outlines requirements for aiming and focusing prior to turn-over
	3.03	**Cleaning**	• Outlines requirements for cleaning lighting equipment prior to turn-over

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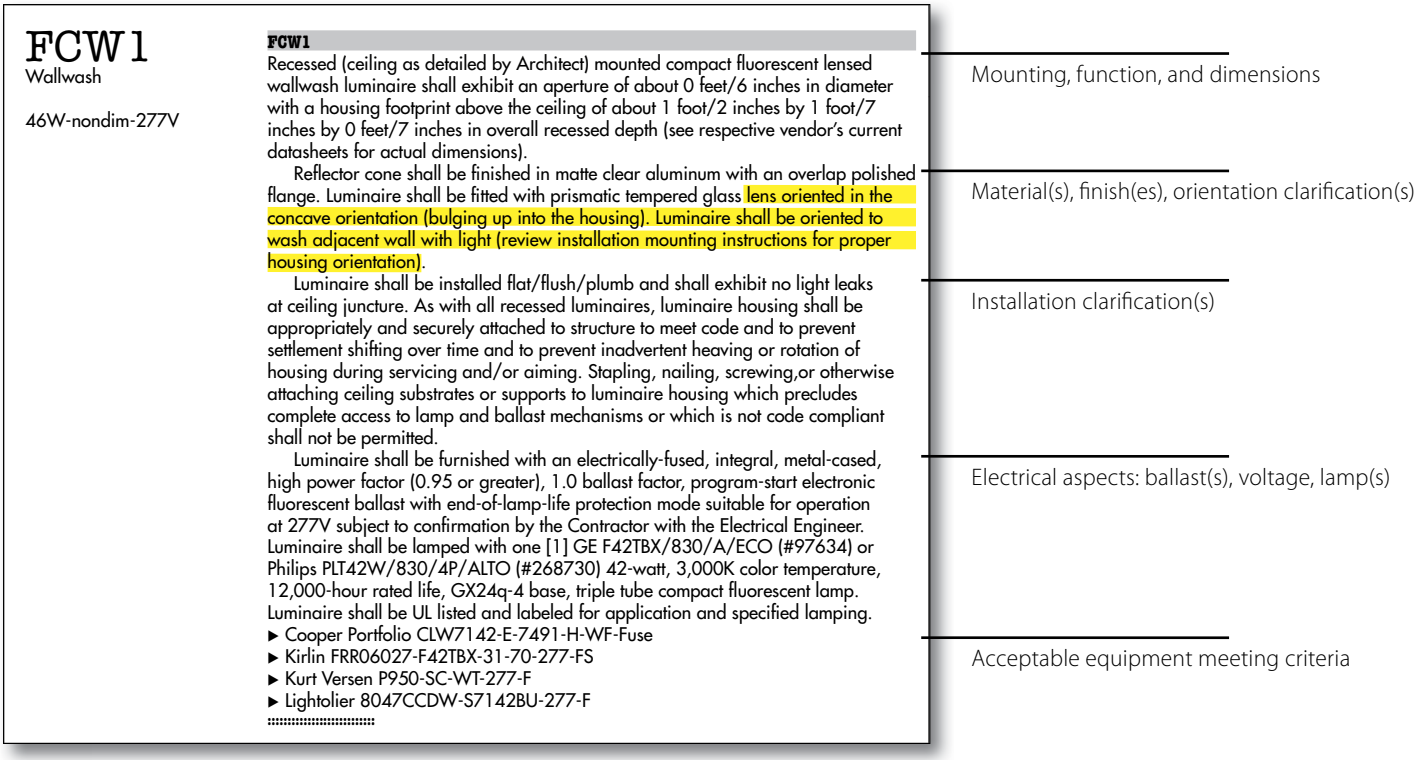


Figure 20.6 | Luminaire Specification Schedule Excerpt
Using the project illustrated in Figure 20.4 as example, a luminaire specification for Type FCW1 identifies the salient features of the luminaire in writing, including lamping and ballasting. Clarifications (highlighted for emphasis here) on optics and orientation are made based on previous experience and/or a review of vendors' catalog cutsheets and/or discussions with manufacturers' representatives. Acceptable manufacturers' catalog number is listed.

20.4.6 Cleaning (Specification Section 3.03)

The effects of dirt accumulation on lighting performance are well documented. However, construction dirt and debris are more significant than the typical environmental dust encountered during normal operations at most project sites. Cleaning of lighting equipment by the contractor immediately prior to project completion is critical to optimal system performance. A specification entry addressing cleaning might read:

> All luminaires and accessories shall be thoroughly cleaned after being installed. All fingerprints, dirt, tar, smudges, drywall mud and dust, etc. shall be removed by the Contractor from the luminaire bodies, reflectors, trims, and lens or louvers prior to final acceptance. All reflectors shall be free of paint other than factory-applied, if any. All reflectors, cones and lenses shall be cleaned only according to manufacturers' instructions.

20.5 Controls Preset Schedule

Lighting controls save significant amounts of lighting energy when designed and implemented appropriately for the situation. Controls also serve to establish various settings or scenes based on functional or time-of-day needs (see 16 | LIGHTING CONTROLS). Documenting the control zones and proposed schedule and manner of operation are, therefore, an important part of contract documents. Figure 20.7 illustrates a simple example taken from the project illustrated in Figure 20.4. In this example, occupancy sensors, automated time scheduling, and bi-level switching are employed. Electric shades, photocells and keypads are also identified in the preset schedule where these devices are

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	Customer Zone	What	Description	Load Type	6:00 AM - 7:00 PM	7:01 PM - Midnight	12:01 AM - 5:59 AM	Notes
2	**Lobby (automated astronomical timeclock and keypad override)**				**ON**	**DIM**	**OFF**	
3	Z1-L	FTC1	FL cove/half level	FL switched	ON	ON (half level)	ON (half level)	P = Photocell Operation
4	Z2-L	FTC1	FL cove/half level	FL switched	ON	OFF	OFF	
5	Z3-L	FCD1	CFL downlights	FL switched	ON	ON	OFF	
6	Z4-L	FCD1	CFL downlights	FL switched	P	OFF	OFF	
7	Z5-L	FCW1	CFL wallwashers	FL switched	ON	OFF	OFF	
8	Z6-L	FCD1	CFL downlights	FL switched	ON	ON	OFF	

Figure 20.7 | Initial Preset Schedule
A spreadsheet outlines the proposed initial preset schedule for the project illustrated in Figure 20.4. The intent is to provide light only when deemed necessary. Keypad labels are identified as on, dim, and off for the override functions. Line numbers are used to the left for convenient reference (most helpful on large schedules).

used for interface with and/or control of electric light. Control zones must be checked against daylight zones for effective daylight harvesting.

Preset schedules are usually identified as "initial" since final settings are likely to be influenced by the client soon after the time of project completion. Preset schedules are shown on plans or in the specifications. Where the project is relatively small or where the lighting designer is not the electrical engineer, the spreadsheet might appear in the lighting specification (26 51 00) or used by the electrical engineer in development of the controls specification. MasterFormat™ for controls 26 09 00 Instrumentation and Control for Electrical Systems is the section within which complete controls specifications are made. The engineered controls layout and specification are typically the responsibility of the electrical engineer.

20.6 Commissioning

Control systems require commissioning to assure their effective and intended operation at the time the project is turned over to the client. Commissioning is an aspect most commonly addressed by the electrical engineer in Section 26 08 00 Commissioning of Electrical Systems. Commissioning is typically not undertaken until all devices are in place and set in accordance with submittals and vendors instructions. Key lighting aspects to be included in the specification section on control systems commissioning are: [10]

1. Sensor placement and orientation for all sensor types.
2. Occupancy sensor function, sensitivity, and time delays.
3. Daylight harvesting sensor calibration.
4. Automated shade operation.
5. Manual control placement and operation.
6. Automated control operation, including scheduled on/off functions and dimming trims and presets.
7. Override operation, access, and functionality.
8. Centralized control interfaces and operation.
9. Client education of operations.
10. Documentation archived to client.

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20.7 Plan Checks

Throughout CD, if not the entire project, a round-robin approach to plan checking is recommended. Lighting plans, architectural RCPs, electrical plans, mechanical plans, AV plans, food-service plans, landscape plans, etc. should be exchanged amongst all team members and reviewed for potential conflicts or clashes and for missed or changed design opportunities. Near the end of CDs, and presumably after previous round-robins have resolved many of these items, careful review by the team members responsible for lighting, architecture, and electrical engineering of their respective plans and the plans of their fellow team members is in order. This may result in the exchange of red-lined drawings or a series of Internet-based conferences.

Lighting efficiency and planning of its effects and intensities are closely tied to architectural configurations, surface reflectances, and a proper placement and accounting of all lighting equipment. Therefore, it is imperative for configurations to remain as used in lighting and energy models. Surface reflectances cannot be changed by a few percentage points without risking non-compliance on connected load, energy use, or illuminance criteria. Last-minute, uncoordinated, and so-called themed decorative lighting additions, whether portable or permanent, work against the project-long effort to minimize energy use and heat-generation while maintaining satisfactory luminances and illuminances.

If daylighting aspects are not employed to the extent the team anticipated during design development, then the electric lighting system may fail in its goals to meet various criteria, including energy expectations. Additionally, the project may fail to provide daylighting that is comfortable for users if shades are not automated and luminances balanced and re-balanced throughout the day, for example. The architectural and interior design plans and specifications related to daylighting aspects, including glazing, electric shades, surface finishes, architectural enhancements such as light shelves, fins, light-direction-media, brise soleils, skylight and monitor wells and/or splays, and the like must be reviewed and confirmed. Table 20.5 outlines key items affecting daylighting integrity.

Typically, the most low-tech aspect of daylighting, the finishes, is modified between design development and final contract documents. For daylight success in many commercial, healthcare, institutional, industrial, and hospitality situations, IES-recommended reflectances of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively) are typically minimums. These reflectances also have significant effect on the efficiency and quality of the electric lighting system.

Table 20.5 | Daylighting Plan Checklist

Component	Feature
Architecture	Daylight Media
	• glazing transmittances
	• clerestories
	• color
	• diffuse or transparent
	• monitors
	• skylights
	• T_{vis}
	• windows
	• well configurations
	Geometry
	• distribute daylight
	• balance luminances
	Redirection
	• light shelves
	• specular reflectors
	Shading
	• electric/automated
	• image-preserving
	• T_{vis}
	• architectural
	• brise soleils
	• fins
	• light shelves
	• overhangs
Finishes	Ceilings/Walls-Partitions/Floors
	• matte
	• high LRVs
	Daylight Media
	• brise soleil
	• light shelf
	• skylight well
Furnishings	Partitions
	• heights
	• transparencies
	Workstation Orientation

20.8 References

[1] Steffy G. 2008. Architectural lighting design, 3rd edition. Hoboken: John Wiley & Sons. pp 107-128.

[2] United States National CAD Standard® - Version 4.0 (Washington, DC: National Institute of Buildings Sciences, 2007), p. CLG-29.

[3] United States National CAD Standard® - Version 4.0 (Washington, DC: National Institute of Buildings Sciences, 2007), p. UDS-06.122.

[4] [IESNA] Illuminating Engineering Society of North America. 2000. Design Guide for Application of Luminaire Symbols on Lighting Design Drawings ANSI/IESNA DG-3-00. New York: IESNA. pp. 4-6.

[5] The Construction Specifications Institute and Construction Specifications Canada. 2011. MasterFormat™ 2011 Update - Master list of numbers and titles for the construction industry. Alexandria, Va: CSI.

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[6] The Construction Specifications Institute and Construction Specifications Canada. 2011. MasterFormat™ 2011 Update - Master list of numbers and titles for the construction industry. pp 315-317. Alexandria, Va: CSI.

[7] Steffy,G. 2002. Architectural lighting design, 2nd edition. New York: John Wiley & Sons. pp 204-255.

[8] Southern California Edison. 1999. Lighting specifications, classroom lighting [Internet]. Southern California Edison. [cited April 2020]. Available from: http://www.sce.com/NR/rdonlyres/D96ACF23-8409-40C5-90BF-4FC3AF982F79/0/LG_Part4.pdf.

[9] [IALD] International Association of Lighting Designers. 2009. Guidelines for specification integrity, 2009 Edition [Internet]. IALD. [cited July 2010]. Available from: http://62.128.151.219/Library/A1e6jn/IALDGuidelinesforSpe/resources/index.htm?refererUrl=http%3A%2F%2Fwww.iald.org%2Fcouncil%2FGuidelinesforSpecificationIntegrity.asp.

[10] Benya J and others. 2003. Advanced lighting guidelines. White Salmon, WA: New Buildings Institute. p 8-14.

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Applications

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Applications

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LIGHTING FOR ART 21

LIGHTING FOR COMMON APPLICATIONS 22

LIGHTING FOR COURTS AND CORRECTIONAL FACILITIES 23

LIGHTING FOR EDUCATION 24

LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY 25

LIGHTING FOR EXTERIORS 26

LIGHTING FOR HEALTH CARE 27

LIGHTING FOR HOSPITALITY AND ENTERTAINMENT 28

LIGHTING FOR LIBRARIES 29

LIGHTING FOR MANUFACTURING 30

LIGHTING FOR MISCELLANEOUS APPLICATIONS 31

LIGHTING FOR OFFICES 32

LIGHTING FOR RESIDENCES 33

LIGHTING FOR RETAIL 34

LIGHTING FOR SPORTS AND RECREATION 35

LIGHTING FOR TRANSPORT 36

LIGHTING FOR WORSHIP 37

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APPLICATIONS

The IES introduces a broad range of criteria to address many situations encountered by the designer. In an era when vision is known to change significantly with age, where tasks vary greatly by application and observers, where energy and earth resources are scarce, and where users expect productive, comfortable settings, a robust set of criteria is appropriate. Lighting applications are arranged here alphabetically and generally follow architectural namesakes. Applications featured are those commonly encountered or that are significant to society or where lighting can make an important contribution to the overall quality of space for living or working. The breadth and depth of these applications is believed sufficient that new or different applications can likely be correlated with some aspects of those featured here, thereby giving the designer a basis for developing criteria and, subsequently, designs.

Analytic or quantitative lighting criteria recommendations are presented here for the development of normal power architectural lighting systems. IES recommendations identify illuminances and uniformities deemed necessary for users to perform various functions and tasks in a wide range of applications. Meeting these criteria can result in a technically-competent and aesthetically appropriate lighting solution. However, results are typically only as good as the time and effort given to ideating and analyzing, the breadth and depth of background information available through programming, design team and client input, the extent to which criteria outlined in the preceding Design Section are employed, and the level of detail applied to solving the design problem.

Illuminance is extraordinarily robust, but only when manipulated to address luminance and luminance ratio needs of specific observers in specific situations. Newly revised application and task lists and age ranges offer unprecedented depth and breadth in setting criteria for specific projects. A new emphasis on vertical illuminance criteria and on accenting assists in the designer's goal of meeting users' vision needs. Forms of accenting offer observers visual relief and contribute to brightness perceptions, visual attraction, and wayfinding.

On the following double-page spread, a succinct User's Guide identifies the main writing and graphical components used to convey the IES recommendations.

The English language has its quirks. One word can have multiple definitions. Read with care and within context.

This is not a code compliance manual nor a list of all code requirements. Codes, standards, and mandates may supersede any of the IES criteria. The designer is responsible for identifying those applicable to any given project and must design accordingly.

For greater detail on lighting design and criteria related to specific application types, the IES offers Recommended Practices, Design Guides, and Technical Memoranda. These are available at IES Bookstore at www.ies.org. Application-related documents published after 2010 will offer material consistent with or more current than this handbook.

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User's Guide

Criteria Summary
A criteria summary presented as a checklist is near the beginning of most chapters. References to relevant chapters, sections, and tables are cited for convenient reference to criteria relevant to the application under consideration.

Notes on Application Types
Discussions on various application types key on lighting aspects that are important to successful designs for the specific application types and tasks. For example, depending on the application type, notes might be made on controls, color rendering or color temperature, on challenges specific to the application, on energy, sustainability, light trespass or light pollution, on specific illuminance criteria, or on the affects of unique architectural situations on criteria and design.

Illuminance Recommendations
Easy to read tables outline illuminance recommendations for various application types listed alphabetically. Horizontal and vertical illuminance targets based on observers' visual ages are presented with respective uniformity criteria.

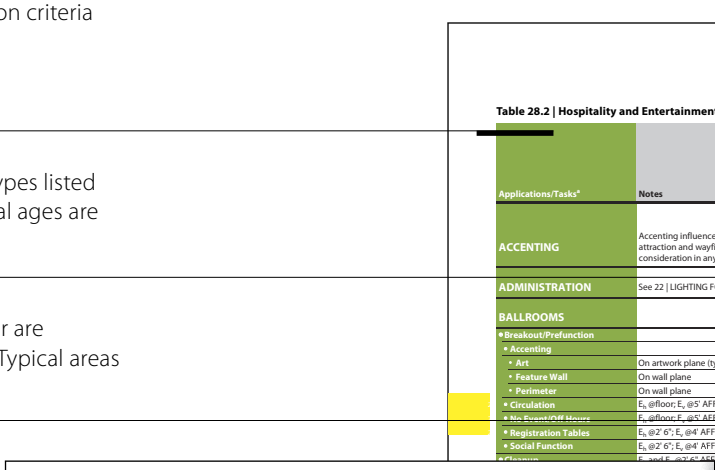
Collateral Guidance
Application types and tasks where daylighting is considered a potential contributor are identified. Where veiling reflections are a potential threat to visibility, this is noted. Typical areas of illuminance coverage from task proper to large area are also indicated.

Application Notes
Notes related to specific applications and tasks are conveniently located alongside each instance of the table.

Examples
Photographs exemplify lighting of some of the various application types. Captions identify relevant criteria aspects or significance of lighting effects. Where specific information is available on illuminance criteria, lamps, luminaires, techniques, or details, this is reported. A few carefully selected photographs are used in each chapter as inspiration on lighting effects and techniques. Some exhibit photo-fill light, others have been digitally enhanced, and some are quite candid. Yet these were all selected for their ability to convey the essence of the applications and tasks and of the lighting. Nothing, however, compares to experiencing settings first hand.

Sidebars
Special criteria, architectural features, or new or uncommon terms are explained in sidebars.

Resource References (not shown here)
In addition to sidebars, resource reference text boxes are positioned in side margins guiding the reader to related areas of the handbook for more detail on background information.


Table 28.2 | Hospitality and Entertainment

Applications/Tasks*	Notes
ACCENTING	Accenting influence attraction and wayfi consideration in any
ADMINISTRATION	See 22 | LIGHTING F
BALLROOMS	
•Breakout/Prefunction	
• Accenting	
• Art	On artwork plane (ty
• Feature Wall	On wall plane
• Perimeter	On wall plane
• Circulation	E_h @floor; E_v @5' AFF
• No Event/Off Hours	E_h @floor; E_v @5' AFF
• Registration Tables	E_h @2' 6"; E_v @4' AFF
• Social Function	E_h @2' 6"; E_v @4' AFF
•Ceiling	E_h and E_v @7' 6" AFF



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Table 28.1 | Hospitality and Entertainment Lighting Checklist

Topics
✔ Criteria and Design Resources
Accenting
15.1.1.3 Accent Lighting
Table 12.2 | Subjective Impressions
Table 15.2 | Accent Illuminance Ratios
Table 22.2 | Common Applications Illuminance Recommendations
Appearance
12.2 Spatial Factors
Color
12.5.6 Color Considerations
Controls
16 | LIGHTING CONTROLS
Daylighting
14 | DESIGNING DAYLIGHTING
Electric Lighting
15 | DESIGNING ELECTRIC LIGHTING
Flicker
4.6 Flicker and Temporal Contrast Sensitivity
Glare
4.10.1 Discomfort Glare
4.10.2 Disability Glare

28.1 Project Type and Status

An understanding of the project type and scope is necessary before commencing design work. This will establish the extent to which daylighting can address the lighting goals. New, renovation, and restoration projects each offer varying opportunities. See 11.2 Planning, 11.3.1 Pre-design, and 11.3.2 Schematic Design. At every opportunity the lighting designer should give every consideration to daylighting as a light source. For some applications and tasks, daylighting can be the primary light source. Critically, this means addressing the host of lighting design factors identified in 12 | COMPONENTS OF LIGHTING DESIGN. Daylight demands attention to moderate or eliminate glare and balance visible and thermal energy.

28.2 Application Types

To develop lighting solutions that meet quality, quantity, and operational criteria, an inventory is made of the hospitality and entertainment space types under consideration and the anticipated occupants, functions, and tasks (see Table 11.2 | Programming: Inventory Scope and Specific Examples and Table 12.3 | Sample Visual Task Survey). Otherwise, lighting cannot be best targeted to the users, their expectations, functions and tasks.

Space type definitions are required early in the project design in order to track design efforts that include inventorying the project knowns, anticipated functions, and tasks and calculating lighting, power, and energy compliance. Room names, from which functions can be deduced, and numbers for tracking should be clearly marked on architectural backgrounds.

- Client wishes and architectural desires
- Degree to which clientele or business prospects visit administrative operations
- View between administrative areas and hospitality or entertainment areas
- Management style and immersion in hospitality or entertainment functions

28.2.3 Ballrooms

Ballrooms are typified by their size and flexibility in use. Ballrooms are typically configurable from one very large space to multiple smaller spaces. Lighting and controls must be laid out to address the various sizes and configurations. Functions are quite varied even within designations dining, exhibition, demonstration, and presentations. This usually requires design of a controls system that may demand operators instructed in the use of the system. Additionally, in smaller meeting room setups it may be necessary to have simplified controls accessible to participants to accommodate AV presentations and overhead projection without the need for professional staffing.

Challenges include lighting system efficiency given high ceilings and large space volumes. Light-finish ceiling and wall surfaces are important. Provisions for entertainment lighting are usually required. Some ballroom designs include sound and light locks where lighting should be designed to manage the luminance change from a darkened ballroom to the adjacent prefunction space. See Figure 24.2 | Sound and Light Lock. If no sound and light locks are employed, then the adjacent prefunction and circulation areas should be designed to limit brightness distractions. This may involve linking the lighting in the prefunction and circulation areas with ballroom lighting controls so that lighting tracks ballroom presets.

Figure 28.2 illustrates a typical ballroom setup and identifies the architectural lighting to support that and other setups.



Figure 28.2 | Ballrooms
This ballroom can be reconfigured into as many as five smaller ballrooms or meeting rooms. Lighting layouts and control zoning and the controls are arranged to accommodate the variations. A combination of cove lighting (not energized here), chandeliers, and recessed downlights (not energized here) are employed. The coves use dimmable long compact fluorescent lamps, the chandeliers use nondim CFLs, and the downlights and accents use halogenIR$_{120V}$. The chandeliers use two zones of control for 2-level lighting. Lamp CCT is 3000 K and CRI is ≥82 and the chandelier lenses are color-tuned to achieve the look of a filament-lamp glow. Stage lighting rigging and instruments are in place for entertainment lighting at this dinner banquet.
» Image ©Kevin Beswick, www.ppt-photographics.com

t Facilities Illuminance Recommendations

Recommended Maintained Illuminance Targets (lux)[b, c, d]										Uniformity Targets[e]			Typical Area of Coverage[h]	
Horizontal (E_h) Targets					Vertical (E_v) Targets					Over Area of Coverage				
Visual Ages of Observers (years) where at least half are					Visual Ages of Observers (years) where at least half are					1st ratio $E_h/2^{nd}$ ratio E_h if different uniformities apply			Task Proper or Task Area	Room or Designated Area
Category		<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	Max:Avg	Avg:Min	Max:Min		
s observers' overall brightness perceptions and provides visual relief. Accenting is also used for visual nding. See 22 | LIGHTING FOR COMMON APPLICATIONS/ACCENTING for default accenting criteria for application.															
OR COMMON APPLICATIONS															
ypically vertical)							see Table 15.2				see 15.1.1.3				
							see Table 15.2				see 15.1.1.3				
							see Table 15.2				see 15.1.1.3				
F	K	25	50	100	Avg	G	7.5	15	30	Avg			3:1		
F	K	25	50	100	Avg	G	7.5	15	30	Avg			3:1		
	O	100	200	400	Avg	L	37.5	75	150	Avg			4:1		
	M	50	100	200	Avg	I	15	30	60	Avg			3:1		
	N	75	150	300	Avg	I	20	40	80	Avg			3:1		

Notes for Table 28.2
The table column headings are discussed in detail in 28.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 28.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 28.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.
b. Values cited are to be maintained over time on the area of coverage.
c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 28.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.
d. Targets are intended to apply to the respective plane or planes of the task.
e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.
f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.
g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.
h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.
i. "High Light Setting" typically employed where exhibit displays have little or no internal lighting and where no theatrical rigging is used. "Low Light Setting" typically employed where exhibit displays have significant internal lighting or where theatrical rigging and instruments are used. "Low Light Setting" used for set-up, tear-down, and cleanup.
j. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.
k. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.
l. Make half the illuminance available from lamps exhibiting CCTs of 5000 K or 6500 K and CRI ≥85 and half from lamps exhibiting CCTs of 2700 K or 3000 K and CRI ≥85. Provide three control settings: for one CCT; for the other CCT; and for both CCTs to be energized for maximum viewing flexibility.

and dimmable task lighting illuminating control boards and notes. If programming determines that the control board devices and readouts are backlighted and if notes are displayed on computer, then only floor illuminance is needed during performances. Significant illuminances may be necessary for cleanup and for set-up and tear-down, depending on the permanence of the equipment in the booth. Figure 28.4 illustrates a typical control booth location as seen from the house.

28.2.8 Exhibit Halls

Convention centers and some hotels have exhibit halls of varying sizes. These multipurpose facilities, depending on their size and geographic locale may temporarily house training sessions, trade shows, religious gatherings, vehicular and sports shows, and large corporate and union functions. The normal power architectural lighting system typically accommodates set-up, tear-down, and some amount or all of the functional requirements of some of these various events. Luminaires are typically controlled in small groups to allow for efficient operation of incrementally smaller or larger events or permit some degree of tuning of light levels to types of displays. However, considerable electrical and structural infrastructure is necessary for theatrical rigging and for exhibit-integrated lighting to accommodate all situations. Figure 28.5 identifies just a few basic approaches. These facilities are made more appropriate for activities beyond exhibit displays if wall and/or ceiling surfaces are lighted. This addresses some elements identified in 12.2 Spatial Factors.

28.2.9 Fitness Centers

The fitness center involves a number of situations where, although workout and conditioning are "the tasks," how people look and feel about themselves and their depth of engagement in exercising are as important. Lighting should be flattering and accommodate conversation and video-watching. Video watching may be susceptible to veiling reflections, so harsh directional lighting should be avoided. Well-shielded direct or totally indirect lighting are often appropriate given the potential for users looking to the ceiling during exercise sessions.

Many fitness centers, even in hotels, are a revenue stream and operate like a club. Here, reception and waiting, locker rooms and showers, and even retail areas are common. Lighting should be sympathetic to the fitness experience and to a club atmosphere. These facilities typically have swimming pools and hot tubs indoor or outdoor. Overlighting or gymnasia-like techniques should be avoided as these risk the potential for direct glare and wasted energy. For indoor pools, the anticipated activity level determines illuminance recommendations. See Table 22.4 for indoor activity level definitions. Lighting within the pools and hot tubs is necessary for observation of occupants and for comfortable use during dark-hours of operation or when daylight is insufficient. Vendors of such equipment should be consulted for recommendations on underwater luminaire wattage and lumen requirements for a given situation.

All pool criteria outlined in Table 28.2 are intended for relaxation and non-competitive exercising. For competitive situations, see 37 | LIGHTING FOR SPORTS AND RECREATION. Figure 28.6 illustrates an indoor hospitality pool application. Pool lighting should be planned with respect to maintenance and addressed with the client prior to final layouts and specifications.

Veiling reflections from pools are common in indoor and outdoor situations depending on view angles and sight lines. Daylighting and electric lighting can be arranged to limit veiling reflections, but this is practical where a fixed position view, such as that of a lifeguard can be planned or where polarized-lens eyewear is used as in outdoor situations.

With outdoor pools, the activity level and the nighttime outdoor lighting zone determine illuminance recommendations. See Table 22.4 for nighttime outdoor activity level

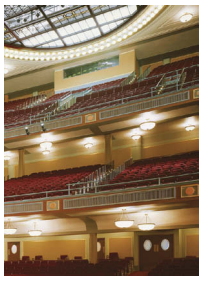
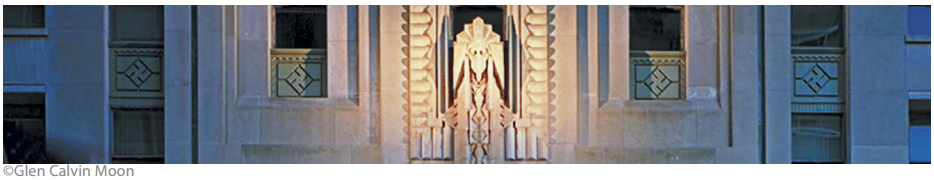


Figure 28.4 | Control Booth
The sound and light booth for this large auditorium (top center) houses sound and lighting control boards and can accommodate follow spots. Some of the theatrical lighting instruments controlled from the booth are just visible in a "seam" in the *laylight* (top left).
» Image ©Balthazar Korab Photography Ltd.

Laylight is an architectural feature or element that is a decorative light diffuser typically positioned below a skylight or roof monitor. Patterns of obscuring decorative glass or acrylic diffuse the light. Where no skylight or monitor exists or during dark hours, electric light is used to backlight the decorative diffuser [4].

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21 | LIGHTING FOR ART

The moment you cheat for the sake of beauty, you know you're an artist.
David Hockney, English Artist [1]

Art *is* in the eyes of the beholder and as such possesses value to at least one person. Valued objects for museum collections are those of scientific, artistic, or historical importance and commonly include fine art, antiquities, and artifacts. For commercial, other institutional, or private interests, valued objects may also be those of sentimental importance, corporate or institutional significance, or of considerable monetary value. The purpose, value, and intended display of the objects greatly influence their lighting. Unlike other applications, lighting for art may, indeed, be more about lighting for the task, in this case the artwork, than for the observer. Where artworks are deemed preservation-worthy, optical radiation must be limited in magnitude and spectra, otherwise damage to the objects will be induced or accelerated. This chapter discusses lighting for artwork regardless of its display venue. Lighting for museum facilities is also addressed here.

Comprehensive design efforts involve synthesizing the information in this chapter with material in 12 | COMPONENTS OF LIGHTING DESIGN, 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS, 14 | DESIGNING DAYLIGHTING, 15 | DESIGNING ELECTRIC LIGHTING, and, for non-museum facilities, the application chapter of the venue of art display. Design tenets deemed appropriate from those chapters must be identified and lighting goals and strategies developed accordingly. This chapter primarily addresses illuminance specifics related to lighting for art and for museum applications which should influence luminaire optical selections, lampings, and final layouts based on design thought-starters (see 15.2 A Lighting Scheme). Use of the material in this chapter to the exclusion of material in Chapters 12, 13, 14, and 15 will likely lead to unsatisfactory results. Previous IES related documents provide archival reference [2] [3].

Careful thought must be given to details beyond the illuminance citations in this chapter. For example, in Table 21.2 the citation EXHIBITS AND GALLERIES/Objects/ High Sensitivity to Light identifies illuminance for those objects deemed highly sensitive to light. These criteria are maxima. If such an object or objects were displayed on the wall in an office, conference room, or lobby, then the designer must evaluate the vertical illuminance falling on the objects from all of the lighting producing media, including daylight, in the space to determine that this does not exceed the recommended maximum illuminance. This is counter intuitive to the notion of adding light specifically to highlight the displayed objects. There may be no need to introduce lighting equipment solely to illuminate the objects. Indeed, the lighting equipment used in these spaces for ambient, task, and other accenting may significantly over light the objects and accelerate damage to the objects. Such an analysis may not appear necessary or even obvious, yet the designer must be concerned about the effects of all lighting in a space. Table 21.1 offers a checklist of IES lighting topics and criteria. The design team is responsible for determining and addressing indoor and outdoor lighting and energy criteria set forth by authorities having jurisdiction (AHJ) which may be different from and supersede IES criteria. See also 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

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Table 21.1 | Art Lighting Checklist

Topics
✔ **IES Criteria and Design Resources**
Accenting
15.1.1.3 Accent Lighting
Table 12.2 | Subjective Impressions
Table 15.2 | Accent Illuminance Ratios
Table 22.2 | Common Applications Illuminance Recommendations
Appearance
12.2 Spatial Factors
Color
Table 6.1 | Color-related Design Questions
12.5.6 Color Considerations
Controls
16 | LIGHTING CONTROLS
Daylighting
14 | DESIGNING DAYLIGHTING
Electric Lighting
15 | DESIGNING ELECTRIC LIGHTING
Flicker
4.6 Flicker and Temporal Contrast Sensitivity
Glare
4.10.1 Discomfort Glare
4.10.2 Disability Glare
Illuminance
This Chapter: Table 21.2
12.5.5.1 Applications and Tasks
Table 12.6 | Default Illuminance Ratio Recommendations
Figure 12.22 | Task Coverage Example
Light Distribution
12.3.2 Subjective Impressions
Luminances
12.5.2 Luminance
Table 12.5 | Default Luminance Ratio Recommendations
Maintenance
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Systems Integration
12.6 Systems Factors
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This Chapter: Section 21.3.6
12.5.4 Veiling Reflections
Visual Tasks
This Chapter: Section 21.2
This Chapter: Table 21.2
Table 11.2 | Programming: Inventory Scope and Specific Examples
12.5.1 Visual Tasks
Table 12.3 | Sample Visual Task Survey

21.1 Project Type and Status

Before any design work, an understanding of the project type and scope is necessary. New, renovation, and restoration projects each offer varying opportunities. As do the kinds of artworks displayed and the intent of their display. See 11.2 Planning, 11.3.1 Pre-design, and 11.3.2 Schematic Design. This will establish the extent to which daylighting can address the lighting goals for artworks. Although every opportunity should be given to daylight as a light source, the sensitivity of the artworks to light must have direct bearing on the applicability of daylighting. Daylight demands attention to moderate or eliminate glare and balance the visible and thermal energy which may damage artworks.

21.2 Application Types

To develop lighting solutions that meet quality, quantity, and operational aspects, the art application space types under consideration and consequently the anticipated occupants, functions, and tasks are inventoried (see Table 11.2 | Programming: Inventory Scope and Specific Examples and Table 12.3 | Sample Visual Task Survey). Otherwise, lighting cannot be best targeted to the users, their expectations, functions and tasks.

Space type definitions are required early in the project design in order to track design efforts that include inventorying the project knowns, anticipated functions, and tasks and calculating lighting, power, and energy compliance. Room names, from which functions can be deduced, and numbers for tracking should be clearly marked on architectural backgrounds. The applications and tasks cited in Table 21.2 | Art Facilities Illuminance Recommendations should be reviewed against the project knowns and correlated with the named space types and functions to establish recommended illuminance criteria. Seek clarification with the client where discrepancies occur between programming information, the list of room names, and the available application and task citations in Table 21.2.

Art applications must be carefully defined. Preservation-worthy objects are typically categorized according to their sensitivity to light:

- High sensitivity
- Low sensitivity
- No sensitivity

Table 21.3 identifies the light sensitivity categories for displayed objects and cites examples.

Intended viewing situations may significantly affect the display lighting. Consider the implications of an object highly sensitive to light in a private collection in the wine cellar of a summer home versus a similar object in a museum collection. The risk of damage from light exposure in the museum is likely greater than that in the private collection example. Regardless, in any situation with such sensitive objects, the lighting designer is obligated to document and report IES criteria recommendations, but address client wishes.

The following discussion is keyed to major application headings in Table 21.2. Couple this with topics in Table 21.1 for comprehensive qualitative and quantitative criteria.

21.2.1 Accenting

In many applications accenting can be used to positively affect people's brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. Default accent lighting techniques and criteria are identified in Table 21.2. Also see 15.1.1.3 Accent Lighting. Accenting of artwork introduces focal points of visual relief in work settings. Softly accenting selective artwork promotes an impression of relaxation (see Table 12.2 | Subjective Impressions). While good for people, accenting artwork may damage the artwork.

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The team must understand the client's intention with art objects. Where art is a collection of valuables under the care of a client for future generations, then depending on the composition of the objects, exposure to visible and UV radiation must be well-controlled in intensity, time of exposure, or both. Illuminance criteria should follow those recommendations in Table 21.2 under EXHIBITS AND GALLERIES and discussed in 21.2.7 Exhibits and Galleries. Where art objects are readily replaceable or considered a commercial commodity and where the client has no expectations for the longevity of the works, illuminance criteria may follow the recommendations in Table 21.2 under ACCENTING. The design challenge is securing clear definition of the client's intention with the art objects.

There are methods for displaying seemingly highly light-sensitive objects in work and public settings and lighting these for the benefit of the viewing public with little regard for damaging the objects. Some reproduction techniques like that shown in Figure 21.1 can themselves display iconic imagery in cost effective and easily reproduced media. Figure 21.2 illustrates the lighting of historic flag replicas in a historic setting.

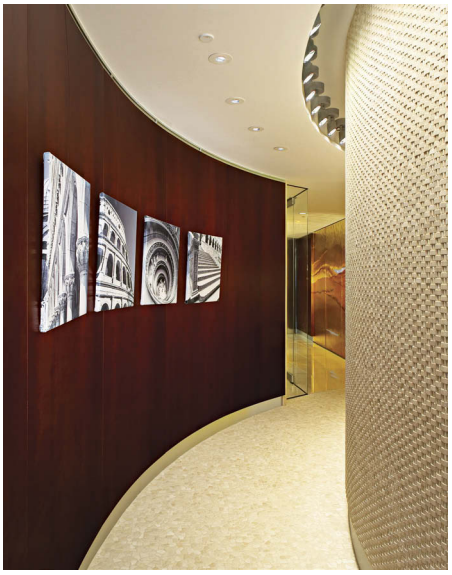


Figure 21.1 | Artwork Media
Iconic imagery reproduced on canvas may not be considered as preservation-worthy and, therefore, deemed not as light sensitive as original photographs. Pinhole linear-spread lens wallwashers lamped with 37 W MR16/NFL halogenIR$_{LV}$ lamps meet criteria for objects of low sensitivity to light and softly highlight the wall and art.
» Image ©Beth Singer Photographer, Inc.

21.2.2 Administration

In museum and gallery projects, administrative areas may be part of the project scope. Lighting for these administrative areas is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. The architectural scheme and even task specifics may vary based on the associated art facility, from a gallery in a higher education setting to public and private museums. These distinctions may affect the lighting design by influencing the kinds of lighting effects, the lighting equipment styling, and the luminances and illuminances.

On large projects, the administrative areas may be dispersed throughout an art facility or complex or may be centralized into a single area, wing, or building. Depending on client wishes and architectural desires, this centralization or decentralization may affect the degree to which the lighting design in administrative areas is sympathetic to or different from that of the other applications and tasks at the art facility in question.

21.2.3 Atria and Courtyards

Lighting for atria and courtyards is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. However, in art facilities these spaces may be specifically designed to display objects in addition to being places of respite. Where artworks are involved, great care must be taken in defining the objects' sensitivities to light and designing accordingly.

21.2.4 Auditoria

Lighting for auditoria is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

21.2.5 Building Entries

Lighting for building entries is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

21.2.6 Conservation Labs

Although conservation of artworks relies on scientific analyses to establish the underlying substrates, designs, and colors, conservation work involves highly artistic and delicate procedures. The available illuminance and the directionality of light can greatly aid or hinder conservation. Additionally, the act of lighting itself is damaging to many of the works to be conserved. Labs are typically independent spaces or even standalone facilities where lighting is highly flexible and discretely controlled to aid the conservation process while limiting exposure. Conservation illuminances may be best achieved with a task lighting system which should be on dimmer control to allow for tuning to specific object's materiality, finish, and level of conservation. Ambient lighting should be on dimmer control as well and zoned to permit relatively small areas to be set as needed. All lamps in

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Table 21.2 | Art Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
ACCENTING	Accenting influences observers' overall brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. See 15.1.1.3 Accent Lighting. These are criteria for consideration in any application.										
• Art	On artwork plane (typically vertical). See EXHIBITS AND GALLERIES for preservation-worthy materials.								see Table 15.2		
• Feature Wall	On wall plane								see Table 15.2		
• Important Focal Point	On focal point plane			see Table 15.2					see Table 15.2		
• Perimeter	On wall plane								see Table 15.2		
ADMINISTRATION	See 22 | LIGHTING FOR COMMON APPLICATIONS										
ATRIA and COURTYARDS	See 22 | LIGHTING FOR COMMON APPLICATIONS										
AUDITORIA	See 24 | LIGHTING FOR EDUCATION										
BUILDING ENTRIES	See 22 | LIGHTING FOR COMMON APPLICATIONS										
CONSERVATION LABS	Examination and treatment of preservation-worthy artworks, artifacts, and antiquities, rare books and materials, or objects deemed of monetary or sentimental value for future generations and all referenced below as objects.										
• General[i,j,k]	E_h @2' 6"; E_v @4' 0" AFF	P	150	300	600	Max	P	150	300	600	Max
• Task Areas[i,j,l]	Over area of detailed work	S	375	750	1500	Max	S	375	750	1500	Max
EXHIBITS AND GALLERIES	Display of preservation-worthy artworks, artifacts, and antiquities, rare books and materials, or objects deemed of monetary or sentimental value for future generations and all referenced below as objects.										
• Circulation/General[i,j,k,m]	Illuminance for circulation and general background in galleries is based on the intended degree of visual attraction of displayed objects. See TRANSITION SPACES/Circulation Corridors for circulation illuminance criteria where no art is displayed.										
• Displays are Dramatic Focals	Circulation and general background in galleries to set scene for displayed objects to appear as a dramatic focal points.										
• With Object Reflectance ≥0.5	E_h @floor; E_v @5' AFF			Avg = 0.1 times object E_h or as cameras require, but with min ≥10 lx					Avg of 0.1 times object E_v or as cameras require		
• With Object Reflectance <0.5	E_h @floor; E_v @5' AFF			Avg = 0.05 times object E_h or as cameras require, but with min ≥10 lx					Avg of 0.05 times object E_v or as cameras require		
• Diplays to Moderate Focals	Circulation and general background to set scene for displayed objects to appear as a moderate focal points.										
• With Object Reflectance ≥0.5	E_h @floor; E_v @5' AFF			Avg = 0.2 times object E_h or as cameras require, but with min ≥10 lx					Avg of 0.2 times object E_v or as cameras require		
• With Object Reflectance <0.5	E_h @floor; E_v @5' AFF			Avg = 0.1 times object E_h or as cameras require, but with min ≥10 lx					Avg of 0.1 times object E_v or as cameras require		
• Displays are Subdued Focals	Circulation and general background to set scene for displayed objects to appear as a subdued focal points.										
• With Object Reflectance ≥0.5	E_h @floor; E_v @5' AFF			Avg = 0.5 times object E_h or as cameras require, but with min ≥10 lx					Avg of 0.5 times object E_v or as cameras require		
• With Object Reflectance <0.5	E_h @floor; E_v @5' AFF			Avg = 0.2 times object E_h or as cameras require, but with min ≥10 lx					Avg of 0.2 times object E_v or as cameras require		
• Objects[n]	Over the area of the artworks, artifacts, antiquities or other preservation-worthy objects. Consult owner or steward to categorize object's sensitivity to light. For preservation purposes, these are the maximum recommended illuminances. Time exposure should be limited to minimum practical for patrons' viewing. Consider vacancy sensors or timers to limit exposure.										
• High Sensitivity to Light[i,j,k]	See Table 21.3 for definition	K	25	50	100	Max	K	25	50	100	Max
• Low Sensitivity to Light[i,j,k]	See Table 21.3 for definition	O	100	200	400	Max	O	100	200	400	Max
• No Sensitivity to Light[i,k]	See Table 21.3 for definition	T	500	1000	2000	Max	T	500	1000	2000	Max

Table 21.2 | Art Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	see 15.1.1.3		☀	◪	■	
	see 15.1.1.3		☀		■	
	see 15.1.1.3		☀	◪	■	
	see 15.1.1.3		☀		■	
	2:1	4:1	☀			■
	2:1	4:1	☀		■	
	4:1		☀			■
	4:1		☀			■
	4:1		☀			■
	4:1		☀			■
	4:1		☀			■
	4:1		☀			■
	2:1	4:1		◪	■	
	2:1	4:1	☀	◪	■	
	2:1	4:1	☀	◪	■	

Notes for Table 21.2

The table column headings are discussed in detail in 21.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 21.4 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 21.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage as needed.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 21.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches. A shaded icon ◪ indicates applications and tasks are sensitive to daylight and appropriate measures, including blackout capabilities, must be taken to limit daylight exposure, if daylight is deemed a suitable source of light.

g. Tasks with specular components, like object under glass or CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◪ signals high likelihood; gray and white ◪ signals moderate likelihood; pale gray and white ◪ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. Use motion-sensing control to toggle lighting off or dim to standby setting when spaces or areas are unoccupied. Use instant-on lighting equipment.

j. Filter UV from daylight and electric light sources where UV radiation exceeds 75 µW/lumen below 400 nm.

k. Use lamps exhibiting CRI ≥85.

l. Equip conservation laboratories with adjustable portable luminaires for treatment efforts.

m. The circulation and general lighting in an exhibit or gallery space should establish the background against which the displayed objects are to be experienced. This circulation/general lighting must therefore be based on the intended display experience and the display reflectance values. Room surface reflectance's are assumed to be IES-recommended values of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively). Lower room surface LRVs will result in more dramatic lighting contrasts. In no event should illuminances on preservation-worthy objects exceed the maximum values cited.

n. Where any doubt exists, assigning objects to categories of higher sensitivity to light with concomitant reduction in illuminance criteria is recommended.

o. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
EXHIBITS AND GALLERIES	(continued)										
• Security Patrol[i,j]	For after-hours security patrol of exhibits. Eh @floor; Ev @5' AFF.	I	15	30	60	Max	I	15	30	60	Avg
• Work Light (Install/Uninstall)[i,j,k]	For installation and uninstallation of exhibits. Eh @floor; Ev @5' AFF.	N	75	150	300	Max	I	15	30	60	Avg
CIRCULATION	See EXHIBITS AND GALLERIES/Circulation/General for circulation criteria where art is displayed. See TRANSITION SPACES/Circulation Corridors for circulation criteria where no art is displayed.										
CLASSROOMS	See 24 | LIGHTING FOR EDUCATION										
CONFERENCING	See 22 | LIGHTING FOR COMMON APPLICATIONS										
CORRIDORS	See EXHIBITS/GALLERIES/Circulation/General for circulation criteria where art is displayed. See TRANSITION SPACES/Circulation Corridors for circulation criteria where no art is displayed.										
FOOD SERVICE	See 22 | LIGHTING FOR COMMON APPLICATIONS										
IT	See 22 | LIGHTING FOR COMMON APPLICATIONS										
PARKING	See 26 | LIGHTING FOR EXTERIORS										
PEDESTRIAN WAYS	See 26 | LIGHTING FOR EXTERIORS										
SUPPORT SPACES											
• Break Rooms/ Lunch Rooms	E_h @2' 6" AFF; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Coat Check or Coat Rooms	E_h @3' 0"; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Copy/Print Rooms											
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Machines	E_h and E_v @3' 6" AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Janitor's Closet	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Receiving/Shipping											
• Dock	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Receiving/Staging	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Storage											
• Art objects											
• Circulation/General[i,j,k,l]	E_h @floor; E_v @4' AFF		10	10	10	Min	H	10	20	40	Max
• Examination of objects[i,j,k,l]	E_h @2' 6" AFF; E_v @4' AFF	S	375	750	1500	Avg	S	375	750	1500	Avg
• Food	See FOOD SERVICE										
• Frequent Use	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Infrequent Use	E_h @floor; E_v @4' AFF	K	25	50	100	Avg	H	10	20	40	Avg

Table 21.2 | Art Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	4:1	4:1				
	2:1	4:1				
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	2:1					
	2:1					
	2:1	4:1				
	2:1	4:1				
	3:1					
	3:1					

Notes for Table 21.2

The table column headings are discussed in detail in 21.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 21.4 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 21.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage as needed.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 21.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches. A shaded icon indicates applications and tasks are sensitive to daylight and appropriate measures, including blackout capabilities, must be taken to limit daylight exposure, if daylight is deemed a suitable source of light.

g. Tasks with specular components, like object under glass or CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. Use motion-sensing control to toggle lighting off or dim to standby setting when spaces or areas are unoccupied. Use instant-on lighting equipment.

j. Filter UV from daylight and electric light sources where UV radiation exceeds 75 µW/lumen below 400 nm.

k. Use lamps exhibiting CRI ≥85.

l. Equip conservation laboratories with adjustable portable luminaires for treatment efforts.

m. The circulation and general lighting in an exhibit or gallery space should establish the background against which the displayed objects are to be experienced. This circulation/general lighting must therefore be based on the intended display experience and the display reflectance values. Room surface reflectance's are assumed to be IES-recommended values of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively). Lower room surface LRVs will result in more dramatic lighting contrasts. In no event should illuminances on preservation-worthy objects exceed the maximum values cited.

n. Where any doubt exists, assigning objects to categories of higher sensitivity to light with concomitant reduction in illuminance criteria is recommended.

o. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 21.2 | Art Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
TOILETS/LOCKER ROOMS	Typical applications and tasks cited here. Check TOILETS/LOCKER ROOMS in respective chapter for application-specific criteria.										
• Fixtures	E_h @top of plumbing fixture; E_v @3'-5' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• General	E_h @floor; E_v @3'-5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Lockers	E_h @floor; E_v @locker faces	K	25	50	100	Avg	K	25	50	100	Avg
• Showers	E_h @floor; E_v @3'-5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Vanities	E_h @3' AFF; E_v @3'-5' AFF	N	75	150	300	Avg	O	100	200	400	Avg
TRANSITION SPACES	Typical applications and tasks cited here. Check TRANSITION SPACES in respective chapter for application-specific criteria.										
• Circulation Corridors	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• Back-of-house											
• Adjacency Passageways	E_h @floor; E_v @5' AFF	Avg ≥0.3 times task E_h of adjacent space or as cameras require, but with min ≥10 lx					Avg ≥0.3 times task E_v of adjacent space or as cameras require				
• Independent Passageways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Public											
• Adjacency Passageways	E_h @floor; E_v @5' AFF	Avg ≥0.2 times task E_h of adjacent space or as cameras require, but with min ≥10 lx					Avg ≥0.2 times task E_v of adjacent space or as cameras require				
• Independent Passageways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Elevators											
• Freight											
• Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Threshold											
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Passenger											
• Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Threshold											
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Entries	See BUILDING ENTRIES										
• Escalators/Moving Walkways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Lobbies											
• Circulation, Elevator Lobbies	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• General											
• At building entries	Close proximity to exterior. Lighting should assist with adaptation when passing to/from exterior..										
◦ Day	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
◦ Night	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Distant from entries	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Security Screening	E_h @3' AFF; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Reading/Work Areas	E_h and E_v @2' 6" at sitting areas	N	75	150	300	Avg	K	25	50	100	Avg
• Reception Lobbies	Including registration, business center, fitness center, spa, concierge lounge										
• Desk											
• Desk top	E_h @3' 6" AFF; E_v @5' AFF	N	75	150	300		K	25	50	100	Avg
• Focal wall behind desk	On wall plane	see Table 15.2									

Table 21.2 | Art Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1		☀		■	
	2:1		☀			■
	2:1		☀		■	
	2:1		☀			■
	2:1		☀		■	
	2:1		☀			■
	2:1		☀			■
	3:1		☀			■
	2:1		☀			■
	2:1		☀			■
	2:1		☀		■	
	2:1		☀		■	
	2:1		☀			■
	2:1		☀		■	
	2:1		☀		■	
	4:1		☀			■
	4:1					■
	4:1		☀			■
	2:1		☀		■	
see Table 12.6			☀		■	
	4:1		☀		■	
			☀		■	

Notes for Table 21.2

The table column headings are discussed in detail in 21.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 21.4 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 21.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage as needed.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 21.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches. A shaded icon ☀ indicates applications and tasks are sensitive to daylight and appropriate measures, including blackout capabilities, must be taken to limit daylight exposure, if daylight is deemed a suitable source of light.

g. Tasks with specular components, like object under glass or CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◥ signals high likelihood; gray and white ◥ signals moderate likelihood; pale gray and white ◥ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. Use motion-sensing control to toggle lighting off or dim to standby setting when spaces or areas are unoccupied. Use instant-on lighting equipment.

j. Filter UV from daylight and electric light sources where UV radiation exceeds 75 µW/lumen below 400 nm.

k. Use lamps exhibiting CRI ≥85.

l. Equip conservation laboratories with adjustable portable luminaires for treatment efforts.

m. The circulation and general lighting in an exhibit or gallery space should establish the background against which the displayed objects are to be experienced. This circulation/general lighting must therefore be based on the intended display experience and the display reflectance values. Room surface reflectance's are assumed to be IES-recommended values of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively). Lower room surface LRVs will result in more dramatic lighting contrasts. In no event should illuminances on preservation-worthy objects exceed the maximum values cited.

n. Where any doubt exists, assigning objects to categories of higher sensitivity to light with concomitant reduction in illuminance criteria is recommended.

o. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 21.2 | Art Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
TRANSITION SPACES	(continued)										
• Lounges											
• Clubs and Game Rooms											
• General	E_h and E_v @2' 6"	J	20	40	80	Avg	G	7.5	15	30	Avg
• Table games	E_h @table; E_v @5' AFF	P	150	300	600	Avg	K	25	50	100	Avg
• Video games	E_h @game controls; E_v @4' AFF	H	10	20	40	Avg	C	2	4	8	Avg
• Reading/Work Areas	E_h and E_v @2' 6" at sitting areas	N	75	150	300	Avg	K	25	50	100	Avg
• Social/Waiting Areas		J	20	40	80	Avg	G	7.5	15	30	Avg
• Stairs	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• High Activity[o]	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Live Surveillance	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Typical	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	4:1		☀			■
	see Table 12.6		☀	◪	■	
	see Table 12.6		☀	◪	■	
	see Table 12.6		☀		■	
	2:1		☀			■
	2:1		☀			■
	2:1		☀			■
	2:1		☀			■

Notes for Table 21.2

The table column headings are discussed in detail in 21.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 21.4 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 21.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage as needed.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 21.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches. A shaded icon ▨ indicates applications and tasks are sensitive to daylight and appropriate measures, including blackout capabilities, must be taken to limit daylight exposure, if daylight is deemed a suitable source of light.

g. Tasks with specular components, like object under glass or CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◪ signals high likelihood; gray and white ◪ signals moderate likelihood; pale gray and white ◪ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. Use motion-sensing control to toggle lighting off or dim to standby setting when spaces or areas are unoccupied. Use instant-on lighting equipment.

j. Filter UV from daylight and electric light sources where UV radiation exceeds 75 µW/lumen below 400 nm.

k. Use lamps exhibiting CRI ≥85.

l. Equip conservation laboratories with adjustable portable luminaires for treatment efforts.

m. The circulation and general lighting in an exhibit or gallery space should establish the background against which the displayed objects are to be experienced. This circulation/general lighting must therefore be based on the intended display experience and the display reflectance values. Room surface reflectance's are assumed to be IES-recommended values of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively). Lower room surface LRVs will result in more dramatic lighting contrasts. In no event should illuminances on preservation-worthy objects exceed the maximum values cited.

n. Where any doubt exists, assigning objects to categories of higher sensitivity to light with concomitant reduction in illuminance criteria is recommended.

o. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 21.3 | Light Sensitivity Categories

Sensitivity to Light	Example Objects[a,b]
High	books, botanical specimens, costumes, cotton, drawings, dyed leather, feathers, fugitive dyes, fur, gouache, insects, manuscripts, miniatures, paintings in distemper media, paper, prints, silk, skins, some minerals, some photographs, stamps, tapestries, textiles, wallpapers, watercolors, wool, and writing inks
Low	bone, horn, ivory, lacquer, leather, oil paintings, some plastics, some photographs, tempura paintings, textiles with stable dyes, and wood finishes
No	ceramics, enamel, glass, jewels, metal, most minerals, stone, and wood

a. Example distinctions are based on several references [4] [5] [6] [7]. Where any doubt exists, assigning objects to categories of higher sensitivity to light with concomitant reduction in illuminance criteria is recommended.

b. Objects or artworks consisting of a variety of the exemplified materials should be categorized in the most sensitive category. Some objects, such as ceramics or metal, may exhibit fugitive finishes and should be assigned to the high-sensitivity-to-light category.

c. Consult with conservator to establish light sensitivity categories for given objects.

task lighting systems in conservation labs should exhibit CRI of 100. Lamps in ambient lighting systems should exhibit CRI ≥85. Lamps or dimming techniques should not result in color shifting or reduction in color rendering. For many situations, though not all as Figure 21.3 illustrates, any use of daylight must be well controlled and permit total blackout. Vacancy sensors should be used to strictly limit light exposure.

21.2.7 Exhibits and Galleries

Artworks, artifacts, antiquities or other preservation-worthy objects must be defined and placed in plan in order to develop appropriate lighting solutions. These objects are classified according to their sensitivity to light for which consultation with a curator may be necessary. For preservation purposes, Table 21.2 cites maximum recommended illuminances. There is no avoiding the obvious, however draconian: preservation-worthy objects are best preserved in the dark. This may bear repeating for the project record. Other environmental aspects, such as humidity and temperature, are likely to be as, if not more, damaging to objects as are visible and UV radiation from daylight and other sources. Lighting is a sufficient contributor to damage for some objects that designs must be developed accordingly.

The reasons for displaying preservation-worthy objects is their effect on the human psyche, an understanding of our past, an appreciation of the contribution or significance of fellow humans and nature, or all of this. Such object displays are, therefore, celebrated with light. The levels of light and the durations of exposure can be manipulated to allow for this celebration while minimizing damage to the objects.

Time exposure should be limited to minimum practical for patrons' viewing. Vacancy sensors or timers or some combination should be considered to limit exposure.

21.2.7.1 Circulation/General

The circulation and general lighting in an exhibit or gallery space should establish the background against which the displayed objects are to be experienced. This circulation/general lighting must therefore be based on the intended display experience and the display reflectance values. For the following recommendations, room surface reflectances are assumed to be IES-recommended values of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively). Lower room surface LRVs will result in more dramatic lighting effects.

Display experiences are categorized for dramatic focal points, moderate focal points, and subdued focal points. These may relate to the experience programmed by the client or curator of the exhibit or by the design team or by the lighting designer, depending on the level of project involvement by an informed client or the availability of a curator. Objects' reflectance values are categorized as ≥0.5 (greater than or equal to 50% reflectance) or <0.5 (less than 50% reflectance). These, too, are programmed or designer-assigned. Though security camera technologies now require little light for effective function, the designer should confirm illuminance minimums for cameras. In any event, for purposes of comfortable and convenient circulation throughout exhibits and galleries, horizontal illuminance on the floor plane should be no less than 10 lx.

Where dramatic displays are desired, the circulation/general illuminance should be just 10 percent of the display illuminance for a display exhibiting at least a 50% reflectance, but no less than 10 lx. If the display exhibits a reflectance lower than 50% reflectance, then the circulation/general illuminance should be just 5 percent of the display illuminance, but no less than 10 lx. That is, since the display is relatively dark in tone, the circulation/general lighting must be that much lower in order for the display to appear dramatically illuminated.

Where moderate focal points are desired, the circulation/general illuminance should be 20 percent of the display illuminance for a display exhibiting at least a 50% reflectance, but no less than 10 lx. If the display exhibits a reflectance lower than 50%, then the circulation/general illuminance should be just 10 percent of the display illuminance, but no less than 10 lx.

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Figure 21.2 | Historic Objects
The original flags displayed for a hundred-plus years in the cases encircling the rotunda floor of the Michigan Capitol were found to be disintegrating during the capitol's restoration in 1989. A fisheye view of the entire rotunda is on the left. Flags now displayed here are replicas of the Civil War era counterparts which are themselves now preserved in the state historical museum. [7] Fluorescent lamps concealed above wood louvers and opal lensing along with exposed filament lamps illuminate the replicas to criteria appropriate for preservation-worthy objects of low sensitivity to light. Even the replicas are handled with care. This lighting is more consistent with the flags' presentation in a historic landmark than would be the more dramatic accenting that would be achieved by selecting illuminance criteria from ACCENTING in Table 21.2.

Oil paint portraits of governors on the second and third floor rotunda balconies, seen more clearly in the image on the right are lighted with low wattage fluorescent picture lights fitted with UV filters.

» Left image Dietrich Floeter Photography ©1992
» Right image ©Richard Cummins/Corbis

For subdued focal points, the circulation/general illuminance should be half of the display illuminance for a display exhibiting at least a 50% reflectance, but no less than 10 lx. If the display exhibits a reflectance lower than 50%, then the circulation/general illuminance should be 20 percent of the display illuminance, but no less than 10 lx.

21.2.7.2 Objects

Lighting of preservation-worthy objects on display must respect the objects' sensitivities to light. Table 21.2 outlines illuminance criteria. Where light sources exhibit UV radiation, apply reduction filters to the lamps or luminaires. Daylighting should only be considered where objects are not sensitive to UV and visible radiation or where automated and fail-safe control of daylight is employed.

Direct sun can be most destructive, causing damage in a very short time. North skylight was arguably the source of choice for masters in painting. With orientation and geometry, north skylight can be properly controlled to avoid direct sun at all times. Glazings and geometries can be used to greatly reduce daylight levels. Glazing interlayers and films can reduce UV, however, specifications must cover the range below 400 nm. Skylight wells', tubes', and splays' finishes consisting of titanium dioxide can be used to further reduce UV for sensitive objects. Shades, louvers, and other mechanical devices should be automated to limit daylight to the maximum allowed for a given object or series of objects. Fail-safe modes should block all daylight. Very close scrutiny of the program and close collaboration with the curators, conservators, and directors of facilities in which sensitive objects are to be displayed is a must where daylight is under consideration. Such systems can only be successful if careful analyses and mockups are undertaken. Figure 21.4 illustrates a unique approach to daylighting for exhibits.

Ultraviolet radiation induces photochemical damage on many materials and is generally more detrimental than visible radiation. Photochemical damage is evidenced by color change and physical deterioration and is irreversible. [8] For purposes of this discussion, UV radiation is that which is ≤400 nm. A maximum recommended value of UV radiation is 75 µW/lm. If lamps exceed this value, then UV reduction filters should be applied to limit UV.

Filters should be selected that eliminate as much radiation as practical in the respective region of the spectrum. This requires detailed review of the specific spectral power distri-

Table 21.4 | SI Dimensional Conversions

US Customary	SI
General	**Hard Conversion**
inches	mm [inches × 25.40]
feet	m [feet × 0.30]
Specific	**Convenient Conversions[a]**
2'	610 mm or 0.6 m
2' 6"	760 mm or 0.75 m
3'	915 mm or 0.9 m
3' 6"	1065 mm or 1.1 m
4'	1220 mm or 1.2 m
5'	1525 mm or 1.5 m

a. Hard conversions rounded for reporting convenience. Not to be confused with metric-sized luminaires or other building materials. Not for precision construction.

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Figure 21.3 | Art Conservation Labs
Unlike many conservation labs, daylight and ample fluorescent backlight are used in this lab for conservation work on stained glass. The designer must review the programming information and consult with the art conservators and curators to understand the vision and lighting needs for a given lab. This may necessitate criteria other than that recommended by the IES. Such criteria anomalies should be documented and agreed to by the team and client.
» Image ©Camille Moirec/Hemis/Corbis

butions for the lamps and filters under consideration. Lamp technologies vary too much and evolve too frequently to cite any reliable UV performance data of lamps here. The significance of the UV radiation depends on lamp wattage, center beam candlepower and beam spread, and distance between lamp and preservation-worthy material and exposure duration. If doubt exists and credible documented UV radiation data is unavailable, use UV filters. Filters should be scrutinized for their range of effectiveness and the degree of reduction.

Where daylight is under consideration in collection areas for high- or low-sensitivity-to-light preservation-worthy objects or materials, the magnitude of daylight must be well-controlled or automatically responsive to available daylight or both. Films on glass and interlayers in laminated glazing can reduce UV. However, the magnitudes experienced with daylight are so significant, that review of the remaining UV component must be made to assure the residual levels are acceptable. Regardless of UV mitigation, visible radiation from daylight may also be damaging given its potential magnitude. Glazing should be selected for its relative damage-factor transmittance, T_{df}, where lower is better. T_{df} accounts for radiation in the 300 nm to 600 nm range [10] [11].

Figure 21.5 exemplifies a gallery set for an exhibit of middle east stone panels, carvings, and bas reliefs and other artifacts that are thousands of years old. Figure 21.6 illustrates an exhibit featuring displays of 18th, 19th, and 20th century puppets.

The illuminance criteria outlined in Table 21.2 for EXHIBITS AND GALLERIES/Objects are not limited to objects displayed in museum exhibits and galleries, but apply to preservation-worthy objects displayed in any application. Preservation-worthy objects may encompass items considered of value and worthy of preservation for future generations. So, for example, where decorative ceilings and walls and painted graphics in historic facilities are to be lighted, citations under EXHIBITS AND GALLERIES/Objects in Table 21.2 are recommended. These criteria were used to illuminate the decoratively painted historic ceiling in Figure 21.7 and the historic ceiling mural shown in Figure 21.8.

Some objects have very little, if any, sensitivity to light. However, these objects should be lighted relative to their setting. For example, the sculpture shown in Figure 21.9 is illuminated in the context of its surround.

In addition to illuminance criteria based on objects' sensitivities to light, lighting objects depends on the viewing conditions and the objects' finishes or, if under glass or acrylic, the design and orientation of the glass or acrylic. The 2- and 3-dimensional nature of these objects, the nearly infinite number of finishes and materials used in their creation, and the many vantage points from which these are viewed limit the utility of general rules of thumb on the types of lighting equipment and the number of lighting positions and aiming angles to consider. Calculations are useful, but mockups are most informative.

Expressed previously, an object's sensitivity to light can be mitigated by not exposing the object to light. A less draconian technique is to limit the illuminance on a light-sensitive object and limit duration of exposure to UV and visible radiation. Continuous exposure to even low illuminance will ultimately deteriorate a light-sensitive object. Limiting the duration of light exposure through hours of operation, time clock operation of object lighting, in a lobby, for example, and rotating artworks from display to storage periodically are all methods of limiting the duration of exposure. To this end, some attempts have been made to establish lux-hour limits for artworks based on light sensitivity. The rationale is to allow greater illuminances for shorter time periods on sensitive objects or extend display durations by reducing illuminances. For high-sensitivity-to-light objects, an annual cumulative exposure should not exceed 150,000 lx-hours. For low-sensitivity-to-light objects, an annual cumulative exposure should not exceed 600,000 lx-hours. [12] However, it is important to consider these exposures as maximums and not entitlements.

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21.2.7.3 Patrol

Where facilities exhibiting preservation-worthy objects use human patrols for security, lighting must be available during the patrol period to assist in live visual surveillance. This lighting should only be energized when the area is occupied. Occupancy sensing may be best, though switches with timers strictly limited to the time required for the patrol surveillance may be appropriate. Instant-on lighting equipment must be used to provide on-demand lighting.

21.2.7.4 Work Light

During periods of exhibit installation and closing and dismantling, sufficient light should be available to assist in the basic tasks involved. This lighting scheme is also appropriate for cleaning.

21.2.8 Classrooms

Lighting for classrooms is discussed in 24 | LIGHTING FOR EDUCATION.

21.2.9 Conferencing

Lighting for conferencing facilities is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

21.2.10 Food Service

Lighting for food service is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

21.2.11 IT

Lighting for IT facilities is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

21.2.12 Parking

Lighting for parking facilities is discussed in 26 | LIGHTING FOR EXTERIORS.

21.2.13 Pedestrian Ways

Lighting for pedestrian ways is discussed in 26 | LIGHTING FOR EXTERIORS.

21.2.14 Support Spaces

These relatively back-of-house citations are self-explanatory. For dock areas, outdoor nighttime lighting zones determine which illuminance criteria are appropriate. In any event, these are applied immediately at the exterior of the dock overhead door. Lighting equipment should direct all light downward (see Figure 22.4). Lighting the outdoor parking or dock staging area should conform to criteria identified in 26 | LIGHTING FOR EXTERIORS.

Lighting for storage spaces for preservation-worthy objects should be on vacancy sensors with short time-outs to limit light exposure. Lighting layouts and control zoning should accommodate circulation/general lighting and discrete zones of additional lighting should accommodate inspection on an as-needed basis to limit exposure to high illuminance.

21.2.15 Toilets/Locker Rooms

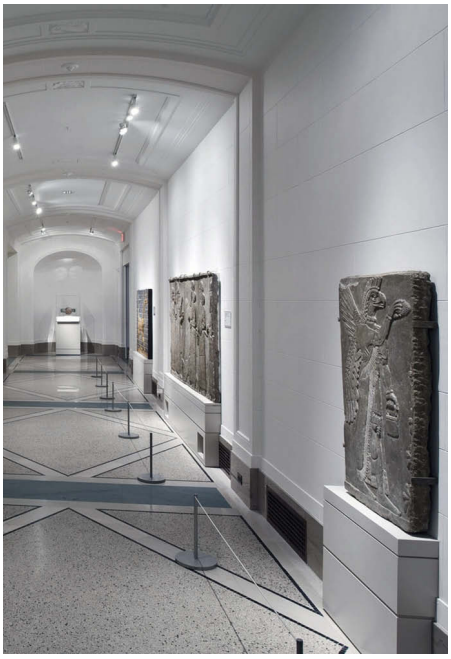
Lighting for toilets and locker rooms is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. Addressing the plumbing fixtures (for example, toilets, urinals, vanities) will provide sufficient light where needed without overlighting the entire toilet room.



Figure 21.4 | Daylighting
A passive daylighting system consisting of north oriented skylight elements provides soft, diffuse light on horizontal and vertical surfaces, including displayed objects. [9] Electric lights are used to supplement or supplant daylight as necessary. See also Figure 11.1.

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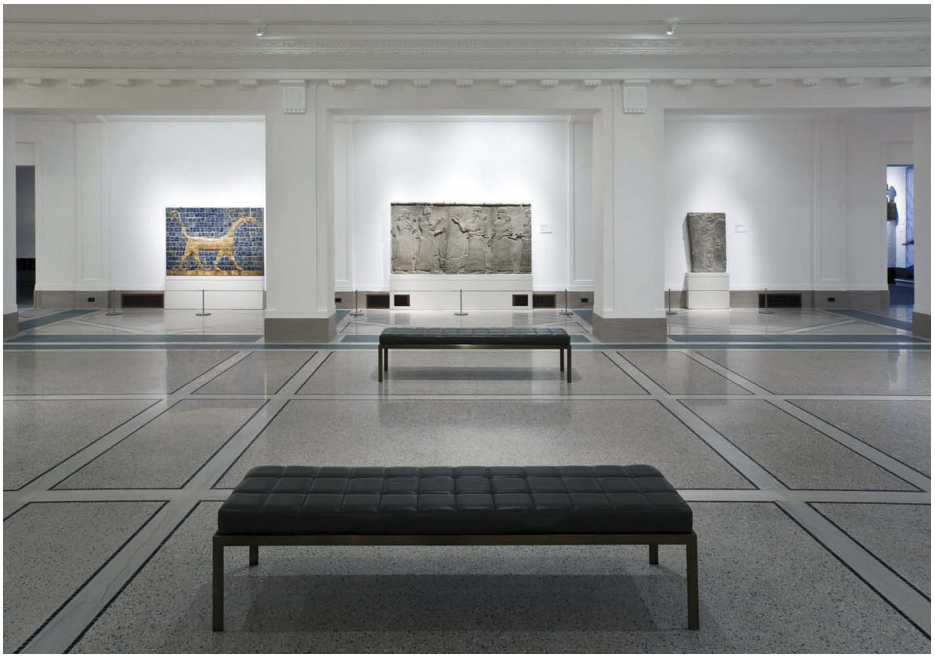


Figure 21.5 | Exhibit Displays
The Ancient Middle East Exhibit at the Detroit Institute of Arts is illuminated with 20 W MR16 halogenIR$_{LV}$ lamps of varying beam spreads to meet criteria for objects of low sensitivity to light. Circulation/general lighting meets criteria appropriate for displays as moderate focal points. Surface mounted tracks are strategically positioned to provide aiming angles between 25° and 40° as shown in the top left image.
» Images ©Detroit Institute of Arts

21.2.16 Transition Spaces

Most of these spaces are self-explanatory. However, attention should be given to the illuminances of spaces adjacent to exhibits and galleries. Harsh transitions to and from the exhibit areas should be avoided. Maintaining a 5-to-1 ratio from one room illuminance to another minimizes the disorientation when traversing from high-illuminance zones to low-illuminance zones. This may necessitate *light locks* if one space, say a daylighted lobby or corridor, is overly bright and located adjacent to a gallery of high-sensitivity-to-light objects. Harshness can also be minimized if low-illuminance spaces use high reflectance ceilings, walls, and floors and if high-illuminance spaces use lower reflectance ceilings, walls, and floors. See Figure 24.2 | Sound and Light Lock.

Light locks as used here is reference to a space separating a bright space from a dark space to avoid disturbing flashes of brightness as people enter/exit the dark space. The light lock is usually large enough to prevent a person from holding open the door to the bright space while simultaneously holding open the door to the dark space. Sometimes light locks are also used as sound locks to minimize sound transmission from louder spaces to quieter spaces are people enter/exit the quieter space. These are called sound and light locks.

21.3 Illuminance Criteria

Illuminance criteria, when fully deployed, are a robust set of quantitative values that influence visibility, visual performance, and visual comfort and attention. Short-circuiting the criteria selection or designing to a single criterion value, such as horizontal illuminance, to address worst-case tasks will surely result in dissatisfaction. Even if clients accept the visual results, not getting the most from the energy expended or, worse, energy waste is a likely result. Following are notes related to various topics outlined in Table 21.2.

21.3.1 Applications and Tasks

Applications and tasks encountered on any given project may be different from those identified in Table 21.2 and may warrant different illuminance criteria. Cross-referencing closely-associated applications or tasks is appropriate. Sometimes naming trends or conventions for space types or functions change to conform to current practice, client programming, or architectural conventions, but the actual activities and tasks remain the same and this cross-referencing works. Failing this technique, reviewing the list in Table 21.2 may be in order to determine if any applications or tasks exhibit a similar visual-component to the unique applications or tasks. Otherwise, reviewing 4.12 An Illuminance Determination System and Table 4.1 is necessary to establish a task category based on the task characteristics or visual performance descriptions most closely associated with

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the unique applications or tasks. Curators and conservators will have valuable input on lighting requirements. These exercises as well as any deviations from recommendations the designer intends to make should be carefully documented for the record.

21.3.2 Notes

The notes in Table 21.2 may refer to other task headings in the table or to other handbook chapters as appropriate. Where some degree of clarification is warranted, notes are made.

21.3.3 Recommended Maintained Illuminance Targets

Values cited are maintained on the area of coverage for the task under consideration as needed. Illuminance is additive. Where practical and without negatively affecting the intended application of light, target values are achieved with any combination of daylighting and/or electric lighting in whatever mix of ambient, task, and accent lighting is deemed appropriate to meet these and the other lighting goals established during design. For objects worthy of preservation for future generations, illuminance targets are maxima. See 12 | COMPONENTS OF LIGHTING DESIGN and see 10.7.1 Light Loss Factors.

With respect to light loss factors, account for anticipated losses through the point in time at which group relamping and cleaning should occur. Group relamping and cleaning should be standard practice, though these need not occur at the same frequency. Periodic cleaning and group relamping essentially maintain the illuminance at criteria and make the most efficient use of the installed equipment. For purposes of sustainability, cleaning and group relamping can no longer be presumed to be infrequent or unlikely. Maintenance procedures must be part of the design discussions with the client. See the IES document IESNA/NALMCO RP-36 Recommended Practice for Planned Indoor Lighting Maintenance for additional information. Where maintenance is deferred or practiced poorly or not at all, the actual illuminance values will fall below criteria targets. This is inefficient, unsustainable, and may be unsafe while adversely affecting users' quality of life or work. Ratcheting initial illuminances higher is poor practice and not recommended. Maintenance procedures may be especially problematic with LEDs where promises of extraordinarily long life may be offered, but usually with the caveat that lamp lumen depreciation (LLD) at that rated life is 70% or perhaps even as low as 50% of initial rating. If replacement cycles are presumed to be rated life, then LLD alone must be 0.7 or 0.5 or whatever lumen rating is certified by the LED vendor. See 13.3 Life and Lumen Maintenance.

Targets cited are consensus and recommended for respective functional activity. For some applications, IES recommendations are within 10% of code requirements. This apparently is an artifact of metrication. Footcandle conversions of any values cited in Table 21.2 should be made at 1 fc to 10 lx. This soft conversion avoids a redundant diminishing of illuminance values after multiple citations and conversions over time. This also eliminates a false sense of accuracy advanced by an ever-increasing number of decimal places and a false sense of urgency advanced by eccentric fractional values introduced by hard conversions. Nevertheless, a lighting design must meet code and the mechanics of which must be coordinated amongst the design team. The IES recommendations should not, do not, and cannot reflect all of the various code requirements in force in all jurisdictions at any given time.

Targets are intended to apply to the dominant plane of the task, typically, but not always, horizontal or vertical. In some situations, illuminance criteria are cited for one plane, such as the vertical plane for lighting white boards, while the other plane is blank. The blank signifies that illuminance on that plane is unimportant and may be a consequence of the illuminance of other tasks within the vicinity or by whatever illuminance results from meeting the target illuminance for the prescribed plane of interest.

21.3.3.1 Target Planes

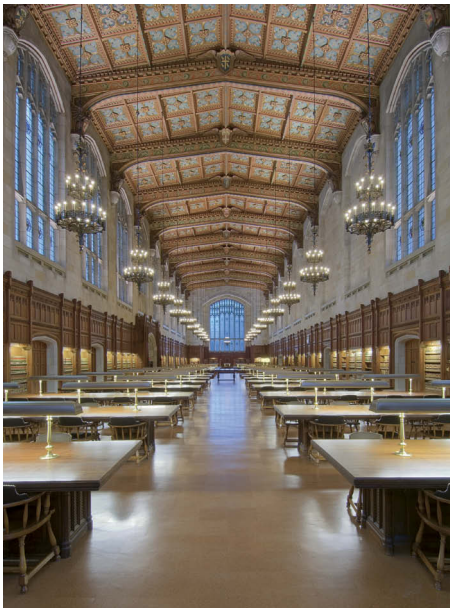
Many, though certainly not all, tasks are performed with the task in roughly a horizontal orientation or vertical orientation. Additionally, most tasks are expected to have both a





Figure 21.6 | Exhibit Displays
LEDs offer a means of introducing color contrast for visual attraction where illuminance must be kept low and heat directed away from displays. RGB LEDs also allow for color change over time introducing a unique capability that enhances the theatrical nature of this display and better engages patrons.
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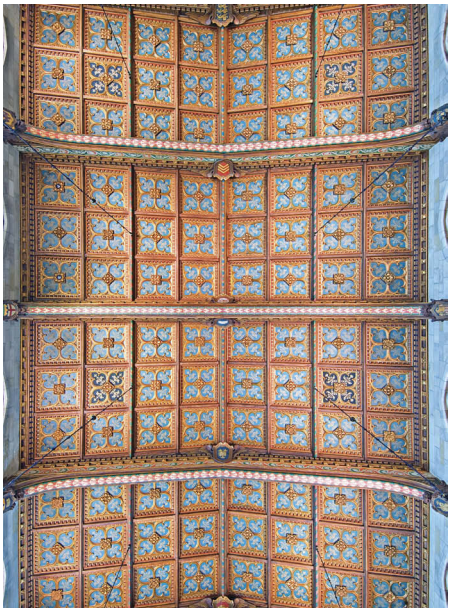


Figure 21.7 | Decorative Painting
Uplighting the decorative ceiling in this 1931 library reading room was introduced during restoration work to better balance room and task contrasts and improve overall brightness perceptions. The ceiling surface is illuminated to criteria appropriate to low-sensitivity-to-light objects. 39 W PAR20 CMH lamps exhibiting 10° beam spread, CCT of 3000 K, and 86 CRI were added at window sills to uplight the cleaned and refinished ceiling. Uplights are step-switched in accordance with daylight availability. Uplights are lensed with UV filters. See also Figure 29.7.
» Images ©Curt Clayton

horizontal illuminance component (E_h) and a vertical illuminance component (E_v). Where these illuminance components are intended at differing planar elevations, such is indicated under "Notes." For example, in art storage rooms, horizontal illuminances apply to what might be table height of 2' 6" AFF and vertical illuminances apply to what might be hanging or stacking systems at 4' AFF. In situations where art objects are stored on planes of different elevations or orientations, then those elevations and orientations must be established and criteria applied to the respective planes of interest.

For planes related to vertical illuminance targets, some guidance is indicated under "Notes." However, the designer may elect to use alternate or multiple vertical planes. In some situations the vertical planes could be oriented in a number of directions and the designer must determine which are most appropriate for the situation. For example, in a gallery with 2-dimensional objects mounted on walls there is only one plane and one orientation per wall. However, 3-dimensional objects mounted on pedestals in the middle of galleries may deserve several vertical planes and orientations. The illuminance criteria apply to these planes.

21.3.3.2 Visual Ages of Observers
Illuminance criteria are based on the visual ages of more than half the intended observers. This aspect should be resolved during programming with the client. It may be reasonable to assume that in a gallery some majority of the patrons at some of the time may be over 65 years of age. However, since there are no time or accuracy constraints associated with viewing artworks, it may be determined acceptable that design targets should be set for a majority of patrons between the ages of 25 and 65 years old.

21.3.3.3 Illuminance Categories
Illuminance categories are designated by letters A through Y. These are shown in Table 21.2 for more convenient reference to Table 4.1 | Recommended Illuminance Targets should the designer wish to explore other criteria targets or if applications or tasks on a specific project are not readily correlated to the table citations.

21.3.3.4 Gauge
The common gauge for determining illuminance target compliance is cited for each application. All gauges presume that point-by-point techniques are used for predictive calculations and presume that uniformity criteria are closely monitored. Where an average illuminance value over the area of coverage can satisfy target compliance, "Avg" is cited. In applications or tasks where a minimum or maximum target is necessary, the gauge for compliance is "Min" or "Max" respectively.

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The designer may elect to use other methods to evaluate target compliance, such as criterion rating (CR) or coefficient of variation (C_v). See 4.12.4.5 Tasks at Uncertain Locations Over a Large Area.

In any event, once illuminance targets and uniformities are established, then any calculated deviation from them should be limited. Standard engineering allowance of ±10% might be acceptable for targets gauged as average unless contractual or code obligations demand otherwise. Minima and maxima must be achieved as intended.

Designs should be adjusted until predictions are within allowance for averages and meet minima and maxima. For additional information, see 4.12.4.1 Recommended Illuminances at Design Time, 4.12.5 Illuminance Ratios, 9.15.1.1 Average Illuminance, and 10.8 Assessing Computed Results.

21.3.4 Uniformity Targets

Illuminance uniformity targets work in conjunction with luminance uniformities and surface reflectances, all of which must be addressed as part of the design to avoid visual discomfort, glare, and strain. Uniformity ratios are targets that define the widest recommended ranges. In many situations, uniformity ratio criteria are those between average values of an array of points and the minimum value in the same array of points. Uniformity targets apply to both horizontal and vertical illuminances over the area of coverage. Where horizontal uniformity criterion is different from vertical uniformity criterion, two ratios are reported with the first value for horizontal illuminance (E_h).

21.3.4.1 Maximum-to-average

This is the recommended ratio of maximum illuminance to the average illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations sensitive to even a relatively small degree of overlighting.

21.3.4.2 Average-to-minimum

This is the recommended ratio of average illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where illuminance too far below average conditions is noticeable and detrimental to task performance or inconsistent with normal expectations.

21.3.4.3 Maximum-to-minimum

This is the recommended ratio of maximum illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where too much variation in illuminance is considered undesirable and untenable from a performance or safety perspective.

21.3.5 Daylighting Advancement

Generally, design strategies should embrace any combination of daylighting and electric lighting to achieve target values during daylight hours. The preference is for daylighting to provide all or most of the recommended illuminance presuming that all aspects of daylighting are properly addressed. A sunburst icon depicts those applications and tasks where daylighting is considered a strategic candidate. A shaded sunburst icon indicates applications and tasks are sensitive to daylight and appropriate measures, including blackout capabilities, must be taken to limit daylight exposure, if daylight is deemed a suitable source of light. Where users are willing to cede to automation, photocells and stepped-dimming or continuous dimming can be used to reduce or eliminate electric lighting during daylight hours. See 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Even for those applications where daylighting is not traditionally a strategic candidate, it may be determined that very careful and coordinated design will offer great sustainability opportunities along with positive influences associated with daylight and views.

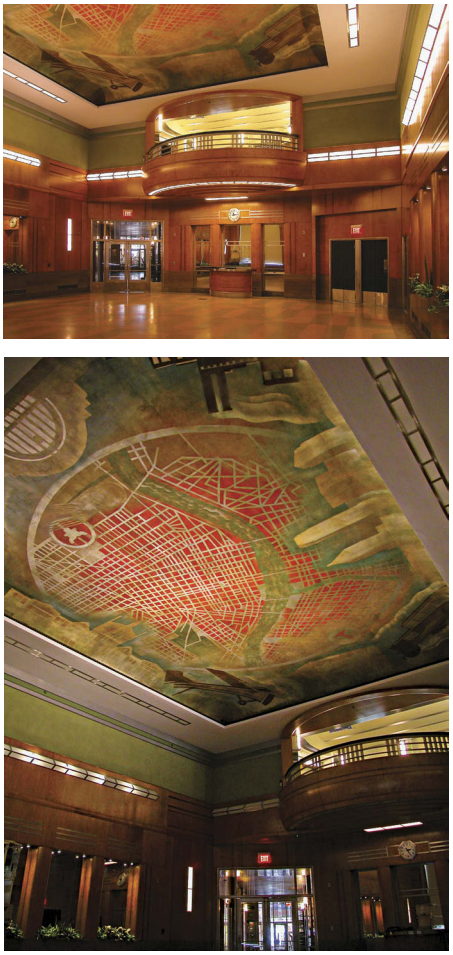


Figure 21.8 | Murals
Uplighting the mural, a stylized layout of the City of Cincinnati completed in 1933, in this dining room in the historic Cincinnati Union Terminal highlights this restored feature for banquet, party, and meeting guests. The top image illustrates a MEETING scene while the bottom image illustrates a COCKTAIL scene. The ceiling surface is illuminated to criteria appropriate to low-sensitivity-to-light objects in each scene. Uplight lamps are 20 W MR16 ceramic metal halide spots exhibiting CCT of 3000 K and CRI of 81 and are on switching channels separate from the dimmable lighting in the room. Uplights are lensed with UV filters. Cincinnati Union Terminal is now home to Cincinnati Museum Center.
» Images ©Gary Steffy Lighting Design Inc.

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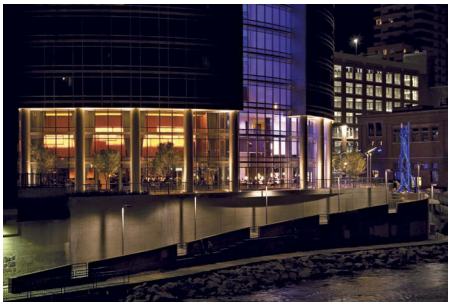




Figure 21.9 | Sculpture
Blue gels were used on the majority of the luminaires to illuminate this sculpture to a rich blue, using color contrast in the night environment, as seen at the right of the top image, rather than luminance contrast. Lamps are 39 W T4.5 exhibiting CCT of 3000 K and CRI of 84 and are on various switching channels to allow for mid-evening and curfew setbacks without total loss of light.
» Images©KevinBeswick,www.ppt-photographics.com

IESH/10e CSA/ISO

> 12.5 Task Factors
- for information on CSA/ISO computer screen qualities

21.3.6 Veiling Reflections

Tasks with specular components, such as artifacts under horizontal glass or artworks under vertical glass are prone to veiling reflections. The likelihood of particular applications and tasks predisposed to veiling reflections is indicated by a "reflected light" icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood. Veiling reflections are particularly annoying in art viewing situations. Where objects are displayed behind glass or acrylic, careful study of the orientation of the display glass or acrylic and lighting positions is necessary to avoid or minimize the effects of veiling reflections. Veiling reflections are minimized by controlling the overall amount and direction of light with respect to the task locations and orientations. Alternatively, tasks sensitive to veiling reflections can be screened or isolated so that distant bright sources not associated with lighting the particular task or object are essentially masked. Other effective strategies include employing indirect soft, diffuse electric lighting or direct electric lighting with multiple low-output luminaires, or positioning tasks and luminaires and luminance patterns to avoid harsh reflections from tasks. In display cases, internal lighting can greatly limit, if not eliminate, veiling reflections, though the issue of proximity of light source to artifact and any associated heat issues must be considered. Addressing luminance recommendations (see Table 12.4 | Default Luminance and Luminaire Intensity Recommendations for VDT Applications) minimizes veiling reflections. Changing the task will reduce or eliminate veiling reflections, such as use of CSA/ISO Type I or II computer screens and matte paper versus their specular counterparts.

21.3.7 Defining Areas of Coverage

In addition to establishing planes of task orientation, the areas of coverage to which targets apply must be determined. Typical areas of task illuminance coverage are identified here, but these may not be appropriate to specific project situations. One area of coverage is "task proper or task area." Here, the illuminance criteria are applied to the task itself or to a relatively small area to which the task is confined. See 12.5.5.1 Applications and Tasks and Figure 12.22 | Task Coverage Example. In some situations, such as accenting, the "task" area may consist of the entire wall when "feature wall" or "perimeter" accenting is desired. It is important to remember that illuminance is additive, that is, task illuminance can be achieved with some combination of ambient lighting, task lighting, and/or accent lighting, providing that the total illuminance on the task proper or task area meets the illuminance criteria outlined in Table 21.2.

Another area of coverage is "room or designated area." In this situation, illuminance criteria are applied to the room or an area of fairly substantive size representing the zone in which the applications and tasks are expected to occur. The designated area is typically established by the furniture layout, for example, or might be established by the design team or homeowner. The area-of-coverage citations in Table 21.2 are based on traditional notions.

An assessment and determination must be made on which area of coverage best satisfies the lighting goals on a particular project.

21.4 Designing

Information provided here is specific to art facilities or wherever preservation-worthy objects are displayed and should be used as part of the design and documentation processes outlined in Chapters 12, 15, and 20. For outdoor applications, lamps and ballasts, transformers, and drivers must be selected for ambient temperature conditions, some of which are extremely hot and others extremely cold. See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY for additional information on respective aspects. Addressing

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all code requirements is a must. Energy efficient and sustainable practices are an integral part of all IES recommendations. Key design tenets include, but are not limited to:

- designing for the satisfaction of the observers intended to use the project
- using baseline reflectances of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively) in interior production and work-oriented spaces
- using daylighting that meets luminance and illuminance criteria
- using highest-efficacy lamps that meet color, optical and electrical control, and output criteria
- using highest-efficiency luminaires that meet aesthetic and luminance criteria
- using accenting to provide luminance balancing or improve brightness perceptions where necessary
- using controls liberally, preferably automated varieties such as presets, occupancy and vacancy sensors, astronomical time clocks, and photocells
- establishing IES-recommended illuminance criteria to meet programmed tasks
- establishing layouts that just meet IES-recommended illuminance criteria
- addressing outdoor environmental needs
- using calculations, photometrically-realistic renderings, and operational samples and mockups to prove concepts
- identifying and designing to code-specific requirements, if any, for ambient, task, and accent lighting
- documenting all code-, energy-, sustainability-, and IES-criteria compliance
- documenting criteria and design deviations and rationale and subsequent disposition by team, client, or AHJ
- documenting clearly the layouts, controls, and luminaire and lamp selections

Designing for the satisfaction of the observers is the paramount design tenet and must be kept in perspective during all aspects of design. If the observers' expectations are not fulfilled, then how much energy could be saved is moot, as is how many fewer earth resources were spared, as is how much the whole affair cost or how much value engineering saved or the photogenic qualities of the project. See sidebar references for additional guidance on the key tenets. The design effort must be undertaken with coordinated and realistic expectations by all involved on initial and life cycle costs. Budgeting should include designer input and dialogue with the team and client at project commencement and design milestones. In other words, and paraphrasing Thomas Edison, genius is, indeed, just 1% inspiration and 99% perspiration.

21.5 References

[1] Hockney D. 2011. BrainyQuote.com, Xplore Inc. 2011. [Internet]. cited January, 2011. Available from: http://www.brainyquote.com/quotes/quotes/d/davidhockn119306.html.

[2] Mark S. Rea, ed. 2000. The IESNA lighting handbook: Reference and application. 9th edition. New York: IESNA. Ch 14.

[3] [IESNA] Illuminating Engineering Society of North America. 1996. Museum and art gallery lighting: A recommended practice. RP-30-96(R2008). New York: IESNA. 91 p.

[4] Thomson G. 1986. The museum environment. 2n Edition. London: Butterworth-Heinemann. p 23.

[5] Lein L. 1986. Exhibits: Planning and design. New York: Madison Square Press. p 94.

IESH/10e Economics Resources

> 15.3.3 Budgets
- for more on budgets and value engineering

> 18 | ECONOMICS
- for more on estimating costs
- for more on life cycle costs
- for more on paybacks and rates of return

IESH/10e Energy Efficiency Resources

> 17.2 New Construction
- for more on designing for daylighting
- for more on electric lighting equipment
- for more on lighting controls

> 17.4 Lighting Codes, Regulations and Standards
- for more on application standards
- for more on equipment regulations

IESH/10e Lighting Exteriors Resources

> 12.5.5.6 Nighttime Outdoor Illuminances
- for more on lamp efficacies under mesopic adaptation

> 26 | LIGHTING FOR EXTERIORS
- for more on criteria

IESH/10e Sustainability Resources

> 13.11 Sustainability
- for more on lamps

> 19 | SUSTAINABILITY
- for more on controls
- for more on earth resources
- for more on energy
- for more on life cycle analyses
- for more on lighting design
- for more on recycling

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[6] Michalski S. 2010. Light, ultraviolet and infrared. [Internet]. cited January 2011. Available from: http://www.cci-icc.gc.ca/crc/articles/mcpm/chap08-eng.aspx.

[7] Michigan Legislature. 1992. Your state capitol: Michigan state capitol rededicated November 19, 1992. [Internet]. cited January, 2011. Available from: http://www.docstoc.com/docs/31331231/Michigan-State-Capitol. p 9.

[8] The Chartered Institution of Building Services Engineers. 1994. Lighting for Museums and Art Galleries. LG8: 1994. London. p 18.

[9] Sommerhoff, E. Dec, 2005. A sculptural approach to daylight. Archit Light [Internet]. [cited January 1, 2011] . Available from: http://www.archlighting.com/industry-news.asp?sectionID=1331&articleID=453680.

[10] [ISO] International Organization for Standardization Central Secretariat. 2003. ISO 9050:2003(E). Glass in building—Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors. Geneva, Switzerland. p. 14.

[11] [CIE] Commission Internationale de l'Éclairage. 1991. On the seterioration of exhibited museum objects by optical radiation. CIE Publication 89-1991. Bureau Central de la CIE. Vienna. pp 25-36.

[12] The Chartered Institution of Building Services Engineers. 1994. Lighting for Museums and Art Galleries. LG8: 1994. London. p 23.

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22 | LIGHTING FOR COMMON APPLICATIONS

New opinions are always suspected, and usually opposed, without any other reason but because they are not already common.

John Locke, 17th Century, Philosopher and Physician

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There need not be anything commonplace about lighting for applications that are common to many building projects. Some of these applications, such as lobbies, make first impressions. Others, like conferencing and food service can be the amenities that set one employer apart from others. Lighting for these applications is important and can infuse a facility with uncommon character. Daylighting is quite effective in addressing illuminances in many of these applications.

Comprehensive design efforts involve the information in this chapter combined with material in 12 | COMPONENTS OF LIGHTING DESIGN, 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS, 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Design tenets deemed appropriate from those chapters must be identified and lighting goals and strategies developed accordingly. This chapter primarily addresses illuminance criteria for common applications which should influence luminaire optical selections, lampings, and final layouts based on design thought-starters (see 15.2 A Lighting Scheme). Use of the material in this chapter to the exclusion of material in Chapters 12, 13, 14, and 15 will likely lead to unsatisfactory results. Previous IES related documents serve as archival reference sources [1].

Deliberate thought must be given to details beyond the recommended illuminances in this chapter. For example, in FOOD SERVICE/Bar/Back Bar, the vertical illuminance citation does not necessarily demand a uniform array of low-wattage wallwashers. Such lighting can be achieved with uplight or downlight in each shelf, a perimeter slot-like detail along the back bar elevation, adjustable accents, the smallest of daylight-slots in the top of the back bar (for at least the daytime condition) or some combination of these. Each of these can achieve the target illuminance, but each has a distinctly different appearance and requires different architectural detailing. Such specific details are not enumerated for all tasks. Table 22.1 offers a checklist of IES lighting topics and criteria. The design team is responsible for determining and addressing indoor and outdoor lighting and energy criteria set forth by authorities having jurisdiction (AHJ) which may be different from and supersede IES criteria. See also 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

22.1 Project Type and Status

Before any design work, an understanding of the project type and scope is necessary. This will establish the extent to which daylighting can address most or many or some of the lighting goals. New, renovation, and restoration projects each offer varying opportunities. See 11.2 Planning, 11.3.1 Pre-design, and 11.3.2 Schematic Design. At every opportunity the lighting designer should give every consideration to daylighting as a light source. For some applications and tasks, daylighting can be the primary light source. Critically, this means addressing the host of lighting design factors identified in 12 | COMPONENTS OF LIGHTING DESIGN. Daylight demands attention to moderate or eliminate glare and balance visible and thermal energy.

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Table 22.1 | Common Applications Lighting Checklist

Topics
✔ IES Criteria and Design Resources
Accenting
15.1.1.3 Accent Lighting
Table 12.2 | Subjective Impressions
Table 15.2 | Accent Illuminance Ratios
Table 22.2 | Common Applications Illuminance Recommendations
Appearance
12.2 Spatial Factors
Color
12.5.6 Color Considerations
Controls
16 | LIGHTING CONTROLS
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14 | DESIGNING DAYLIGHTING
Electric Lighting
15 | DESIGNING ELECTRIC LIGHTING
Flicker
4.6 Flicker and Temporal Contrast Sensitivity
Glare
4.10.1 Discomfort Glare
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This Chapter: Table 22.2
12.5.5.1 Applications and Tasks
Table 12.6 | Default Illuminance Ratio Recommendations
Figure 12.22 | Task Coverage Example
Light Distribution
12.3.2 Subjective Impressions
Luminances
12.5.2 Luminance
Table 12.5 | Default Luminance Ratio Recommendations
Maintenance
15.4.4 Installation and Maintenance
Nighttime Outdoor Environment
Table 15.6 | Nighttime Operational Strategies for Improved Outdoor Environmental Regard
Systems Integration
12.6 Systems Factors
Veiling Reflections
This Chapter: Section 22.3.6
12.5.4 Veiling Reflections
Visual Tasks
This Chapter: Section 22.2
This Chapter: Table 22.2
Table 11.2 | Programming: Inventory Scope and Specific Examples
12.5.1 Visual Tasks
Table 12.3 | Sample Visual Task Survey

22.2 Application Types

To develop lighting solutions that meet quality, quantity, and operational criteria, an inventory is made of the common applications space types under consideration and the anticipated occupants, functions, and tasks (see Table 11.2 | Programming: Inventory Scope and Specific Examples and Table 12.3 | Sample Visual Task Survey). Otherwise, lighting cannot be best targeted to the users, their expectations, functions and tasks.

Space type definitions are required early in the project design in order to track design efforts that include inventorying the project knowns, anticipated functions, and tasks and calculating lighting, power, and energy compliance. Room names, from which functions can be deduced, and numbers for tracking should be clearly marked on architectural backgrounds. The applications and tasks cited in Table 22.2 | Common Applications Illuminance Recommendations should be reviewed against the project knowns and correlated with the named space types and functions to establish recommended illuminance criteria. Seek clarification with the client where discrepancies occur between programming information, the list of room names, and the available application and task citations in Table 22.2.

The following discussion is keyed to major application headings in Table 22.2. Couple this with topics in Table 22.1 for comprehensive qualitative and quantitative criteria.

22.2.1 Accenting

Accenting affects people's brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. Default accent lighting techniques and criteria are identified in Table 22.2. Also see 15.1.1.3 Accent Lighting.

22.2.2 Administration

Administrative functions on many projects typically include circulation, conferencing, counseling, lounges, filing or records, interviewing, lobbies, mail sorting, and officing. Each of these in turn may involve a number of specifics including some form or degree of acknowledgment, conversation, reading, periods of respite or relaxation, and writing—all tasks within applications. Acknowledgement of other people and conversation, for example, require some vertical illuminance at face height (seating or standing depending on the nature of the application). Vertical illuminance criteria are cited for such applications.

The architectural scheme and even task specifics will vary based on the associated facility function and type. These variations should affect the lighting design—from kinds of lighting effects to lighting equipment styling to luminances and illuminances.

The administrative areas may be dispersed throughout a facility or complex or may be centralized into a single area, wing, or building. Depending on client wishes and architectural desires, this centralization or decentralization may affect the degree to which the lighting design in administrative areas is sympathetic to or different from that of other applications.

See also 32 | LIGHTING FOR OFFICES.

22.2.3 Atria and Courtyards

Atria and courtyards are many times synonymous with daylighting. Where these spaces are used for circulation and where adjacent spaces are appropriately shielded from direct solar penetration, daytime lighting can be achieved without electric lighting. During dark hours, electric lighting must respond to function. Circulation can be achieved with relatively low-to-the-floor electric lighting techniques or with spill lighting from adjacent spaces.

Challenges include maintaining a sense of nighttime volume and limiting outdoor light pollution. Where live plants are used, daylighting and electric lighting must provide sufficient illuminance of an appropriate spectrum and for an appropriate duration to maintain the plants or provide plant growth. See 22.2.10 Plants for more information.

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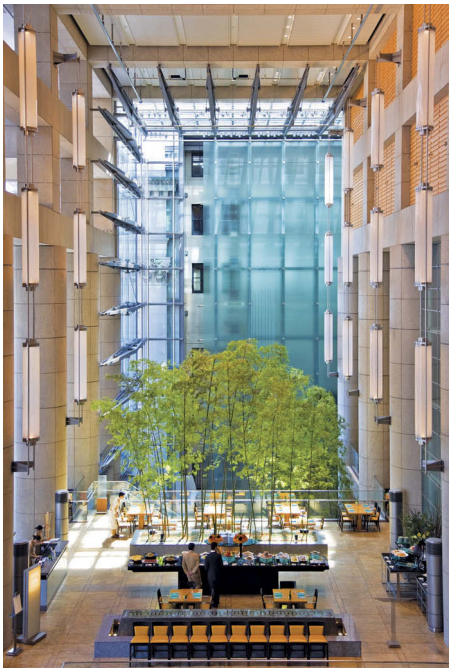




Figure 22.1 | Atria
Daylight and decorative lighting are arguably hallmarks of both atria. The lighting in the atrium on the far left is of a scale and cadence designed to complement the scale of the atrium—defining it as a room. Each luminaire provides a soft light. These are energized during the day to welcome guests and enhance place and character. Live plants require attention to the duration and quantity of illuminance at canopies. See 22.2.10 Plants.

Lighting in the atrium on the near left is contained within balcony setbacks and at the main floor. This solution reflects the history of the structure and how early electric lighting was introduced into buildings.

» Far Left Image ©B.S.P.I./Corbis
» Near Left Image ©Richard T. Nowitz/Corbis

Usually the architecture, the nature of the functions, and the illuminances involved help minimize outdoor environmental lighting effects from atria and courtyards. Where overhead glazing is used, aiming lights toward the glazing should be avoided unless these are controlled-beam luminaires lighting artwork or features suspended in the space. In-floor or on-wall uplights to highlight foliage or architecture should exhibit controlled-beam optics fitted with louvers, snoots or barn doors to trim light spill. This also minimizes glare to occupants of the space. Nighttime curfews should be established whereby this interior lighting is dimmed or stepped-back to only those levels necessary for low-activity circulation. Unless the architectural finishes are, say, <20% over a significant portion of the space, even a small amount of light will create some surface luminance and a sense of volume during dark hours. This is most successful, however, if occupants enter the space from adjacent spaces exhibiting transitional brightnesses. Figure 22.1 illustrates two very different hotel atria.

Atria and courtyards typically involve a significant amount of skylight or roof, or some combination. With the advent of building integrated photovoltaics (BIPVs), overlighting, glare, and cooling loads associated with daylighting can also be addressed by BIPVs. BIPVs can integrate with glazing in much the same way that frit covers glazing—allowing for some visible transmittance while blocking a significant amount of visible and solar radiation. Figure 22.2 illustrates a study series for a small atrium space identifying BIPV-glazed surfaces (graphically shown in white and oriented south) and clear-vision-glazed surfaces (shown in "clear" and oriented north).

22.2.4 Building Entries

For building entries several conditions influence lighting:

- Degree to which entries are covered from the elements
- Proximity of vehicular traffic to pedestrian traffic
- Anticipated nighttime activity levels
- Nighttime outdoor lighting zone for the project under consideration
- Security

Table 22.2 outlines an extensive list of entry types and situations. Although exterior situations predominate, the interior lighting of vestibules must relate to the exterior lighting condition for comfortable transition between the interior and exterior and vice versa.

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Table 22.2 | Common Applications Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
ACCENTING	Accenting influences observers' overall brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. See 15.1.1.3 Accent Lighting. These are criteria for consideration in any application.										
• Art	On artwork plane (typically vertical). See 21 | LIGHTING FOR ART for preservation-worthy materials.							see Table 15.2			
• Feature Wall	On wall plane							see Table 15.2			
• Important Focal Point	On focal point plane			see Table 15.2				see Table 15.2			
• Perimeter	On wall plane							see Table 15.2			
ADMINISTRATION											
• Circulation	See TRANSITION SPACES										
• Conferencing	See CONFERENCING										
• Copy/Print Room	See SUPPORT SPACES										
• Counseling	See ADMINISTRATION/Interviews										
• Filing	E_h @2' 6" AFF; E_v at front face of filing cabinet over area from 1' AFF to top of filing cabinet or filing system.										
• Constant		P	150	300	600	Avg	O	100	200	400	Avg
• Intermittent		N	75	150	300	Avg	M	50	100	200	Avg
• Seldom		M	50	100	200	Avg	L	37.5	75	150	Avg
• Interviews	E_h @2' 6" AFF; E_v @4' AFF										
• Conversational		N	75	150	300	Avg	L	37.5	75	150	Avg
• Formal	Includes form-filling and reading	Q	200	400	800	Avg	N	75	150	300	Avg
• Lobbies	See TRANSITION SPACES										
• Mail Facility											
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	J	20	40	80	Avg
• Security Inspection	E_h and E_v @3' 6" AFF	T	500	1000	2000	Avg	P	150	300	600	Avg
• Sorting	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	L	37.5	75	150	Avg
• Offices	See READING AND WRITING, establish tasks and normalize to illuminance of most important task or most common task; use controls to provide illuminance variability if tasks so demand. Also see 32 | LIGHTING FOR OFFICES.										
• Training	See CONFERENCING. Alternatively, see READING and WRITING, establish tasks and normalize to illuminance of most important task or most common task; use controls to provide illuminance variability if tasks so demand.										
ATRIA AND COURTYARDS	(presumed daylit)										
• Day											
• Applications/Tasks	See relevant applications tasks (e.g., FOOD SERVICE, TRANSITION SPACES/Lobbies, etc.).										
• General	See TRANSITION SPACES/Lobbies/Circulation/General										
• Plants	See PLANTS										
• Night											
• Applications/Tasks	See relevant applications tasks (e.g., FOOD SERVICE, TRANSITION SPACES/Lobbies, etc.).										
• General	See TRANSITION SPACES/Lobbies/Circulation/General										
• Late Curfew	Set-back at predetermined time	I	15	30	60	Avg	F	5	10	20	Avg

Table 22.2 | Common Applications Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
		see 15.1.1.3				
		see 15.1.1.3				
		see 15.1.1.3				
		see 15.1.1.3				
		see Table 12.6				
		3:1				
		3:1				
		3:1				
		3:1				
		3:1				
		see Table 12.6				
		2:1				
		2:1				

Notes for Table 22.2

The table column headings are discussed in detail in 22.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 22.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 22.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 22.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

m. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

n. Make electrical provisions for portable work lights.

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Table 22.2 | Common Applications Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
BUILDING ENTRIES	**INDOOR** applications and tasks cited here. See BUILDING ENTRIES - OUTDOORS for respective outdoor applications and tasks.										
• Vestibules											
• High Activity[i]	Entry/Exit vestibules typified by periods of high pedestrian traffic										
• Day	E_h @floor; E_v @5' AFF	N	75	150	300	Avg	L	37.5	75	150	Avg
• Night	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Medium Activity[i]	Entry/Exit vestibules typified by periods of medium pedestrian traffic										
• Day	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Night	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Low Activity[i]	Entry/Exit vestibules typified by periods of low pedestrian traffic										
• Day	E_h @floor; E_v @5' AFF	L	37.5	75	150	Avg	I	15	30	60	Avg
• Night	E_h @floor; E_v @5' AFF	J	20	40	80	Avg	G	7.5	15	30	Avg
BUILDING ENTRIES	**OUTDOOR** applications and tasks cited here. See BUILDING ENTRIES - INDOOR for interior vestibules.										
• Canopied Entries/Exits	At dropoff curbs to entries under canopy. Also see BUILDING ENTRIES/No Cover and BUILDING ENTRIES/Porte Cocheres.										
• High Activity[i]	Curbs typified by periods of high pedestrian and vehicular traffic; E_h @grade; E_v @5' AFG in directions of ingress/egress										
• LZ4[j]		J	20	40	80	Avg	H	10	20	40	Avg
• LZ3[j] (and LZ4 curfew)		I	15	30	60	Avg	G	7.5	15	30	Avg
• LZ2[j] (and LZ3 curfew)		H	10	20	40	Avg	F	5	10	20	Avg
• LZ1[j] (and LZ2 curfew)		G	7.5	15	30	Avg	E	4	8	16	Avg
• LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	F	5	10	20	Avg	D	3	6	12	Avg
• Medium Activity[i]	Curbs typified by periods of medium pedestrian and vehicular traffic; E_h @grade; E_v @5' AFG in directions of ingress/egress										
• LZ4[j]		H	10	20	40	Avg	F	5	10	20	Avg
• LZ3[j] (and LZ4 curfew)		G	7.5	15	30	Avg	E	4	8	16	Avg
• LZ2[j] (and LZ3 curfew)		F	5	10	20	Avg	D	3	6	12	Avg
• LZ1[j] (and LZ2 curfew)		E	4	8	16	Avg	C	2	4	8	Avg
• LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	D	3	6	12	Avg	B	1	2	4	Avg
• Low Activity[i]	Curbs typified by periods of low pedestrian and vehicular traffic; E_h @grade; E_v @5' AFG in directions of ingress/egress										
• LZ4[j]		F	5	10	20	Avg	D	3	6	12	Avg
• LZ3[j] (and LZ4 curfew)		E	4	8	16	Avg	C	2	4	8	Avg
• LZ2[j] (and LZ3 curfew)		D	3	6	12	Avg	B	1	2	4	Avg
• LZ1[j] (and LZ2 curfew)		C	2	4	8	Avg	A	0.5	1	2	Avg
• LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	B	1	2	4	Avg	-	0	0	0	
• Intercom call system access	E_v on call-interface device, unless self-illuminated						H	10	20	40	Avg
• Non-covered Entries/Exits											
• Immediate Exterior	Width of door; E_h @grade at threshold; E_v within 3' of threshold and @5' AFG in direction of ingress or security camera										
• High activity[i]	Entries/Exits typified by periods of high pedestrian traffic										
◦ LZ4[j]			10	10	10	Min	H	10	20	40	Avg
◦ LZ3[j] (and LZ4 curfew)			10	10	10	Min	G	7.5	15	30	Avg
◦ LZ2[j] (and LZ3 curfew)			10	10	10	Min	F	5	10	20	Avg
◦ LZ1[j] (and LZ2 curfew)			10	10	10	Min	E	4	8	16	Avg
◦ LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]		10	10	10	Min	D	3	6	12	Avg

Table 22.2 | Common Applications Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1		☀			
	2:1					
	2:1		☀			
	2:1					
	2:1		☀			
	2:1					
4:1	2:1					
4:1	2:1 (4:1)					
3:1	2:1 (4:1)					
3:1	2:1 (4:1)					
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4:1	2:1					
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4:1	2:1					
4:1	2:1 (4:1)					
3:1	2:1 (4:1)					
3:1	2:1 (4:1)					
2:1						

Notes for Table 22.2

The table column headings are discussed in detail in 22.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 22.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 22.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 22.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

m. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

n. Make electrical provisions for portable work lights.

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Table 22.2 | Common Applications Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]								
		Horizontal (E_h) Targets				Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are				Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
BUILDING ENTRIES	(Outdoor Non-covered Entries/Exits/Immediate Exterior continued)										
• Medium Activity[i]	Entries/Exits typified by periods of medium pedestrian traffic										
◦ LZ4[j]			10	10	10	Min	F	5	10	20	Avg
◦ LZ3[j] (and LZ4 curfew)			10	10	10	Min	E	4	8	16	Avg
◦ LZ2[j] (and LZ3 curfew)			10	10	10	Min	D	3	6	12	Avg
◦ LZ1[j] (and LZ2 curfew)			10	10	10	Min	C	2	4	8	Avg
◦ LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]		10	10	10	Min	B	1	2	4	Avg
• Low Activity[i]	Entries/Exits typified by periods of low pedestrian traffic										
◦ LZ4[j]			10	10	10	Min	E	4	8	16	Avg
◦ LZ3[j] (and LZ4 curfew)			10	10	10	Min	D	3	6	12	Avg
◦ LZ2[j] (and LZ3 curfew)			10	10	10	Min	C	2	4	8	Avg
◦ LZ1[j] (and LZ2 curfew)			10	10	10	Min	B	1	2	4	Avg
◦ LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]		10	10	10	Min	A	0.5	1	2	Avg
• Paths to Curb	For paths-to-curb longer than 50', illuminate 10' of path at curb end and 10' of path at building entry-exit end. E_h @grade; E_v @5' AFG in directions of ingress/egress and security camera..										
• High activity[i]	Entry paths typified by periods of high pedestrian traffic										
◦ LZ4[j]		G	7.5	15	30	Avg	E	4	8	16	Avg
◦ LZ3[j] (and LZ4 curfew)		F	5	10	20	Avg	D	3	6	12	Avg
◦ LZ2[j] (and LZ3 curfew)		E	4	8	16	Avg	C	2	4	8	Avg
◦ LZ1[j] (and LZ2 curfew)		D	3	6	12	Avg	B	1	2	4	Avg
◦ LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	C	2	4	8	Avg	A	0.5	1	2	Avg
• Medium Activity[i]	Entry paths typified by periods of medium pedestrian traffic										
◦ LZ4[j]		E	4	8	16	Avg	C	2	4	8	Avg
◦ LZ3[j] (and LZ4 curfew)		D	3	6	12	Avg	B	1	2	4	Avg
◦ LZ2[j] (and LZ3 curfew)		C	2	4	8	Avg	A	0.5	1	2	Avg
◦ LZ1[j] (and LZ2 curfew)		B	1	2	4	Avg	-	0	0	0	
◦ LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	A	0.5	1	2	Avg	-	0	0	0	
• Low Activity[i]	Entry paths typified by periods of low pedestrian traffic										
◦ LZ4[j]		C	2	4	8	Avg	C	2	4	8	Avg
◦ LZ3[j] (and LZ4 curfew)		B	1	2	4	Avg	B	1	2	4	Avg
◦ LZ2[j] (and LZ3 curfew)		A	0.5	1	2	Avg	A	0.5	1	2	Avg
◦ LZ1[j] (and LZ2 curfew)		A	0.5	1	2	Avg	-	0	0	0	
◦ LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	A	0.5	1	2	Avg	-	0	0	0	
• Porte Cocheres	E_h @grade; E_v @5' AFG in directions of ingress/egress and security camera										
• High Activity[i]	Porte cocheres typified by periods of high pedestrian and vehicular traffic										
• LZ4[j]		L	37.5	75	150	Avg	J	20	40	80	Avg
• LZ3[j] (and LZ4 curfew)		K	25	50	100	Avg	I	15	30	60	Avg
• LZ2[j] (and LZ3 curfew)		J	20	40	80	Avg	H	10	20	40	Avg
• LZ1[j] (and LZ2 curfew)		H	10	20	40	Avg	G	7.5	15	30	Avg
• LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	G	7.5	15	30	Avg	F	5	10	20	Avg
• Medium Activity[i]	Porte cocheres typified by periods of medium pedestrian and vehicular traffic										
• LZ4[j]		J	20	40	80	Avg	H	10	20	40	Avg
• LZ3[j] (and LZ4 curfew)		I	15	30	60	Avg	G	7.5	15	30	Avg
• LZ2[j] (and LZ3 curfew)		H	10	20	40	Avg	F	5	10	20	Avg
• LZ1[j] (and LZ2 curfew)		G	7.5	15	30	Avg	E	4	8	16	Avg
• LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	F	5	10	20	Avg	D	3	6	12	Avg

Table 22.2 | Common Applications Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage			[f] [g] Typical Area of Coverage[h]	
1st ratio E_h/2nd ratio E_v if different uniformities apply			Task Proper or Task Area	Room or Designated Area
Max:Avg	Avg:Min	Max:Min		
4:1	2:1			
4:1	2:1 (4:1)			
3:1	2:1 (4:1)			
3:1	2:1 (4:1)			
2:1				
4:1	2:1			
4:1	2:1 (4:1)			
3:1	2:1 (4:1)			
3:1	2:1 (4:1)			
2:1				
	3:1			
	3:1 (6:1)			
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	2:1 (4:1)			
	2:1			
	2:1 (4:1)			
	2:1 (4:1)			
	2:1 (4:1)			
	2:1 (4:1)			

Notes for Table 22.2

The table column headings are discussed in detail in 22.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 22.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 22.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 22.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

m. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

n. Make electrical provisions for portable work lights.

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Table 22.2 | Common Applications Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
BUILDING ENTRIES	(Outdoor Porte Cocheres continued)										
• Low Activity[j]	Porte cocheres typified by periods of low pedestrian and vehicular traffic										
• LZ4[j]		H	10	20	40	Avg	F	5	10	20	Avg
• LZ3[j] (and LZ4 curfew)		G	7.5	15	30	Avg	E	4	8	16	Avg
• LZ2[j] (and LZ3 curfew)		F	5	10	20	Avg	D	3	6	12	Avg
• LZ1[j] (and LZ2 curfew)		E	4	8	16	Avg	C	2	4	8	Avg
• LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	D	3	6	12	Avg	B	1	2	4	Avg
• Site Gated Entries	See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY for entries to sites deemed security risks.										
• Manned											
• Pedestrians											
◦ Credentialing area	Lighting should address an area of 5' by 5' centered on the designated credentialing area. E_v should be on planes oriented toward the gatehouse at designated credentialing area.										
LZ4[j]	E_h @3' AFG; E_v @3'-5' AFG	F	5	10	20	Avg	F	5	10	20	Avg
LZ3[j] (and LZ4 curfew)	E_h @3' AFG; E_v @3'-5' AFG	E	4	8	16	Avg	E	4	8	16	Avg
LZ2[j] (and LZ3 curfew)	E_h @3' AFG; E_v @3'-5' AFG	D	3	6	12	Avg	D	3	6	12	Avg
LZ1[j] (and LZ2 curfew)	E_h @3' AFG; E_v @3'-5' AFG	C	2	4	8	Avg	B	1	2	4	Avg
LZ0[j] (and LZ1 curfew)	E_h @3' AFG; E_v @3'-5' AFG and control with motion sensors.[k]	B	1	2	4	Avg	A	0.5	1	2	Avg
◦ General area	Lighting should address an area extending 15' beyond the gatehouse in all directions or to property lines or rights-of-way, whichever is less. E_v should be on planes perpendicular to the direction of travel and oriented toward the gatehouse.										
LZ4[j]	E_h @3' AFG; E_v @3'-5' AFG	D	3	6	12	Avg	D	3	6	12	Avg
LZ3[j] (and LZ4 curfew)	E_h @3' AFG; E_v @3'-5' AFG	C	2	4	8	Avg	C	2	4	8	Avg
LZ2[j] (and LZ3 curfew)	E_h @3' AFG; E_v @3'-5' AFG	B	1	2	4	Avg	B	1	2	4	Avg
LZ1[j] (and LZ2 curfew)	E_h @3' AFG; E_v @3'-5' AFG	B	1	2	4	Avg	A	0.5	1	2	Avg
LZ0[j] (and LZ1 curfew)	E_h @3' AFG; E_v @3'-5' AFG and control with motion sensors.[k]	A	0.5	1	2	Avg	-	0	0	0	
• Vehicles	Lighting should address the area of vehicle arrival and departure with emphasis at the area designated for presentation of credentials. E_v at the approach should be on planes perpendicular to the direction of travel and oriented toward the gatehouse. E_v at the area of presentation of credentials should be on a plane representing the driver's side window oriented toward the gatehouse.										
◦ Cars and light trucks	E_v at height range representing windshield and driver's side window elevations for most cars and light trucks.										
Credentialing area	Lighting should address an area of 5' by 10' centered on the designated credentialing area with the long dimension running parallel with the direction of travel. E_v should be on planes oriented toward the gatehouse at designated credentialing area.										
LZ4[j]	E_h @4' AFG; E_v @3'-5' AFG	H	10	20	40	Avg	G	7.5	15	30	Avg
LZ3[j] (and LZ4 curfew)	E_h @4' AFG; E_v @3'-5' AFG	G	7.5	15	30	Avg	F	5	10	20	Avg
LZ2[j] (and LZ3 curfew)	E_h @4' AFG; E_v @3'-5' AFG	F	5	10	20	Avg	E	4	8	16	Avg
LZ1[j] (and LZ2 curfew)	E_h @4' AFG; E_v @3'-5' AFG	E	4	8	16	Avg	D	3	6	12	Avg
LZ0[j] (and LZ1 curfew)	E_h @4' AFG; E_v @3'-5' AFG and control with motion sensors.[k]	D	3	6	12	Avg	C	2	4	8	Avg

Table 22.2 | Common Applications Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f] [g] Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min	Task Proper or Task Area	Room or Designated Area
	2:1		■	
	2:1 (4:1)		■	
	2:1 (4:1)		■	
	2:1 (4:1)		■	
	2:1 (4:1)		■	
2:1	2:1		■	
2:1	2:1 (4:1)		■	
2:1	2:1 (4:1)		■	
2:1	2:1 (4:1)		■	
2:1	2:1 (4:1)		■	
3:1	3:1		■	
3:1	3:1 (6:1)		■	
3:1	3:1 (6:1)		■	
3:1	3:1 (6:1)		■	
3:1	3:1 (6:1)		■	
2:1	2:1		■	
2:1	2:1 (4:1)		■	
2:1	2:1 (4:1)		■	
2:1	2:1 (4:1)		■	
2:1	2:1 (4:1)		■	

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The table column headings are discussed in detail in 22.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 22.3 | SI Dimensional Conversions.

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b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 22.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

m. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

n. Make electrical provisions for portable work lights.

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Table 22.2 | Common Applications Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
BUILDING ENTRIES	(Outdoor Site Gated Entries continued)										
General area	Lighting should address an area the width of one vehicular lane immediately adjacent to the gatehouse and extending 30' beyond the gatehouse in both the approaching and departing directions or to property lines or rights-of-way, whichever is less. E_v should be on planes perpendicular to the direction of travel and oriented toward the gatehouse.										
LZ4[j]	E_h @5' AFG; E_v @3'-5' AFG	F	5	10	20	Avg	F	5	10	20	Avg
LZ3[j] (and LZ4 curfew)	E_h @5' AFG; E_v @3'-5' AFG	E	4	8	16	Avg	E	4	8	16	Avg
LZ2[j] (and LZ3 curfew)	E_h @5' AFG; E_v @3'-5' AFG	D	3	6	12	Avg	D	3	6	12	Avg
LZ1[j] (and LZ2 curfew)	E_h @5' AFG; E_v @3'-5' AFG	C	2	4	8	Avg	B	1	2	4	Avg
LZ0[j] (and LZ1 curfew)	E_h @5' AFG; E_v @3'-5' AFG and control with motion sensors.[k]	B	1	2	4	Avg	A	0.5	1	2	Avg
◦ **Commercial vans/trucks**	E_v at height range representing windshield and driver's side window elevations for most commercial vans and trucks.										
Credentialing area	Lighting should address an area of 5' by 10' centered on the designated credentialing area with the long dimension running parallel with the direction of travel. E_v should be on planes oriented toward the gatehouse at designated credentialing area.										
LZ4[j]	E_h @8' AFG; E_v @6'-9' AFG	H	10	20	40	Avg	G	7.5	15	30	Avg
LZ3[j] (and LZ4 curfew)	E_h @8' AFG; E_v @6'-9' AFG	G	7.5	15	30	Avg	F	5	10	20	Avg
LZ2[j] (and LZ3 curfew)	E_h @8' AFG; E_v @6'-9' AFG	F	5	10	20	Avg	E	4	8	16	Avg
LZ1[j] (and LZ2 curfew)	E_h @8' AFG; E_v @6'-9' AFG	E	4	8	16	Avg	D	3	6	12	Avg
LZ0[j] (and LZ1 curfew)	E_h @8' AFG; E_v @6'-9' AFG and control with motion sensors.[k]	D	3	6	12	Avg	C	2	4	8	Avg
General area	Lighting should address an area the width of one vehicular lane immediately adjacent to the gatehouse and extending 30' beyond the gatehouse in both the approaching and departing directions or to property lines or rights-of-way, whichever is less. E_v should be on planes perpendicular to the direction of travel and oriented toward the gatehouse.										
LZ4[j]	E_h @10' AFG; E_v @6'-9' AFG	F	5	10	20	Avg	F	5	10	20	Avg
LZ3[j] (and LZ4 curfew)	E_h @10' AFG; E_v @6'-9' AFG	E	4	8	16	Avg	E	4	8	16	Avg
LZ2[j] (and LZ3 curfew)	E_h @10' AFG; E_v @6'-9' AFG	D	3	6	12	Avg	D	3	6	12	Avg
LZ1[j] (and LZ2 curfew)	E_h @10' AFG; E_v @6'-9' AFG	C	2	4	8	Avg	B	1	2	4	Avg
LZ0[j] (and LZ1 curfew)	E_h @10' AFG; E_v @6'-9' AFG and control with motion sensors.[k]	B	1	2	4	Avg	A	0.5	1	2	Avg
• **Remote Monitored**											
• **Intercom call system**	Highlight intercom call system unless internally illuminated. Coordinate lighting with camera location to avoid image washout.										
◦ **LZ4[j]**	E_v on system hardware.						G	7.5	15	30	Avg
◦ **LZ3[j] (and LZ4 curfew)**	E_v on system hardware.						F	5	10	20	Avg
◦ **LZ2[j] (and LZ3 curfew)**	E_v on system hardware.						E	4	8	16	Avg
◦ **LZ1[j] (and LZ2 curfew)**	E_v on system hardware.						D	3	6	12	Avg
◦ **LZ0[j] (and LZ1 curfew)**	E_v on system hardware and control with motion sensors.[k]						C	2	4	8	Avg
• **Pedestrians**	Lighting should address an area of 5' by 5' centered on the designated monitoring area. E_v should be on planes oriented toward the camera. Confirm illuminances meet camera requirements.										
◦ **LZ4[j]**	E_h @3' AFG; E_v @5' AFG	G	7.5	15	30	Avg	F	5	10	20	Avg
◦ **LZ3[j] (and LZ4 curfew)**	E_h @3' AFG; E_v @5' AFG	F	5	10	20	Avg	E	4	8	16	Avg
◦ **LZ2[j] (and LZ3 curfew)**	E_h @3' AFG; E_v @5' AFG	E	4	8	16	Avg	D	3	6	12	Avg
◦ **LZ1[j] (and LZ2 curfew)**	E_h @3' AFG; E_v @5' AFG	D	3	6	12	Avg	C	2	4	8	Avg
◦ **LZ0[j] (and LZ1 curfew)**	E_h @3' AFG; E_v @5' AFG and control with motion sensors.[k]	C	2	4	8	Avg	B	1	2	4	Avg

Table 22.2 | Common Applications Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
3:1	3:1				■	
3:1	3:1 (6:1)				■	
3:1	3:1 (6:1)				■	
3:1	3:1 (6:1)				■	
3:1	3:1 (6:1)				■	
2:1	2:1				■	
2:1	2:1 (4:1)				■	
2:1	2:1 (4:1)				■	
2:1	2:1 (4:1)				■	
2:1	2:1 (4:1)				■	
3:1	3:1				■	
3:1	3:1 (6:1)				■	
3:1	3:1 (6:1)				■	
3:1	3:1 (6:1)				■	
3:1	3:1 (6:1)				■	
2:1	2:1				■	
2:1	2:1 (4:1)				■	
2:1	2:1 (4:1)				■	
2:1	2:1 (4:1)				■	
2:1	2:1 (4:1)				■	
2:1	2:1				■	
2:1	2:1 (4:1)				■	
2:1	2:1 (4:1)				■	
2:1	2:1 (4:1)				■	
2:1	2:1 (4:1)				■	

Notes for Table 22.2

The table column headings are discussed in detail in 22.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 22.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 22.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 22.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

m. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

n. Make electrical provisions for portable work lights.

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Table 22.2 | Common Applications Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
BUILDING ENTRIES	(Outdoor Site Gated Entries continued)										
• Vehicles	Lighting should address an area of 5' by 5' centered on the designated monitoring area. E_v should be on a plane representing the driver's side window oriented toward the camera. Confirm illuminances meet camera requirements.										
◦ LZ4[j]	E_v on system hardware.	I	15	30	60	Avg	H	10	20	40	Avg
◦ LZ3[j] (and LZ4 curfew)	E_v on system hardware.	H	10	20	40	Avg	G	7.5	15	30	Avg
◦ LZ2[j] (and LZ3 curfew)	E_v on system hardware.	G	7.5	15	30	Avg	F	5	10	20	Avg
◦ LZ1[j] (and LZ2 curfew)	E_v on system hardware.	F	5	10	20	Avg	E	4	8	16	Avg
◦ LZ0[j] (and LZ1 curfew)	E_v on system hardware and control with motion sensors.[k]	E	4	8	16	Avg	D	3	6	12	Avg
• Unmanned/unmonitored											
• Intercom call system access	Highlight security call system unless internally illuminated.										
◦ LZ4[j]	E_v on system hardware, unless self-illuminated						H	10	20	40	Avg
◦ LZ3[j] (and LZ4 curfew)	E_v on system hardware, unless self-illuminated						G	7.5	15	30	Avg
◦ LZ2[j] (and LZ3 curfew)	E_v on system hardware, unless self-illuminated						F	5	10	20	Avg
◦ LZ1[j] (and LZ2 curfew)	E_v on system hardware, unless self-illuminated						E	4	8	16	Avg
◦ LZ0[j] (and LZ1 curfew)	E_v on system hardware and control with motion sensors.[k]						D	3	6	12	Avg
• Pedestrians	Lighting should address an area 5' by 5' centered on the intercom call system.										
◦ LZ4[j]	E_h @grade	E	4	8	16	Avg					
◦ LZ3[j] (and LZ4 curfew)	E_h @grade	D	3	6	12	Avg					
◦ LZ2[j] (and LZ3 curfew)	E_h @grade	C	2	4	8	Avg					
◦ LZ1[j] (and LZ2 curfew)	E_h @grade	B	1	2	4	Avg					
◦ LZ0[j] (and LZ1 curfew)	E_h @grade and control with motion sensors.[k]	A	0.5	1	2	Avg					
• Vehicles	Lighting should address an area 5' by 5' centered on the intercom call system.										
◦ LZ4[j]	E_h @grade	F	5	10	20	Avg					
◦ LZ3[j] (and LZ4 curfew)	E_h @grade	E	4	8	16	Avg					
◦ LZ2[j] (and LZ3 curfew)	E_h @grade	D	3	6	12	Avg					
◦ LZ1[j] (and LZ2 curfew)	E_h @grade	C	2	4	8	Avg					
◦ LZ0[j] (and LZ1 curfew)	E_h @grade and control with motion sensors.[k]	B	1	2	4	Avg					
CIRCULATION	See TRANSITION SPACES/Circulation Corridors										
CONFERENCING											
• Meeting	Periodic notetaking, reading, and facial detail										
• Discourse	E_h @2' 6"; E_v @4' AFF	P	150	300	600	Avg	L	37.5	75	150	Avg
• Presentation Surfaces	Vertical poster boards, presentation boards, tack surfaces						M	50	100	200	Avg
• White boards											
◦ Analog or Digital											
Reading (reference)							N	75	150	300	Avg

Table 22.2 | Common Applications Illuminance Recommendations continued next page

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
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	2:1					
	2:1					
	2:1					
	2:1					
	2:1					
2:1	3:1					
2:1	3:1 (6:1)					
2:1	3:1 (6:1)					
2:1	3:1 (6:1)					
2:1	3:1 (6:1)					
2:1	3:1					
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2:1	3:1 (6:1)					
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	see Table 12.6					
	3:1					
	3:1					

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d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

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k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

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		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
CONFERENCING	(Meeting continued)										
• Presentation											
• Formal speaking											
◦ AV	E_h @2' 6"; E_v @4' AFF	I	15	30	60	Avg	I	15	30	60	Max
◦ Non-AV											
Presentation surfaces	Vertical poster boards, presentation boards, tack surfaces						M	50	100	200	Avg
Reports, handouts	See READING AND WRITING, establish tasks and normalize to illuminance of most important task or most common task; use controls to provide illuminance variability if tasks so demand.										
• White boards											
◦ Analog or Digital											
Reading (presentation)	Interactive use as part of formal presentation						P	150	300	600	Avg
◦ Presenter	At fixed presentation podium or position										
Face	E_v @5' AFF						Avg ≥1 times but ≤ 3 times audience task E_h				
Task surface	E_h @3' 6" AFF	Avg ≥1 times but ≤ 3 times audience task E_h									
• Telepresence	See CONFERENCING/Video Conferencing										
• Video Conferencing	Coordinate lighting criteria with camera and display requirements. Where camera and display technologies permit criteria lower than reported here, use the lower criteria to reduce visual fatigue and discomfort common under relatively high vertical illuminances over long durations of sedentary activity. Address criteria citations for table and wall reflectances. See IES DG-17 Fundamentals of Lighting for Videoconferencing for additional information.										
• Displays											
• Front-screen projection	Over front surface of screen							50	50	50	Max
• Rear-screen projection	Over front surface of screen							150	150	150	Max
• Video displays or monitors	Over front surface of display							200	200	200	Max
• Faces	E_h @4' AFF; E_v @3'-5' AFF in direction(s) of camera(s)		300	300	300	Avg		400	400	400	Avg
• Tables	Matte surface reflectance of 40% is recommended for table. Illuminance recommendations accommodate intermittent reading of reference materials consisting of paper tasks and CSA/ISO Types I and II positive polarity computer screens. See READING AND WRITING if other reference materials must be accommodated.										
• 40% matte reflectance	E_h @2' 6" AFF		300	300	300	Avg					
• Walls	Matte surface reflectances are recommended for walls.										
• 40% matte reflectance	E_v @2' 6"-6' 6" AFF							400	400	400	Avg
• 50% matte reflectance	E_v @2' 6"-6' 6" AFF							300	300	300	Avg
• 60% matte reflectance	E_v @2' 6"-6' 6" AFF							200	200	200	Avg
CORRIDORS	See TRANSITION SPACES/Circulation Corridors										
EQUIPMENT ROOMS	See SUPPORT SPACES/Equipment Rooms										
FOOD SERVICE											
• Accenting	See 21 | LIGHTING FOR ART for museum quality artworks										
• Art	On artwork plane (typically vertical)								see Table 15.2		
• Feature Wall	On wall plane								see Table 15.2		
• Perimeter	On wall plane								see Table 15.2		
• Table Highlight	On table plane			see Table 15.2							

Table 22.2 | Common Applications Illuminance Recommendations continued next page

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
3:1						
	3:1					
	3:1					
	3:1					
	2:1					
2:1						
2:1						
2:1						
	1.5:1					
	1.5:1					
	1.5:1					
	1.5:1					
	1.5:1					
	see 15.1.1.3					
	see 15.1.1.3					
	see 15.1.1.3					
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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
FOOD SERVICE	(continued)										
• Bar											
• Back Bar	E_h @select shelves; E_v @5' AFF	K	25	50	100	Avg	N	75	150	300	Avg
• Bar Top	E_h @bar top; E_v @5' AFF	L	37.5	75	150	Avg	H	10	20	40	Avg
• General Seating	E_h @2' AFF; E_v @4' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Lounge	E_h @2' AFF; E_v @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Work Surfaces	E_h @work surface; E_v @5' AFF	M	50	100	200	Avg	H	10	20	40	Avg
• Cashiers	E_h @2' 6" AFF; E_v @5' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
• Cleanup	E_h and E_v @2' 6" AFF		100	100	100	Min	I	15	30	60	Avg
• Dining Areas (by establishment)											
• Cafeterias	E_h @table plane; E_v@4' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• Coffee Shops	E_h @table plane; E_v@4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Hospitality Properties											
• 3-meal dining rooms											
◦ Breakfast	E_h @table plane; E_v@4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
◦ Lunch	E_h @table plane; E_v@4' AFF	K	25	50	100	Avg	H	10	20	40	Avg
◦ Dinner	E_h @table plane; E_v@4' AFF	H	10	20	40	Avg	E	4	8	16	Avg
• Cafes/Cafeterias	E_h @table plane; E_v@4' AFF	Avg = 3 times adjacent area E_h, but ≤100					Avg = 3 times adjacent area E_v, but ≤30				
• Specialty dining	E_h @table plane; E_v@4' AFF	F	5	10	20	Avg	C	2	4	8	Avg
• Restaurants											
• Casual dining	E_h @table plane; E_v@4' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Fast food dining	E_h @table plane; E_v@4' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
• Fine dining	E_h @table plane; E_v@4' AFF	I	15	30	60	Avg	F	5	10	20	Avg
• Kitchens											
• Dishwashing/Pot Washing	E_h @2' 6" AFF; E_v @4' AFF		200	200	200	Min	M	50	100	200	Avg
• Food Preparation	E_h and E_v @preparation/food-handling surfaces		500	500	500	Min	O	100	200	400	Avg
• Storage											
• Equipment, utensils, ware	E_h and E_v @2' 6" AFF		200	200	200	Min	M	50	100	200	Avg
• Food											
◦ Non-refrigerated	E_h and E_v @2' 6" AFF		100	100	100	Min	I	15	30	60	Min
◦ Refrigerated	E_h and E_v @2' 6" AFF		100	100	100	Min	I	15	30	60	Min
• Refuse/Soiled Ware Return	E_h @plane of return; E_v@4' AFF		100	100	100	Min	K	25	50	100	Avg
• Serveries											
• Buffet Displays	E_h and E_v @planes of food presentation		Avg = 3 times dining area E_h, but ≥200					Avg = 3 times dining area E_h, but ≥200			
• Grab-and-go displays	E_h and E_v @planes of food presentation		200	200	200	Min	N	75	150	300	Avg
• Serving Lines											
• Employee-served	E_h and E_v @preparation/food-handling surfaces		500	500	500	Min	O	100	200	400	Avg
• Self-served	See FOOD SERVICE/Serveries/Buffet Displays										
• Toilet Rooms (staff-dedicated)	E_h and E_v @2' 6" AFF		200	200	200	Min	M	50	100	200	Avg
• Vending/Ice Rooms	E_h and E_v @3' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Wine Cellar	Wines are UV- and heat-sensitive. Select, filter, and locate equipment accordingly. Use motion sensors to limit exposure.										
• Display and Tasting	E_h @3' 6" AFF; E_v @racks 4' AFF	M	50	100	200	Avg	M	50	100	200	Avg
• Sommelier Use	E_h @3' 6" AFF; E_v @racks 4' AFF	K	25	50	100	Avg	K	25	50	100	Avg

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1/5:1		☀		■	
	5:1		☀	◪	■	
	3:1		☀			■
	3:1		☀			■
	1.5:1		☀		■	
	2:1		☀		■	
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	2:1		☀		■	
	see Table 12.6		☀		■	
	2:1		☀		■	
	3:1		☀			■
	3:1		☀			■
	2:1		☀		■	
	3:1		☀	◪	■	
	3:1		☀	◪	■	
	see Table 12.6		☀	◪	■	
			☀	◪	■	
	3:1		☀			■
	3:1		☀			■
	3:1				■	
	3:1				■	

Notes for Table 22.2

The table column headings are discussed in detail in 22.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 22.3 | SI Dimensional Conversions.

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d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◪ signals high likelihood; gray and white ◪ signals moderate likelihood; pale gray and white ◪ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

m. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

n. Make electrical provisions for portable work lights.

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Table 22.2 | Common Applications Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
IT											
• Active operations	Also see READING AND WRITING, establish tasks and normalize to illuminance of most important task or most common task; use controls to provide illuminance variability if tasks so demand.										
• Administrative tasks	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	L	37.5	75	150	Avg
• Programming	E_h @2' 6" AFF; E_v @4' AFF	M	50	100	200	Avg	L	37.5	75	150	Avg
• Media storage											
• Constant filing/retrieval	E_h @3' AFF; E_v @4' AFF	P	150	300	600	Avg	L	37.5	75	150	Avg
• Intermittent filing/retrieval	E_h @3' AFF; E_v @4' AFF	N	75	150	300	Avg	M	50	100	200	Avg
• Seldom filing/retrieval	E_h @3' AFF; E_v @4' AFF	M	50	100	200	Avg	L	37.5	75	150	Avg
• Machine area	CPUs, servers, switches, etc.	M	50	100	200	Avg	M	50	100	200	Avg
• Equipment service	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
PARKING	See 26 | LIGHTING FOR EXTERIORS										
PEDESTRIAN WAYS	See 26 | LIGHTING FOR EXTERIORS										
PLANTS	Live plants presumed to be acclimated for indoor use; consult interior plant specialist; values shown for maintenance and growth										
Common Name	Scientific Name	E_h @top of plant across plant area. Low-to-high range correlates to minimum maintenance-to-growth activity. Intended for 14 hour duration.					E_v @mid-height of plant body or canopy in four orientations. Low-to-high range correlates to minimum maintenance-to-growth activity. Intended for 14 hour duration.				
• Floor Plants	Typically 2' to 6' tall										
• Bamboo Palm	Chamaedorea erumpens		250-750			Min			≥0.5 E_h		Min
• Corn Plant	Dracaena fragrans massangeana		250-750			Min			≥0.5 E_h		Min
• Dwarf Dragon Tree	Dracaena marginata		750-2000			Min			≥0.5 E_h		Min
• European Fanpalm	Chamaerops humilis		>2000			Min			≥0.5 E_h		Min
• False Aralia	Dizygotheca elegantissima		>2000			Min			≥0.5 E_h		Min
• Giant Dumb Cane	Dieffenbachia amoena		750-2000			Min			≥0.5 E_h		Min
• Green Drasena	Dracaena deremensis "Janet Craig"		750-2000			Min			≥0.5 E_h		Min
• Kentia Palm	Howeia forsteriana		250-750			Min			≥0.5 E_h		Min
• Lady Palm	Rhapis exclesa		750-2000			Min			≥0.5 E_h		Min
• Mock Orange	Pittosporum tobira		>2000			Min			≥0.5 E_h		Min
• Neanthe Bella Palm	Chamaedorea elegans "bella"		250-750			Min			≥0.5 E_h		Min
• Palm-Lily	Yucca elephantipes		>2000			Min			≥0.5 E_h		Min
• Parsley Aralia	Polyscias guilfoylei		750-2000			Min			≥0.5 E_h		Min
• Philippine Fig	Ficus philippinensis		750-2000			Min			≥0.5 E_h		Min
• Pigmy Date Palm	Phoenix roebelenii		750-2000			Min			≥0.5 E_h		Min
• Podocarpus	Podocarpus macrophylla Maki		>2000			Min			≥0.5 E_h		Min
• Rubber Plant	Ficus elastica "Decora"		750-2000			Min			≥0.5 E_h		Min
• Schefflera	Brassaia actinophylla		750-2000			Min			≥0.5 E_h		Min
• Selfheading Philodendron	Philodendron x evansii		750-2000			Min			≥0.5 E_h		Min

Table 22.2 | Common Applications Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
see Table 12.6			☀			
see Table 12.6			☀			
	2:1		☀			
	2:1		☀			
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Table 22.2 | Common Applications Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d] Horizontal (E_h) Targets — Visual Ages of Observers (years) where **at least half** are <25	25-65	>65	Vertical (E_v) Targets — Visual Ages of Observers (years) where **at least half** are <25	25-65	>65
		Category ▼		Gauge ▼	Category ▼		Gauge ▼
PLANTS	(continued)						
Common Name	Scientific Name	E_h @top of plant across plant area. Low-to-high range correlates to minimum maintenance-to-growth activity. Intended for 14 hour duration.			E_v @mid-height of plant body or canopy in four orientations. Low-to-high range correlates to minimum maintenance-to-growth activity. Intended for 14 hour duration.		
• **Table Plants**							
• **Asparagus Fern**	Asparagus sprengeri	750-2000		Min	≥0.5 E_h		Min
• **Boston Fern**	Nephrolepsis exaltata bostoniensis	750-2000		Min	≥0.5 E_h		Min
• **Bromeliad**	Aechmea fasciata	750-2000		Min	≥0.5 E_h		Min
• **Calamondin**	Citrus mitis	>2000		Min	≥0.5 E_h		Min
• **Common Philodendron**	Philodendron oxycardium	250-750		Min	≥0.5 E_h		Min
• **Corn Plant**	Dracaena fragrans massangeana	250-750		Min	≥0.5 E_h		Min
• **Dumb Cane**	Dieffenbachia "Exotica"	750-2000		Min	≥0.5 E_h		Min
• **Emerald Ripple**	Peperomia caperata	250-750		Min	≥0.5 E_h		Min
• **Golden Aglaonema**	Agalonema "Pseudobacteatum"	250-750		Min	≥0.5 E_h		Min
• **Grape Ivy**	Cissus rhombifolia	750-2000		Min	≥0.5 E_h		Min
• **Kangaroo Vine**	Ciccus antarctiva	>2000		Min	≥0.5 E_h		Min
• **Pewter Plant**	Aglaonema roebelinii	250-750		Min	≥0.5 E_h		Min
• **Prayer Plant**	Maranta leuconeura	750-2000		Min	≥0.5 E_h		Min
• **Variegated Chinese Evergreen**	Aglaonema commutatum	250-750		Min	≥0.5 E_h		Min
• **Wax Plant**	Hoya carnosa	750-2000		Min	≥0.5 E_h		Min
• **White Flag**	Spathiphyllum "Mauna Loa"	750-2000		Min	≥0.5 E_h		Min
• **White-Striped Dracaena**	Dracaena deremensis "Warneckei"	750-2000		Min	≥0.5 E_h		Min
• **Trees**	Typically 5' to 10' tall						
• **Chinese Loquator, Japan Plum**	Eriobotrya japonica	>2000		Min	≥0.5 E_h		Min
• **Fiddleleaf Fig**	Ficus lyrata	750-2000		Min	≥0.5 E_h		Min
• **Indian Laurel**	Ficus retusa nitida	750-2000		Min	≥0.5 E_h		Min
• **Norfolk Island Pine**	Araucaria excelsa	>2000		Min	≥0.5 E_h		Min
• **Waxleaf**	Ligustrum lucidum	750-2000		Min	≥0.5 E_h		Min
• **Weeping Java Fig**	Ficus benjamine "Exotica"	750-2000		Min	≥0.5 E_h		Min

Table 22.2 | Common Applications Illuminance Recommendations continued next page

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		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
READING AND WRITING												
• Computer	See READING AND WRITING/VDT Screen and Keyboard											
• Electronic Readers												
• Electronic Ink Devices	E_h and E_v @height of device	P	150	300	600	Avg	N	75	150	300	Avg	
• LCD or LED Devices	E_h and E_v @height of device	N	75	150	300	Avg	K	25	50	100	Avg	
• Facsimile												
• Analog	E_h @2' 6" AFF; E_v @4' AFF[m]	R	250	500	1000	Avg	M	50	100	200	Avg	
• Digital	E_h @2' 6" AFF; E_v @4' AFF[m]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Handwritten Work	Based on fair-to-good penmanship/hand print on white or canary paper											
• Pencil												
• Graphite/HB	E_h @2' 6" AFF; E_v @4' AFF[m]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Red	E_h @2' 6" AFF; E_v @4' AFF[m]	R	250	500	1000	Avg	M	50	100	200	Avg	
• Ballpoint/Rollerpoint/Felt-tip												
• Black	E_h @2' 6" AFF; E_v @4' AFF[m]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Red, Green, Blue	E_h @2' 6" AFF; E_v @4' AFF[m]	Q	200	400	800	Avg	L	37.5	75	150	Avg	
• Laptop	See READING AND WRITING/VDT Screen and Keyboard											
• Microforms (Projected)		L	37.5	75	150	Avg	I	15	30	60	Avg	
• Print Media	Digital-printing-press-generated, white paper											
• 6-pt Font												
• Matte paper and ink	E_h @2' 6" AFF; E_v @4' AFF[m]	R	250	500	1000	Avg	L	37.5	75	150	Avg	
• Specular paper and ink	E_h @2' 6" AFF; E_v @4' AFF[m]	R	250	500	1000	Avg	L	37.5	75	150	Avg	
• 8- and 10-pt Font												
• Matte paper and ink	E_h @2' 6" AFF; E_v @4' AFF[m]	P	150	300	600	Avg	K	25	50	100	Avg	
• Specular paper and ink	E_h @2' 6" AFF; E_v @4' AFF[m]	P	150	300	600	Avg	K	25	50	100	Avg	
• 12-pt Font												
• Matte paper and ink	E_h @2' 6" AFF; E_v @4' AFF[m]	O	100	200	400	Avg	K	25	50	100	Avg	
• Specular paper and ink	E_h @2' 6" AFF; E_v @4' AFF[m]	O	100	200	400	Avg	K	25	50	100	Avg	
• VDT Screen and Keyboard												
• CSA/ISO Types I and II	See Figure 12.16 | CSA/ISO Computer Screen Qualities											
• Positive polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[m]	P	150	300	600	Avg	N	75	150	300	Avg	
• Negative polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[m]	N	75	150	300	Avg	K	25	50	100	Avg	
• CSA/ISO Type III	See Figure 12.16 | CSA/ISO Computer Screen Qualities											
• Positive polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[m]	N	75	150	300	Avg	K	25	50	100	Avg	
• Negative polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[m]	L	37.5	75	150	Avg	I	15	30	60	Avg	
• White Board												
• Analog or Digital												
• Reading (reference)							N	75	150	300	Avg	
• Reading (with presenter)	Presenter at white board						P	150	300	600	Avg	
• Xerograph	Copier- and printer-generated on white paper											
• ≥8-pt type, common graphics	Select progressively next-higher letter category of illuminance for each 2-point-type decrease in fonts/graphics)											
• Color												
◦ Analog	E_h @2' 6" AFF; E_v @4' AFF[m]	R	250	500	1000	Avg	M	50	100	200	Avg	
◦ Digital	E_h @2' 6" AFF; E_v @4' AFF[m]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Grayscale and/or B+W Print												
◦ Analog	E_h @2' 6" AFF; E_v @4' AFF[m]	P	150	300	600	Avg	L	37.5	75	150	Avg	
◦ Digital	E_h @2' 6" AFF; E_v @4' AFF[m]	O	100	200	400	Avg	K	25	50	100	Avg	

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Uniformity Targets[e] Over Area of Coverage			[f]	[g]	Typical Area of Coverage[h]	
1st ratio E_h/2nd ratio E_v if different uniformities apply					Task Proper or Task Area	Room or Designated Area
Max:Avg	Avg:Min	Max:Min				
2:1						
2:1						
see Table 12.6						
see Table 12.6						
see Table 12.6						
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Notes for Table 22.2

The table column headings are discussed in detail in 22.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 22.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 22.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 22.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

m. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

n. Make electrical provisions for portable work lights.

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Table 22.2 | Common Applications Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
SUPPORT SPACES	Typical applications and tasks cited here. Check SUPPORT SPACES in respective chapter for application-specific criteria.											
• Break Rooms/ Lunch Rooms	E_h @2' 6" AFF; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg	
• Coat Check or Coat Rooms	E_h @3' 0"; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Copy/Print Rooms												
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg	
• Machines	E_h and E_v @3' 6" AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Electrical Closets	E_h @3' 0"; E_v @5' AFF	M	50	100	200	Avg	M	50	100	200	Avg	
• Equipment Rooms[n]	E_h @3' 0"; E_v @5' AFF. Design values for empty-room conditions.	O	100	200	400	Avg	N	75	150	300	Avg	
• Interstitial Space[n]	E_h @floor; E_v @4' AFF	I	15	30	60	Avg	G	7.5	15	30	Avg	
• Janitor's Closet	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg	
• Receiving/Shipping												
• Dock	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg	
• Receiving/Staging	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Storage												
• Food	See FOOD SERVICE											
• Frequent Use	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg	
• Infrequent Use	E_h @floor; E_v @4' AFF	K	25	50	100	Avg	H	10	20	40	Avg	
TOILETS/LOCKER ROOMS	Typical applications and tasks cited here. Check TOILETS/LOCKER ROOMS in respective chapter for application-specific criteria.											
• Fixtures	E_h @top of plumbing fixture; E_v @3'-5' AFF	N	75	150	300	Avg	K	25	50	100	Avg	
• General	E_h @floor; E_v @3'-5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
• Lockers	E_h @floor; E_v @locker faces	K	25	50	100	Avg	K	25	50	100	Avg	
• Showers	E_h @floor; E_v @3'-5' AFF	M	50	100	200	Avg	K	25	50	100	Avg	
• Vanities	E_h @3' AFF; E_v @3'-5' AFF	N	75	150	300	Avg	O	100	200	400	Avg	
TRANSITION SPACES	Typical applications and tasks cited here. Check TRANSITION SPACES in respective chapter for application-specific criteria.											
• ATMs and Service Kiosks	E_h @3' AFF; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg	
• Circulation Corridors	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.											
• Back-of-house												
• Adjacency Passageways	E_h @floor; E_v @5' AFF	Avg ≥0.3 times task E_h of adjacent space or as cameras require, but with min ≥10 lx					Avg ≥0.3 times task E_v of adjacent space or as cameras require					
• Independent Passageways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
• Public												
• Adjacency Passageways	E_h @floor; E_v @5' AFF	Avg ≥0.2 times task E_h of adjacent space or as cameras require, but with min ≥10 lx					Avg ≥0.2 times task E_v of adjacent space or as cameras require					
• Independent Passageways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
• Elevators												
• Freight												
• Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
• Threshold												
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	

Table 22.2 | Common Applications Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
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d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

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k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

m. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

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		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
TRANSITION SPACES	(Elevators continued)										
• Passenger											
• Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Threshold											
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Entries	See BUILDING ENTRIES										
• Escalators/ Moving Walkways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Lobbies											
• Circulation, Elevator Lobbies	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• General											
• At building entries	Close proximity to exterior. Lighting should be designed to assist with adaptation when passing to/from exterior.										
◦ Day	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
◦ Night	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Distant from entries	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Security Screening	E_h @3' AFF; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Reading/Work Areas	E_h and E_v @2' 6" at sitting areas	N	75	150	300	Avg	K	25	50	100	Avg
• Reception Lobbies	Such as visitor registration or informational/directional concierge.										
• Desk	Age determination may be as or more relevant with respect to guest or patron than staff.										
• Desk top	E_h @3' 6" AFF; E_v @5' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• Focal wall behind desk	On wall plane								see Table 15.2		
• Lounges											
• Clubs and Game Rooms											
• General	E_h and E_v @2' 6"	J	20	40	80	Avg	G	7.5	15	30	Avg
• Table games	E_h @table; E_v @5' AFF	P	150	300	600	Avg	K	25	50	100	Avg
• Video games	E_h @game controls; E_v @4' AFF	H	10	20	40	Avg	C	2	4	8	Avg
• Reading/Work Areas	E_h and E_v @2' 6" at sitting areas	N	75	150	300	Avg	K	25	50	100	Avg
• Social/Waiting Areas		J	20	40	80	Avg	G	7.5	15	30	Avg
• Service Kiosks	See TRANSITION SPACES/ATMs and Service Kiosks										
• Stairs	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• High Activity[i]	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Live Surveillance	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Typical	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
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	4:1					
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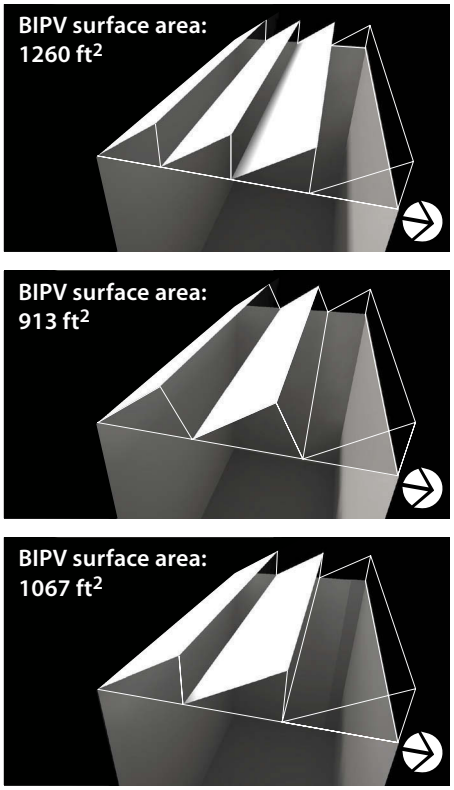


Figure 22.2 | Atria, Daylight, and BIPVs
Generally, transmittance of glazing on tops of large-area atria and courtyards must be low to limit visual discomfort and cooling loads. Advances in Building Integrated Photovoltaics (BIPVs) offer a means to limit transmission of those glazed planes while generating some electricity. Here, a series of studies was made to assess area of coverage available for south-facing BIPVs (shown in white) versus daylight availability. North is as indicated. Sensitivity of the BIPVs and the effective surface area must also be considered.

Vision glass without BIPVs on the vertical or near vertical media admit north light. Vision glass without BIPVs on the north-most skylight segment allows a stronger wallwash effect from daylight on the north wall of the atrium.

If plants are programmed for the atrium or courtyard, the studies would either reveal the daylight availability to which plant selection should be matched or would yield glazing designs to meet the selected plants' needs.

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Entries with no canopies should be lighted to announce the entry threshold proper. Some portion of the path, typically to the curb, is lighted to a lesser degree for sake of efficiency and minimizing deleterious effects on the night environment while still meeting vision requirements for movement, but not to the levels found under canopies of porte cocheres. If the path is longer than perhaps 50 feet, the full length of the path need not be lighted to the path-to-curb criteria cited. A 10-foot section of the path closest to the entry and a 10-foot section closest to the curb should be lighted to meet the cited criteria. For control of lighting in LZ0, motion-sensor control is appropriate. This limits lamp selection to instant-full-on varieties. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and the requirements and design of which must be coordinated amongst the design team.

Canopied entries are an extension of the building, much like a porch (see Figure 22.3). For such areas under cover where there is expectation for some passing conversation and acknowledgement and for a larger crowd of people, somewhat higher illuminances are appropriate than those for open entry paths. Porte cocheres by their nature involve a mix of vehicular and pedestrian traffic. In these situations, still higher illuminances are appropriate.

Outdoor nighttime activity levels vary by type of facility, such as office, school, and hotel, and by specific schedules. For example, office activity may be quite low after 6 p.m. Schools may have high activity, but only for short durations as extra-curricular activities, sports, social, or other events end. Hotels might experience a constant din of activity, with bursts during dinner, after shows, or at particular events. All of this may demand a control system capable of addressing various settings on various evenings through manual intervention, automated time clock, and photocell functions. Table 22.4 distinguishes the various indoor and nighttime outdoor activity levels. The designer must coordinate with the team and client to establish the activity level or levels appropriate to a given project. Where activity levels are anticipated to be quite different or changeable throughout hours of operation, it may be most appropriate to design for a number of activity levels rather than design to highest anticipated activity levels at all times. A number of activity levels can then be accommodated with controls and use of time clock or occupancy sensor inputs.

The nighttime outdoor lighting zone within which the facility is located or to which the team and client elect to design affects the illuminance criteria for outdoor tasks. Nighttime outdoor lighting zone designations vary by local ordinance, sustainability guides, or the team's own definition of place. These are discussed in 26 | LIGHTING FOR EXTERIORS. Also see Table 15.6 | Nighttime Operational Strategies for Improved Outdoor Environmental Regard.

After-hours security requirements, such as on-site or remote monitoring, and lighting at vulnerable areas or 24-hour exits may require that some lights at building entries be available when approached (for example, via occupancy sensors) or remain energized through the night (see Figure 22.4). Control zones and time clock functions must be designed accordingly. Where remote monitoring is done with infrared cameras, lighting may be unnecessary for the cameras, though some light may be of comfort to pedestrians and may be a deterrent to criminals.

Outdoor lighting, regardless of the illuminance, will not necessarily reduce or eliminate crime [2]. Where lighting that addresses normal criteria is introduced as a means to advance public nighttime activity, it might function as a potential deterrent to criminal activity and provide pedestrians with a sense of security (and a sense of safety). Lamps with CRIs ≥80 help people better identify and distinguish colors. It is also important that the lighting is tuned to the nighttime outdoor lighting zone to avoid adaptation issues. Addressing CRI, nighttime outdoor lighting zones, and normal criteria enable users to see and identify surroundings and potential perpetrators. It is this identification that serves to indirectly deter criminal activity. Perpetrators will learn that their risk of exposure and identification is

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greater in such well-designed areas. Adding high-wattage, wide-area floodlights and tripling or quadrupling illuminances is generally counter-productive. Where additional lighting at entries or public pedestrian areas is deemed necessary for purposes of security surveillance, this should be relatively low-wattage equipment directing light down and across the limited area of coverage and contributing an average of 10 lx, 25 lx, and 50 lx on the ground plane respectively in rural, suburban, and urban areas [3]. See Figure 22.4.

Building entries also include an interior component. Named here as vestibules, these spaces are immediately inside the entry threshold. These spaces provide immediate shelter, a place to collect oneself, and generally transition from outside to inside and vice versa. Illuminance criteria vary from day to night to assist with luminance adaptation, particularly as it relates to daytime exterior-to-interior. These spaces may also be lobbies and should be designed according to criteria outlined for TRANSITION SPACES/Lobbies in Table 22.2.

22.2.5 Conferencing

Conferencing runs the gamut from very simple single-purpose functionality (for example, meet to discuss) to rather complex multipurpose tasks (for example, meet to discuss, present, strategize, and learn, or video conference with others). The lighting is influenced accordingly and also by the formality of the setting. Where presentations are common, such as a board room or a meeting room, and where the participants might number two dozen, the lighting should help define the formality and procedural aspects of the meeting. Accenting on presenter positions is appropriate. Some conference settings strike a balance. In these situations, presentations are common, but intended as a group-think-discuss learning situation. Here, although presentation surfaces are still accented, presenters might not be illuminated. In larger spaces, lighting presets are used to respond to room setups and functions. Figure 22.5 illustrates a common conferencing setup. See also Figures 15.5d, 15.16, 32.3, 32.4, and 32.5.

Video conferencing criteria are directly related to camera technology and user expectations. Vertical illuminances and uniformity criteria at faces and background wall surfaces are most important. Coordinate illuminance criteria with latest camera requirements. Telepresence is a variation on video conferencing. Portable all-in-one camera and monitor setups, from single to multiple monitors, offer video conferencing in non-dedicated settings. Preset controls should be used for convenient and consistent toggling between typical conferencing functions and video conferencing.

22.2.6 Food Service

Lighting for food service addresses the dining situation. Fast-food and grab-and-go-food are generally lighted to usher along the decision and experience. Casual dining and fine dining are more about the food, the service, and the setting making the experience at least pleasurable if not memorable. Accent lighting is appropriate in many dining situations and criteria guidelines are offered in Table 22.2. Figures 12.12, 28.7, 28.8, and 32.6 illustrate several dining and bar situations.

Sometimes plan designations are not entirely descriptive. For example, if the lunch room or canteen (a more recent convention on architectural plans denoting a cafeteria) is intended to be a large space servicing employees and clientele (visitors), then citations under FOOD SERVICE should be studied.

Food service lighting can be categorized as food preparation and handling, food consumption, and cleanup. Commercial and institutional food preparation must meet US FDA Food Code requirements for minimum illuminance which have basis in IES guidelines [4]. These illuminance criteria address the safety of those handling and preparing the food and the safety of the food for consumption, which involves inspection, and cleanliness of food stuffs and facilities. Apparently due to metrication, code requirements are within 10% of IES recommendations. Regardless, a lighting design must meet code.

Table 22.3 | SI Dimensional Conversions

US Customary	SI
General	**Hard Conversion**
inches	mm [inches × 25.40]
feet	m [feet × 0.30]
Specific	**Convenient Conversions[a]**
2'	610 mm or 0.6 m
2' 6"	760 mm or 0.75 m
3'	915 mm or 0.9 m
3' 6"	1065 mm or 1.1 m
4'	1220 mm or 1.2 m
5'	1525 mm or 1.5 m

a. Hard conversions rounded for reporting convenience. Not to be confused with metric-sized luminaires or other building materials. Not for precision construction.



Figure 22.3 | Building Entries
This protected or canopied entry is created by the setback. Lighting clearly defines and is confined to the entry. Vertical illuminance on faces from high CRI lamps permits surveillance staff and other pedestrians to see facial expressions and ascertain clothing styles and colors.
» Image ©Peter Foley/epa/Corbis

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Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions

Activity Level	Definition	Application Examples
Indoor	**Indoor activity levels during daytime or nighttime hours**	
• **High**	Areas with relatively high volumes of activity. Activity level is relative to a facility's population, intended density, and proximity to other applications. Typified by consistently high volumes of people or extreme swings of very high volumes over short time periods. Indoor facilities typical of large population centers.	• Stairs during class changes at educational facilities • Indoor pools at family hotels, water parks, and community recreation centers • Urban mall, major-league sports' venue, and large transportation entry vestibules
• **Medium**	Areas with relatively moderate volumes of activity. Activity level is relative to a facility's population, intended density, and proximity to other applications. Typified by some amount of constant activity by people over extended periods or swells of activity from time to time. Indoor facilities typical of small-to-moderate population centers.	• Indoor pools at business hotels and fitness centers • Civic building, shopping center, and minor-league sports' venue entry vestibules
• **Low**	Areas with relatively low-to-very-low volumes of activity. Activity level is relative to a facility's population, intended density, and proximity to other applications. Typified by little activity by people over extended periods or clusters of activity from time to time. Indoor facilities typical of suburban and rural population centers..	• Indoor pools at resorts or spas • Civic building entry vestibules
Outdoor	**Outdoor activity levels during nighttime hours**	
• **High**	Areas with relatively high volumes of pedestrians and vehicles or solely people during dark hours. Activity level is relative to a locale's population, density of related applications, and general expected norms across the community. Typified by consistently high volumes or extreme swings of very high volumes over short time periods. Outdoor facilities typical of large population centers.	• Entertainment districts • Outdoor pools at family hotels and community recreation centers • Shopping districts and sports' venues • Transportation hubs • University campuses
• **Medium**	Areas with relatively moderate volumes of pedestrians and vehicles or solely people during dark hours. Activity level is relative to a locale's population, density of related applications, and general expected norms across the community. Typified by some amount of constant activity over extended periods. Outdoor facilities typical of small-to-moderate population centers.	• Civic and cultural districts • College campuses • Libraries • Office complexes • Outdoor pools at business hotels and community recreation centers • Recreation centers • Residential complexes • Small shopping areas or centers • Transit lines • Urban central and waterfront parks
• **Low**	Areas with relatively low-to-very-low volumes of pedestrians and vehicles or solely people during dark hours. Activity level is relative to a locale's population, density of related applications, and general expected norms across the community. Typified by little activity over extended periods. Outdoor facilities typical of suburban and rural population centers.	• Outdoor pools at resorts and spas • Residential neighborhoods • Small apartments • Small college campuses • Small commercial establishments

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To avoid food contamination from violent lamp failure, lamps used over food preparation areas should be suitably protected or used in enclosed luminaires. New technologies, including LEDs and OLEDs, have not been vetted for violent failure. Consult with AHJ and lamp and luminaire manufacturers for suitability and application.

22.2.7 IT

Lighting for information technology (IT) facilities generally addresses administrative areas, machine or equipment areas, and media storage areas. Administrative functions may include significant if not dedicated and intensive computer use. Criteria and solutions should be established accordingly. In storage areas and in equipment rooms, general diffuse light may be appropriate given the nature of storage and equipment configurations. However, this should be reviewed carefully in programming as storage setups may involve library-like shelving tightly spaced and equipment may involve tall and continuous racks also tightly spaced, where a directed wash of light is most effective (see Figure 22.6). Dual-level lighting may also be appropriate in these areas to allow for periodic review of backlit readouts or, alternatively, maintenance work.

22.2.8 Parking

Lighting for parking facilities is discussed in 26 | LIGHTING FOR EXTERIORS.

22.2.9 Pedestrian Ways

Lighting for pedestrian ways is discussed in 26 | LIGHTING FOR EXTERIORS.

22.2.10 Plants

Where live plants are programmed illuminance criteria are based on the types of plants, their sizes, and the goal of maintaining or sustaining the plants. Criteria are based on a 14-hour exposure cycle in each 24-hour period. Exposure to most any white light source will suffice. Daylighting is best for efficiency and spectral quality.

Consultation with a horticulturist or landscape architect is recommended in order to establish illuminance criteria and spectral requirements for plant growth.

22.2.11 Reading and Writing

Reading and writing tasks occur within various applications. Familiarity with these tasks will aid with assessment of specific application tasks and activities. This may result in the recommendation of illuminance criteria different than that proposed in Table 22.2 for a particular application. For example, if reception lobbies at various floors in a commercial building are more than security monitoring stations and involve extended periods of reading and writing of paperwork, then illuminance criteria should be determined from the READING AND WRITING applications and tasks and not the TRANSITION SPACES/Lobbies/Reception Lobbies/Desk Top application/task.

22.2.12 Support Spaces

Typical support spaces are cited in Table 22.2. Some applications may have unique support spaces or illuminance criteria peculiar to that application—these are outlined in the respective application chapters.

Familiar back-of-house support spaces are janitor's closets and storage rooms. Lighting need be basic and functional. However, consideration should be given to the need for lamp protection to avoid the obvious. Besides lensing, wire guards or lamp sleeves or lamps with integral sealed containment envelopes are methods to protect the lamp.

Break or lunch rooms and copy print rooms may need design attention. Break and lunch rooms are essentially employee amenities. How lighting is applied, not its cost, can significantly enhance a break experience. See Figure 15.12.

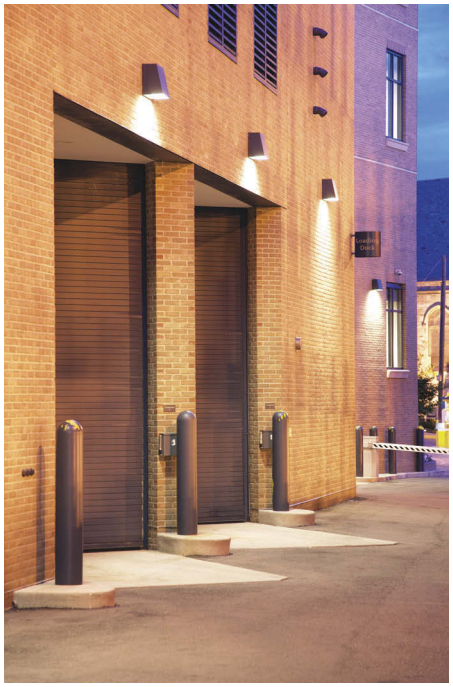


Figure 22.4 | Security Lighting
Service docks and an access alley are lighted with 26 W CFL cutoff wallmounts. Such an approach is visually comfortable, unobtrusive to neighboring properties, and relatively uniform in application of horizontal and vertical illuminance in the vicinity of use.
» Image ©Christopher Lark

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Figure 22.5 | Conferencing
Conferencing might involve laptop presentations (displayed onto larger screens), white board, tack board presentation surfaces, and paper reading and writing tasks. To accommodate the varying tasks and focuses, lighting might include task, ambient, and accent lighting systems. Direct/indirect linear pendant luminaires were found most efficient for the task/ambient lighting. The indirect component provides a general or background ambient light to the entire room. The direct component provides additional light at the table to accommodate the reading and writing tasks. The direct/indirect lighting also provides vertical illuminance sufficiently soft to light faces and yet sufficiently direct to avoid hazy washout. The linear pendant luminaires are dimmable to allow for focus on the presentation surfaces which themselves are illuminated with recessed adjustable accent luminaires.

Preset scenes in this situation are arranged around activities such as WELCOME, COLLABORATION, DISPLAY, and PASSIVE. The WELCOME scene has luminaire outputs adjusted to a mid-level of available light to accommodate pre-meeting discussions. The COLLABORATION scene has outputs adjusted to full-level to accommodate collaboration with analog and digital tasks. The DISPLAY scene has outputs adjusted to dim-level to accommodate video display or projection information sharing. The PASSIVE scene acts as a placeholder before or between meetings where LED amber nightlights are energized.

An automated time clock is programmed to sweep lights off after hours.

» Image ©Workspring

22.2.13 Toilets/Locker Rooms

Restrooms are best addressed by highlighting specific task areas. This offers efficiency while meeting the different illuminance criteria involved. Highlighting toilets, urinals, and vanities offers a more clean, crisp appearance than the haze of general diffuse lighting. Vanity positions require vertical illuminance on an imaginary facial plane (roughly a zone of sufficient size to encompass faces at standing or seated height) in front of the mirror. Figure 22.7 identifies several methods of vanity lighting. Color of light is important for grooming. Lamps exhibiting 2700 K to 3500 K CCT and CRI ≥82, using triphosphor CFLs as benchmark, are appropriate.

22.2.14 Transition Spaces

Typical transition spaces are cited in Table 22.2. Each application may have unique transition spaces or criteria for transition spaces peculiar to that application—these are outlined in the respective application chapters.

How front-of-house transition spaces in many applications are designed and lighted defines the place and welcomes employees and guests. These spaces are transitions from exterior to interior and vice versa or from one kind of interior space to another. Illuminance criteria and accents are an important aspect of making comfortable and safe transitions.

Many of the public spaces may be of a particular sequence of passage, ceremonial in nature, or of special importance. To appropriately serve these roles, subjective impressions outlined in Table 12.2 should guide the application of lighting effects. Illuminances associated with artwork and features that assist with these subjective impressions are outlined in Table 22.2. Throughout the various application chapters examples are presented of some transition spaces.

Adjacency passageways refer to a condition where circulation areas are encompassed by larger work or task areas. Given their adjacency to the open and visually accessible work or task areas, their illuminances, confined to the passageway proper, should be ratios of the nearby task illuminances. This avoids annoying contrasts within the work setting that may result in visual fatigue or discomfort.

For purposes of visual consistency and of maintenance convenience, lamp types and color qualities should match those used elsewhere.

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22.3 Illuminance Criteria

Illuminance criteria, when fully deployed, are a robust set of quantitative values that influence visibility, visual performance, and visual comfort and attention. Short-circuiting the criteria selection or designing to a single criterion value, such as horizontal illuminance, to address worst-case tasks will surely result in dissatisfaction. Even if clients accept the visual results, not getting the most from the energy expended or, worse, energy waste is a likely result. Following are notes related to various topics outlined in Table 22.2.

22.3.1 Applications and Tasks

Applications and tasks encountered on any given project may be different from those identified in Table 22.2 and may warrant different illuminance criteria. Cross-referencing closely-associated applications or tasks is appropriate. Sometimes naming trends or conventions for space types or functions change to conform to current practice, client programming, or architectural conventions, but the actual activities and tasks remain the same and this cross-referencing works. Failing this technique, reviewing the list in Table 22.2 may be in order to determine if any applications or tasks exhibit a similar visual-component to the unique applications or tasks. Otherwise, reviewing 4.12 An Illuminance Determination System and Table 4.1 is necessary to establish a task category based on the task characteristics or visual performance descriptions most closely associated with the unique applications or tasks. These exercises as well as any deviations from recommendations the designer intends to make should be carefully documented for the record.

22.3.2 Notes

The notes in Table 22.2 may refer to other task headings in the table or to other handbook chapters as appropriate. Where some degree of clarification is warranted, notes are made.

22.3.3 Recommended Maintained Illuminance Targets

Values cited are maintained on the area of coverage for the task under consideration. Illuminance is additive. Where practical and without negatively affecting the intended application of light, target values are achieved with any combination of daylighting and/or electric lighting in whatever mix of ambient, task, and accent lighting is deemed appropriate to meet these and the other lighting goals established during design. See 12 | COMPONENTS OF LIGHTING DESIGN and see 10.7.1 Light Loss Factors.

With respect to light loss factors, account for anticipated losses through the point in time at which group relamping and cleaning should occur. Group relamping and cleaning should be standard practice, though these need not occur at the same frequency. Periodic cleaning and group relamping essentially maintain the illuminance at criteria and make the most efficient use of the installed equipment. For purposes of sustainability, cleaning and group relamping can no longer be presumed to be infrequent or unlikely. Maintenance procedures must be part of the design discussions with the client. See the IES document IESNA/NALMCO RP-36 Recommended Practice for Planned Indoor Lighting Maintenance for additional information. Where maintenance is deferred or practiced poorly or not at all, the actual illuminance values will fall below criteria targets. This is inefficient, unsustainable, and may be unsafe while adversely affecting users' quality of life or work. Ratcheting initial illuminances higher is poor practice and not recommended. Maintenance procedures may be especially problematic with LEDs where promises of extraordinarily long life may be offered, but usually with the caveat that lamp lumen depreciation (LLD) at that rated life is 70% or perhaps even as low as 50% of initial rating. If replacement cycles are presumed to be rated life, then LLD alone must be 0.7 or 0.5 or whatever lumen rating is certified by the LED vendor. See 13.3 Life and Lumen Maintenance.

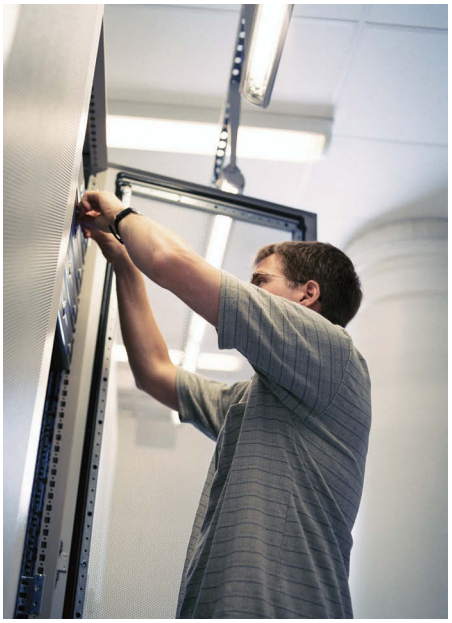


Figure 22.6 | Server Room
General diffuse luminaires running perpendicular to the server racks provide some ambient light. Linear fluorescent wallwashers or sign lights running the length of the server racks provide task lighting.
» Image ©Helen King/Corbis

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Figure 22.7 | Vanities
Front lighting on faces is critical at vanities. Meeting illuminance criteria requires some amount of frontal lighting from the mirror toward the face, but rather softly to avoid glare conditions. In the top image, wall sconces between mirrors are lamped with 13 W CFLs. An overhead wall slot provides overall room ambient and also contributes to the face-plane illuminance. A wall slot on the opposite wall illuminates the toilet and urinal areas and provides some backlighting.

In the middle image, spherical pendants lamped with 13 W CFLs at the mirror provide an ambient glow and sufficient light on the face. Wallwashers opposite the mirror provide some backlighting for primping and are strategically placed to highlight art.

Mirror-integrated lighting in the bottom image is achieved with linear T5 lamps (which can be dimmable) behind etched glass and procured as a complete unit.

» Top Image ©GSLD
» Middle Image ©Far Photography
» Bottom Image ©Kevin Beswick, www.ppt-photographics.com

Targets cited are consensus and recommended for respective functional activity. For some applications, IES recommendations are within 10% of code requirements. This apparently is an artifact of metrication. Footcandle conversions of any values cited in Table 22.2 should be made at 1 fc to 10 lx. This soft conversion avoids a redundant diminishing of illuminance values after multiple citations and conversions over time. This also eliminates a false sense of accuracy advanced by an ever-increasing number of decimal places and a false sense of urgency advanced by eccentric fractional values introduced by hard conversions. Nevertheless, a lighting design must meet code and the mechanics of which must be coordinated amongst the design team. The IES recommendations should not, do not, and cannot reflect all of the various code requirements in force in all jurisdictions at any given time.

Targets are intended to apply to the dominant plane of the task, typically, but not always, horizontal or vertical. In some situations, illuminance criteria are cited for one plane, such as the vertical plane for lighting white boards, while the other plane is blank. The blank signifies that illuminance on that plane is unimportant and may be a consequence of the illuminance of other tasks within the vicinity or by whatever illuminance results from meeting the target illuminance for the prescribed plane of interest.

In some situations, no light is anticipated on at least one plane of a task. A 0 indicates no light or zero light is recommended for the task or application.

22.3.3.1 Target Planes

Many, though certainly not all, tasks are performed with the task in roughly a horizontal orientation or vertical orientation. A dominant orientation must be assigned and the illuminance target determined accordingly. There may be situations where the IES recommended target relating to the typical planar mode of a task must be applied to a different plane. For example, if mail sorting primarily involves vertically-stacked mail slots or boxes and sorted in a standing position, then the illuminance target cited in Table 22.2 (ADMINISTRATION/Mail Sorting), which is for a dominant horizontal orientation, must be applied to the vertical plane of the mail boxes.

Nearly all tasks are expected to have both a horizontal illuminance component (E_h) and a vertical illuminance component (E_v). This allows some degree of task flexibility for off-plane viewing and accommodates various aspects of the task.

Where illuminance targets are intended at differing planar elevations, this is indicated under "Notes." For example, for most corridors (TRANSITION SPACES/Circulation Corridors), horizontal illuminances apply to the floor plane while vertical illuminances apply to standing-face-plane height of 5' AFF oriented in the two main directions of travel. In applications where the majority of users are children or wheelchair-bound adults, the designer may elect to set the elevation for vertical illuminance at 3' AFF. Note the implication for observers' visual ages. Establishing and tracking task orientations and addressing both horizontal and vertical illuminance is necessary. If orientations in the project under consideration are programmed to be flipped from what might be considered normal-viewing, then criteria must be adjusted accordingly. If a task is scheduled to be oriented on some plane off axis from horizontal or vertical by more than 10°, say, then the illuminance criteria must be applied to that off-axis orientation. This is an important distinction for luminaire optical selection and aiming capabilities and for layout, calculations, and field measurements.

For planes related to vertical illuminance targets, some guidance is indicated under "Notes." However, the designer may elect to use alternate or multiple vertical planes. In some situations the vertical planes could be oriented in a number of directions and the designer must determine which are most appropriate for the situation. For example, in a commercial kitchen, E_v at preparation surfaces (FOOD SERVICE/Kitchens/Food Preparation), the number and orientation of vertical planar points assessed depends on the preparation surface. On a counter against a full-height wall, the vertical planes of most interest are the one facing the preparer and the two planes perpendicular to the preparer

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(one oriented toward the right and one toward the left). The criteria apply to these three planes. On an island or peninsula which may be used from more than one side, there are four planes of interest.

22.3.3.2 Visual Ages of Observers

Illuminance criteria are based on the visual ages of more than half the intended observers. This aspect should be resolved during programming with the client. It may be determined that illuminance criteria for an age group other than that representing the majority of the intended observers is appropriate. However, this may result in overlighting, underlighting, harsh lighting, visual displeasure, or visual discomfort for many of the observers. See 12.5.5 Illuminance and 4.12 An Illuminance Determination System for additional information and guidance. In some situations, such as video conferencing, lighting must meet the requirements of the camera technology and, therefore, is not tied to ages of observers.

22.3.3.3 Illuminance Categories

Illuminance categories are designated by letters A through Y. These are shown in Table 22.2 for more convenient reference to Table 4.1 | Recommended Illuminance Targets should the designer wish to explore other criteria targets or if applications or tasks on a specific project are not readily correlated to the table citations.

22.3.3.4 Gauge

The common gauge for determining illuminance target compliance is cited for each application. All gauges presume that point-by-point techniques are used for predictive calculations and presume that uniformity criteria are closely monitored. Where an average illuminance value over the area of coverage can satisfy target compliance, “Avg” is cited. In applications or tasks where a minimum or maximum target is necessary, the gauge for compliance is “Min” or “Max” respectively.

The designer may elect to use other methods to evaluate target compliance, such as criterion rating (CR) or coefficient of variation (C_v). See 4.12.4.5 Tasks at Uncertain Locations Over a Large Area.

In any event, once illuminance targets and uniformities are established, then any calculated deviation from them should be limited. Standard engineering allowance of ±10% might be acceptable for targets gauged as average unless contractual or code obligations demand otherwise. Minima and maxima must be achieved as intended.

Designs should be adjusted until predictions are within allowance for averages and meet minima and maxima. For additional information, see see 4.12.4.1 Recommended Illuminances at Design Time, 4.12.5 Illuminance Ratios, 9.15.1.1 Average Illuminance, and 10.8 Assessing Computed Results.

22.3.4 Uniformity Targets

Illuminance uniformity targets work in conjunction with luminance uniformities and surface reflectances all of which must be addressed as part of the design to avoid visual discomfort, glare, and strain. Uniformity ratios are targets that define the widest recommended ranges. In many situations, uniformity ratio criteria are those between average values of an array of points and the minimum value in the same array of points. Uniformity targets apply to both horizontal and vertical illuminances over the area of coverage. Where horizontal uniformity criterion is different from vertical uniformity criterion, two ratios are reported with the first value for horizontal illuminance (E_h). In some situations, notably those with regard to exterior illuminances, two uniformity values are cited. The first value addresses the primary cited application or task. The parenthetical value references the parenthetical application or task, such as a curfew situation associated with nighttime outdoor lighting.

Generally the more important speed and accuracy and the more demanding the visual task, the tighter the ratio.

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22.3.4.1 Maximum-to-average

This is the recommended ratio of maximum illuminance to the average illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations sensitive to even a relatively small degree of overlighting.

22.3.4.2 Average-to-minimum

This is the recommended ratio of average illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where illuminance too far below average conditions is noticeable and detrimental to task performance or inconsistent with normal expectations.

22.3.4.3 Maximum-to-minimum

This is the recommended ratio of maximum illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where too much variation in illuminance is considered undesirable and untenable from a performance or safety perspective.

22.3.5 Daylighting Advancement

Generally, design strategies should embrace any combination of daylighting and electric lighting to achieve target values during daylight hours. The preference is for daylighting to provide all or most of the recommended illuminance presuming that all aspects of daylighting are properly addressed. A sunburst icon depicts those applications and tasks where daylighting is considered a strategic candidate. Use photocells and stepped-dimming or continuous dimming to reduce or eliminate electric lighting during daylight hours. See 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Even for those applications where daylighting is not traditionally a strategic candidate, it may be determined that very careful and coordinated design will offer great sustainability opportunities along with positive influences associated with daylight and views.

IESH/10e CSA/ISO

> 12.5 Task Factors
- for information on CSA/ISO computer screen qualities

22.3.6 Veiling Reflections

Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper or, worse, both, are prone to veiling reflections. The likelihood of particular applications and tasks predisposed to veiling reflections is indicated by a "reflected light" icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood. Veiling reflections are minimized by controlling the overall amount and direction of light with respect to the task locations and orientations. Alternatively, tasks sensitive to veiling reflections can be screened or isolated. Effective strategies include employing indirect soft, diffuse electric lighting or direct electric lighting with multiple low-output luminaires, or positioning tasks and luminaires and luminance patterns to avoid harsh reflections from tasks. Addressing luminance recommendations (see Table 12.4 | Default Luminance and Luminaire Intensity Recommendations for VDT Applications) minimizes veiling reflections. Changing the task will reduce or eliminate veiling reflections, such as use of CSA/ISO Type I or II computer screens and matte paper versus their specular counterparts.

22.3.7 Defining Areas of Coverage

In addition to establishing planes of task orientation, the areas of coverage to which targets apply must be determined. Typical areas of task illuminance coverage are identified here, but these may not be appropriate to specific project situations. One area of coverage is "task proper or task area." Here, the illuminance criteria are applied to the task itself or to a relatively small area to which the task is confined. See 12.5.5.1 Tasks and Applications and Figure 12.22 | Task Coverage Example. In some situations, such as accenting, the "task" area may consist of the entire wall when "feature wall" or "perimeter" accenting is desired. It is important to remember that illuminance is additive, that is, task illuminance can be

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achieved with some combination of ambient lighting, task lighting, and/or accent lighting, providing that the total illuminance on the task proper or task area meets the illuminance criteria outlined in Table 22.2.

Another area of coverage is "room or designated area." In this situation, illuminance criteria are applied to the room or an area of fairly substantive size representing the zone in which the applications and tasks are expected to occur. The designated area is typically established by the furniture layout, for example, or might be established by the design team or client. The area-of-coverage citations in Table 22.2 are based on traditional notions. So, for example, it may be determined that a "task proper or task area" coverage would result in some amount of LPD reduction when compared to "room or designated area" coverage. If the task can be confined to one area rather then multiple areas, if the room or area in which the task is located is itself relatively small, such as a single-occupant office, and if the other design goals and criteria outlined in 12 | COMPONENTS OF LIGHTING DESIGN are addressed, then this strategy of redefining area of coverage has merit.

An assessment and determination must be made on which area of coverage best satisfies the lighting goals on a particular project.

22.4 Designing

Information provided here is specific to common applications and should be used as part of the design and documentation processes outlined in Chapters 12, 15, and 20. Equipment selection and location strategies may need to address the possibility of lighting equipment abuse in some situations. For outdoor applications, lamps and ballasts, transformers, and drivers must be selected for ambient temperature conditions, some of which are extremely hot and others extremely cold. See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY for additional information on respective aspects. Addressing all code requirements is a must. Energy efficient and sustainable practices are an integral part of all IES recommendations. Key design tenets include, but are not limited to:

- designing for the satisfaction of the observers intended to use the project
- using baseline reflectances of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively) in interior production and work-oriented spaces
- using daylighting that meets luminance and illuminance criteria
- using highest-efficacy lamps that meet color, optical and electrical control, and output criteria
- using highest-efficiency luminaires that meet aesthetic and luminance criteria
- using accenting to provide luminance balancing or improve brightness perceptions where necessary
- using controls liberally, preferably automated varieties such as presets, occupancy and vacancy sensors, astronomical time clocks, and photocells
- establishing IES-recommended illuminance criteria to meet programmed tasks
- establishing layouts that just meet IES-recommended illuminance criteria
- addressing outdoor environmental needs
- using calculations, photometrically-realistic renderings, and operational samples and mockups to prove concepts
- identifying and designing to code-specific requirements, if any, for ambient, task, and accent lighting
- documenting all code-, energy-, sustainability-, and IES-criteria compliance
- documenting criteria and design deviations and rationale and subsequent disposition by team, client, or AHJ
- documenting clearly the layouts, controls, and luminaire and lamp selections

IESH/10e Economics Resources

> 15.3.3 Budgets
  - for more on budgets and value engineering

> 18 | ECONOMICS
  - for more on estimating costs
  - for more on life cycle costs
  - for more on paybacks and rates of return

IESH/10e Energy Efficiency Resources

> 17.2 New Construction
  - for more on designing for daylighting
  - for more on electric lighting equipment
  - for more on lighting controls

> 17.4 Lighting Codes, Regulations and Standards
  - for more on application standards
  - for more on equipment regulations

IESH/10e Lighting Exteriors Resources

> 12.5.5.6 Nighttime Outdoor Illuminances
  - for more on lamp efficacies under mesopic adaptation

> 26 | LIGHTING FOR EXTERIORS
  - for more on criteria

IESH/10e Sustainability Resources

> 13.11 Sustainability
  - for more on lamps

> 19 | SUSTAINABILITY
  - for more on controls
  - for more on earth resources
  - for more on energy
  - for more on life cycle analyses
  - for more on lighting design
  - for more on recycling

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Designing for the satisfaction of the observers is the paramount design tenet and must be kept in perspective during all aspects of design. If the observers' expectations are not fulfilled, then how much energy could be saved is moot, as is how many fewer earth resources were spared, as is how much the whole affair cost or how much value engineering saved or the photogenic qualities of the project. See sidebar references for additional guidance on the key tenets. The design effort must be undertaken with coordinated and realistic expectations by all involved on initial and life cycle costs. Budgeting should include designer input and dialogue with the team and client at project commencement and design milestones. In other words, and paraphrasing Thomas Edison, genius is, indeed, just 1% inspiration and 99% perspiration.

22.5 References

[1] Mark S. Rea, ed. 2000. The IESNA lighting handbook: Reference and application. 9th Edition. New York: IESNA. Ch 14,10, 3.

[2] Boyce PR. 2003. Human factors in lighting. 2nd edition. London: Taylor & Francis. p 425-427.

[3] Boyce PR. 2003. Human factors in lighting. 2nd edition. London: Taylor & Francis. p 413.

[4] [USDA] US Food and Drug Administration, Public Health Service. 2009. Food Code FDA. College Park, MD: United States Department of Health and Human Services, 2009. p 176 and 295.

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23 | LIGHTING FOR COURTS AND CORRECTIONAL FACILITIES

The place of justice is a hallowed place.
Francis Bacon, 16th and 17th Century English Jurist, Lawyer, Statesman, Scientist, and Philosopher

Contents

23.1 Project Type and Status. . . 23.1
23.2 Application Types 23.2
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The buildings in which justice is rendered and served require lighting that supports tasks in what are sometimes matters of the gravest consequences. Viewing evidence, considering fellow deliberators, maintaining security, guarding the incarcerated are all important functions supported by lighting. But the rule of law, and the dignity of the buildings in which justice functions, is also a matter of perception, and lighting can infuse a facility with the character required of such important spaces.

Comprehensive design efforts involve the information in this chapter combined with material in 12 | COMPONENTS OF LIGHTING DESIGN, 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS, 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Design tenets deemed appropriate from those chapters must be identified and lighting goals and strategies developed accordingly. This chapter primarily addresses illuminance criteria for courts and correctional facilities which should influence luminaire optical selections, lampings, and final layouts based on design thought-starters (see 15.2 A Lighting Scheme). Use of the material in this chapter to the exclusion of material in Chapters 12, 13, 14, and 15 will likely lead to unsatisfactory results. Previous IES related documents serve as archival reference sources [1].

Deliberate thought must be given to details beyond the recommended illuminances in this chapter. For example, with CORRECTIONAL FACILITIES/Circulation Corridors, the illuminance citations do not necessarily satisfy the amount and distribution requirements for security cameras. The designer must know the requirements of the security equipment being used. Such specific details are not enumerated for tasks. Table 23.1 offers a checklist of IES lighting topics and criteria. The design team is responsible for determining and addressing indoor and outdoor lighting and energy criteria set forth by authorities having jurisdiction (AHJ) which may be different from and supersede IES criteria. See also 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

23.1 Project Type and Status

Before any design work, an understanding of the project type and scope is necessary. This will establish the extent to which daylighting can address most or many or some of the lighting goals. New, renovation, and restoration projects each offer varying opportunities. See 11.2 Planning, 11.3.1 Pre-design, and 11.3.2 Schematic Design. At every opportunity the lighting designer should give every consideration to daylighting as a light source. For some applications and tasks, daylighting can be the primary light source. Critically, this means addressing the host of lighting design factors identified in 12 | COMPONENTS OF LIGHTING DESIGN. Daylight demands attention to moderate or eliminate glare and balance visible and thermal energy.

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Table 23.1 | Courts and Correctional Facilities Lighting Checklist

Topics
✔ Criteria and Design Resources
Accenting
15.1.1.3 Accent Lighting
Table 12.2 | Subjective Impressions
Table 15.2 | Accent Illuminance Ratios
Table 22.2 | Common Applications Illuminance Recommendations
Appearance
12.2 Spatial Factors
Color
12.5.6 Color Considerations
Controls
16 | LIGHTING CONTROLS
Daylighting
14 | DESIGNING DAYLIGHTING
Electric Lighting
15 | DESIGNING ELECTRIC LIGHTING
Flicker
4.6 Flicker and Temporal Contrast Sensitivity
Glare
4.10.1 Discomfort Glare
4.10.2 Disability Glare
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This Chapter: Table 23.2
12.5.5.1 Applications and Tasks
Table 12.6 | Default Illuminance Ratio Recommendations
Figure 12.22 | Task Coverage Example
Light Distribution
12.3.2 Subjective Impressions
Luminances
12.5.2 Luminance
Table 12.5 | Default Luminance Ratio Recommendations
Maintenance
15.4.4 Installation and Maintenance
Nighttime Outdoor Environment
Table 15.6 | Nighttime Operational Strategies for Improved Outdoor Environmental Regard
Systems Integration
12.6 Systems Factors
Veiling Reflections
This Chapter: Section 23.3.6
12.5.4 Veiling Reflections
Visual Tasks
This Chapter: Section 23.2
This Chapter: Table 23.2
Table 11.2 | Programming: Inventory Scope and Specific Examples
12.5.1 Visual Tasks
Table 12.3 | Sample Visual Task Survey

23.2 Application Types

To develop lighting solutions that meet quality, quantity, and operational criteria, an inventory is made of the courts and correctional facilities space types under consideration and the anticipated occupants, functions, and tasks (see Table 11.2 | Programming: Inventory Scope and Specific Examples and Table 12.3 | Sample Visual Task Survey). Otherwise, lighting cannot be best targeted to the users, their expectations, functions and tasks.

Space type definitions are required early in the project design in order to track design efforts that include inventorying the project knowns, anticipated functions, and tasks and calculating lighting, power, and energy compliance. Room names, from which functions can be deduced, and numbers for tracking should be clearly marked on architectural backgrounds. The applications and tasks cited in Table 23.2 | Courts and Correctional Facilities Illuminance Recommendations should be reviewed against the project knowns and correlated with the named space types and functions to establish recommended illuminance criteria. Seek clarification with the client where discrepancies occur between programming information, the list of room names, and the available application and task citations in Table 23.2.

In many situations in courts and correctional facilities, security is an inherent part of the task: securing detainees and prisoners to prevent their escape or destructive actions to property, self, or others; securing key personnel of courts and correctional facilities from harm. Lighting plays a role, but only as part of a much broader security program to be effective. Lighting hardware itself must be considered a target of destructive behavior in some of these situations. The designer must review the programming information and consult with the team and owner to establish the full extent of security issues affecting lighting.

The following discussion is keyed to major application headings in Table 23.2. Couple this with topics in Table 23.1 for comprehensive qualitative and quantitative criteria.

23.2.1 Accenting

Accenting affects people's brightness perceptions and provides visual relief. Accenting is also used for visual attraction, inspection, and wayfinding. Accenting enhances architectural spatial forms and limits and impressions of spatial volume. See Tables 12.1a, 12.1b, and 12.2. Accenting can make spaces appear less institutional. Several perimeter accenting techniques are illustrated in Figure 23.1.

23.2.2 Administration

Lighting for administrative areas is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. The architectural scheme and even task specifics will vary based on the courts and correctional facilities involved. In some projects these details should affect the lighting design, from the kinds of lighting effects to lighting equipment styling to luminances and illuminances. In other projects, notably more secure prisons, the straightforward requirements of security and abuse will override some lighting effects and equipment styling aspects.

The administrative areas are typically consolidated into a single area, wing, or building of courts and correctional facilities. Several aspects may affect the degree to which the lighting design in the administrative area is sympathetic to or different from that of the other applications and tasks at the facility in question:

- Owner wishes and architectural desires
- Visual connection between administrative areas and other areas of the facility
- Management style

See also 32 | LIGHTING FOR OFFICES.

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Figure 23.1 | Courtroom Lighting
Top left is view from judge's bench. Bottom left view is from audience seating area. Right view is a detail of the feature stone wall behind the judge's bench. Perimeter accenting contributes to pleasantness and spaciousness in this courtroom. The diffuse reflected light of the wall accenting and the cove contributes greatly to vertical illuminances which assist in facial modeling. Downlighting contributes here to visual clarity and horizontal illuminances for reading and writing tasks.

Ambient lighting consists of the cove lighting ❶ which uses an asymmetric reflector housed in a drywall detail. The asymmetric reflector is lamped with T5 standard output linear fluorescent lamps exhibiting 3000 K CCT and 85 CRI. Task lighting consists of the downlights ❷ which are open reflector and lamped with 32 W triple-tube CFLs exhibiting 3000 K CCT and 82 CRI. Accenting consists of one approach, perimeter lighting. This is achieved with two techniques. Spread lens wallwashers ❸ lamped with 32 W triple-tube CFLs are used along two side walls. A linear wallslot detail ❹ grazes the stone feature wall behind the bench also shown in the detail image to the right. The wallslot is a drywall detail consisting of monopoints on 15″ centers. The monopoints are lamped with 20 W T4.5/GU6.5 CMH lamps exhibiting 3000 K CCT and 80 CRI.

Downlights are dimmable and grouped in three zones: a zone at the bench; a zone in the middle of the room to address the well; and a zone at the public seating area. Cove lighting is dimmable and is on an independent zone. Perimeter wall washing is dimmable and on three zones: one for each side and one at the main entrance wall. The front wallslot is nondim on a single zone. This level of control permits presets that might include these scenes: ADMIN, SESSION, AV, SPECIAL, and OFF.

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Table 23.2 | Courts and Correctional Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
ACCENTING	Accenting influences observers' overall brightness perceptions and provides visual relief. Accenting is also used for visual attraction, inspection, and wayfinding. See 15.1.1.3 Accent Lighting. These are criteria for consideration in any application.											
• Art	On artwork plane (typically vertical). See 21 | LIGHTING FOR ART for preservation-worthy materials.				see Table 15.2					see Table 15.2		
• Feature Wall	On wall plane				see Table 15.2					see Table 15.2		
• Important Focal Point	On focal point plane				see Table 15.2					see Table 15.2		
• Perimeter	On wall plane				see Table 15.2					see Table 15.2		
ADMINISTRATION	See 22 | LIGHTING FOR COMMON APPLICATIONS											
ATRIA and COURTYARDS	See 22 | LIGHTING FOR COMMON APPLICATIONS											
BUILDING ENTRIES	See 22 | LIGHTING FOR COMMON APPLICATIONS											
CIRCULATION	See specific applications or see TRANSITION SPACES/Circulation Corridors for default values.											
CLASSROOMS	See 24 | LIGHTING FOR EDUCATION											
CONFERENCING	See 22 | LIGHTING FOR COMMON APPLICATIONS											
CORRECTIONAL FACILITIES	Applications and tasks common to facilities for processing and housing detainees or convicts. Address hardware security requirements as necessary. Coordinate lighting with security cameras.											
• Activity Room	E_h @floor; E_v @5' AFF	Q	200	400	800	Avg	N	75	150	300	Avg
• Armory	E_h @floor; E_v @5' AFF on racks	R	250	500	1000	Avg	O	100	200	400	Avg
• General	E_h @floor; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Inspection Table	E_h @floor; E_v @5' AFF on racks	T	500	1000	2000	Avg	P	150	300	600	Avg
• Racks	E_h @3' AFF; E_v @5' AFF on racks	R	250	500	1000	Avg	O	100	200	400	Avg
• Attorney/Client Interview Rooms	E_h @2' 6" AFF; E_v @4' AFF	Q	200	400	800	Avg	N	75	150	300	Avg
• Canteen	See CORRECTIONAL FACILITIES/Food Service										
• Cells											
• Group Holding Cells											
• Day	E_h @floor; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Night	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Individual Cells											
• General											
◦ Day	E_h @floor; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg
◦ Night	E_h @floor; E_v @4' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Task Areas	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Chapel											
• Focal Areas		R	250	500	1000	Avg	R	250	500	1000	Avg
• Meditation	E_h @2' AFF; E_v @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Pre/Post Worship	E_h @3' AFF; E_v @5' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Sermon	E_h @2' AFF; E_v @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg

Table 23.2 | Courts and Correctional Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
see 15.1.1.3						
see 15.1.1.3						
see 15.1.1.3						
see 15.1.1.3						
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	4:1					
	3:1					
	3:1					
	3:1					

Notes for Table 23.2

The table column headings are discussed in detail in 23.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 23.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 23.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 23.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches. A shaded icon indicates applications and tasks are sensitive to daylight and appropriate measures, including blackout capabilities, must be taken to limit daylight exposure, if daylight is deemed a suitable source of light.

g. Tasks with specular components, like object under glass or CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. Control architectural lighting with dimmers to accommodate varied needs.

j. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

k. Use lamps with CCTs of 5000 K and CRIs ≥85.

l. Illuminance targets cited are for target area so noted and achieved with a minimum of 3-level control, if not dimming control, of architectural lighting.

m. Use lamps with CRIs ≥85.

n. Equip physical analyses laboratories with adjustable portable luminaires for analysis efforts.

o. Make electrical provisions for portable work lights.

p. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 23.2 | Courts and Correctional Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
CORRECTIONAL FACILITIES	(continued)											
• Circulation Corridors	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.											
• Public	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
• Secure												
• Day	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg	
• Night	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
• Lockdown	E_h @floor; E_v @5' AFF	Q	200	400	800	Avg	P	150	300	600	Avg	
• Staff	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
• Classrooms	See 24 | LIGHTING FOR EDUCATION											
• Commissary												
• General retail	E_h @2' 6" AFF; E_v @3'-5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
• Perimeter	E_v @5' AFF						R	250	500	1000	Avg	
• Control Posts												
• Direct-view Observation												
• General[i]	E_h @floor; E_v @5' AFF	H	10	20	40	Avg	-	0	0	0		
• Task Area[i]	E_h @2' 6"; E_v @5' AFF	M	50	100	200	Avg	-	0	0	0		
• Video-view Observation												
• General[i]	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg	
• Task Area[i]	E_h @2' 6" AFF; E_v @3' 6" AFF[j]	P	150	300	600	Avg	M	50	100	200	Avg	
• Counseling	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Day Room	See Activity Room											
• Dental Examination, Hygiene, and Treatment[k]	E_h and E_v @3' AFF	T	500	1000	2000	Avg	P	150	300	600	Avg	
• Dining Halls	See CORRECTIONAL FACILITIES/Food Service											
• Elevators	See TRANSITION SPACES/Elevators											
• Firing Range	**INDOOR** E_h @shooting line 3' AFG; E_v @area of target	P	150	300	600	Avg	T	500	1000	2000	Avg	
• Food Service												
• Canteen Dining	E_h @table plane; E_v@4' AFF	N	75	150	300	Avg	K	25	50	100	Avg	
• Kitchen												
• Dishwashing/Pot Washing	E_h @2' 6" AFF; E_v @4' AFF		200	200	200	Min	M	50	100	200	Avg	
• Food Preparation	E_h and E_v @preparation/food-handling surfaces		500	500	500	Min	O	100	200	400	Avg	
• Storage												
◦ Equipment, utensils, ware	E_h and E_v @2' 6" AFF		200	200	200	Min	M	50	100	200	Avg	
◦ Food												
Non-refrigerated	E_h and E_v @2' 6" AFF		100	100	100	Min	I	15	30	60	Min	
Refrigerated	E_h and E_v @2' 6" AFF		100	100	100	Min	I	15	30	60	Min	
• Refuse/Soiled Ware Return	E_h @plane of return; E_v@4' AFF		100	100	100	Min	K	25	50	100	Avg	

Table 23.2 | Courts and Correctional Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1		☀			
	2:1		☀			
	2:1		☀			
	2:1		☀			
	2:1		☀			
1.5:1/3:1	1.5:1/3:1		☀			
2:1	2:1		☀			
	4:1		☀			
	2:1		☀			
	4:1		☀			
	see Table 12.6		☀			
	3:1		☀			
	3:1		☀			
		2:1	☀			
	3:1		☀			
	2:1		☀			
	see Table 12.6		☀			
	2:1		☀			
	3:1		☀			
	3:1		☀			
	2:1		☀			

Notes for Table 23.2

The table column headings are discussed in detail in 23.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 23.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 23.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 23.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches. A shaded icon ☀ indicates applications and tasks are sensitive to daylight and appropriate measures, including blackout capabilities, must be taken to limit daylight exposure, if daylight is deemed a suitable source of light.

g. Tasks with specular components, like object under glass or CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◥ signals high likelihood; gray and white ◥ signals moderate likelihood; pale gray and white ◥ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. Control architectural lighting with dimmers to accommodate varied needs.

j. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

k. Use lamps with CCTs of 5000 K and CRIs ≥85.

l. Illuminance targets cited are for target area so noted and achieved with a minimum of 3-level control, if not dimming control, of architectural lighting.

m. Use lamps with CRIs ≥85.

n. Equip physical analyses laboratories with adjustable portable luminaires for analysis efforts.

o. Make electrical provisions for portable work lights.

p. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 23.2 | Courts and Correctional Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
CORRECTIONAL FACILITIES	(Food Service continued)										
• Serveries											
• Buffet Displays	E_h and E_v @planes of food presentation		Avg = 3 times dining area E_h, but ≥200					Avg = 3 times dining area E_h, but ≥200			
• Grab-and-go displays	E_h and E_v @planes of food presentation		200	200	200	Min	N	75	150	300	Avg
• Serving Lines											
◦ Employee-served	E_h and E_v @preparation/food-handling surfaces		500	500	500	Min	O	100	200	400	Avg
◦ Self-served	See CORRECTIONAL FACILITIES/Food Service/Serveries/Buffet Displays										
• Intake and Release Area											
• General	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Hygiene Suite											
• Changing Room	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Shower	E_h @floor; E_v @3'-5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Toilet	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Identification Processing	E_h @3' 6"; E_v @5' AFF	R	250	500	1000	Avg	Q	200	400	800	Avg
• Property											
• Inventory	E_h @3' 6"; E_v @5' AFF	R	250	500	1000	Avg	Q	200	400	800	Avg
• Property Room											
◦ Face of Shelving or Racks	E_h @3' 6"; E_v over face of shelving	P	150	300	600	Avg	M	50	100	200	Avg
◦ General	Eh @floor; Ev @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Sally Port	See CORRECTIONAL FACILITIES/Vehicle Sally Port										
• Secure Storage	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Security Screening	E_h @3' AFF; E_v @5' AFF	Q	200	400	800	Avg	O	100	200	400	Avg
• Toilets											
• Detainees and Inmates	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Public	See TOILETS/LOCKER ROOMS										
• Staff	See TOILETS/LOCKER ROOMS										
• Waiting											
• Detainees											
◦ Group (TV Room)	E_h @floor; E_v @4' AFF	L	37.5	75	150	Avg	J	20	40	80	Avg
◦ Isolation Cell	E_h @floor; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Public	See TRANSITIONAL SPACES/Lobbies and Waiting Rooms										
• Jail Cells	See CORRECTIONAL FACILITIES/Cells										
• Kitchen	See CORRECTIONAL FACILITIES/Food Service										

Table 23.2 | Courts and Correctional Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1					
	3:1					
see Table 12.6						
	3:1					
	3:1					
	2:1					
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
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	3:1					

Notes for Table 23.2

The table column headings are discussed in detail in 23.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 23.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 23.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 23.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches. A shaded icon indicates applications and tasks are sensitive to daylight and appropriate measures, including blackout capabilities, must be taken to limit daylight exposure, if daylight is deemed a suitable source of light.

g. Tasks with specular components, like object under glass or CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. Control architectural lighting with dimmers to accommodate varied needs.

j. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

k. Use lamps with CCTs of 5000 K and CRIs ≥85.

l. Illuminance targets cited are for target area so noted and achieved with a minimum of 3-level control, if not dimming control, of architectural lighting.

m. Use lamps with CRIs ≥85.

n. Equip physical analyses laboratories with adjustable portable luminaires for analysis efforts.

o. Make electrical provisions for portable work lights.

p. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 23.2 | Courts and Correctional Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
CORRECTIONAL FACILITIES	(continued)										
• Laundry											
• Cart Washer Area	E_h @3' AFF; E_v @3' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Central Liquid Supply	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Clean Linen Flow Rack and Assembly Area	E_h @3' AFF; E_v @3' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Clean Linen Processing	E_h @3' AFF; E_v @3' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Distribution Area (Cart Storage, Dispatch and Dock)	E_h @floor; E_v @4' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
• Linen Collection	E_h @floor; E_v @4' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
• Linen Pack Preparation	E_h @3' AFF; E_v @3' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Linen Repair	E_h and E_v @2' 6" AFF	T	500	1000	2000	Avg	P	150	300	600	Avg
• Linen Storage	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Production and Support	E_h @3' AFF; E_v @3' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Receiving	E_h @3' AFF; E_v @3' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Sorting and Washing	E_h @3' AFF; E_v @3' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Uniform Exchange (Automated)	E_h @3' AFF; E_v @3' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Library	E_h @floor; E_v @5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Loading Dock	See SUPPORT SPACES/Receiving/Shipping										
• Lobby	See TRANSITION SPACES/Lobbies and Waiting Rooms										
• Mail Facility	See SUPPORT SPACES/Mail Facility										
• Medical Care	Examination and treatment. Also see 27 | LIGHTING FOR HEALTH CARE.										
• Charting Station	E_h @3' 6" AFF; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Exam Table[l, m]	E_h @3' AFF; E_v @4' AFF	T	500	1000	2000	Avg	P	150	300	600	Avg
• General[m]	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg
• Prison Cells	See CORRECTIONAL FACILITIES/Cells										
• Power House	See 30 | LIGHTING FOR MANUFACTURING										
• Receiving/Shipping	See SUPPORT SPACES/Receiving/Shipping										
• Recreation											
• Indoor	See CORRECTIONAL FACILITIES/Activity Room										
• Outdoor Exercise Area	E_h @3' 6" AFF; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Security											
• Exteriors	See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY										
• Screening											
• Detainees and Inmates	E_h @3' AFF; E_v @5' AFF	Q	200	400	800	Avg	O	100	200	400	Avg
• Public											
• Station	See CORRECTIONAL FACILITIES/Control Posts										
• Surveillance Rooms	See CORRECTIONAL FACILITIES/Control Posts										
• Vestibules (interlocked)	E_h @3' AFF; E_v @5' AFF	Q	200	400	800	Avg	O	100	200	400	Avg
• Shops (Industrial Arts)	E_h @3' AFF; E_v @4' AFF.	T	500	1000	2000	Avg	R	250	500	1000	Avg
• Showers	E_h @floor; E_v @3'-5' AFF	M	50	100	200	Avg	K	25	50	100	Avg

Table 23.2 | Courts and Correctional Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1					
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	3:1					
	3:1					
	3:1					
	3:1					
	see Table 12.6					
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	3:1					
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n. Equip physical analyses laboratories with adjustable portable luminaires for analysis efforts.

o. Make electrical provisions for portable work lights.

p. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
CORRECTIONAL FACILITIES	(continued)										
• Toilets											
• Detainees and Inmates	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Public	See TOILETS/LOCKER ROOMS										
• Staff	See TOILETS/LOCKER ROOMS										
• Vehicle Sally Port											
• Day	E_h @3' AFF; E_v @5' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
• Night	E_h @3' AFF; E_v @5' AFF	M	50	100	200	Avg	J	20	40	80	Avg
• Visiting Room	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Workshops	See Shops										
FORENSICS LABORATORIES	Criminal Analyses Laboratories										
• Armory											
• General	E_h @floor; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Inspection Table	E_h @floor; E_v @5' AFF on racks	T	500	1000	2000	Avg	P	150	300	600	Avg
• Racks	E_h @3' AFF; E_v @5' AFF on racks	R	250	500	1000	Avg	O	100	200	400	Avg
• Firing Range	**INDOOR** E_h @shooting line 3' AFG; E_v @area of target	P	150	300	600	Avg	T	500	1000	2000	Avg
• Laboratories											
• Benches											
• Electronic Analyses	E_h @2' 6" AFF; E_v @3' 6" AFF; Viewing of CSA/ISO Type I and II positive polarity monitors and some paperwork.	P	150	300	600	Avg	M	50	100	200	Avg
• Physical Analyses[n]	E_h @3' AFF; E_v @4' AFF	T	500	1000	2000	Avg	P	150	300	600	Avg
• General	E_h @3' AFF; E_v @4' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Vehicle Analyses	Garages with lifts or pits for extensive interior and exterior vehicle inspection.										
• General	E_h @floor; E_v @5' AFF	R	250	500	1000	Avg	P	150	300	600	Avg
• Provisional	Provide for portable worklights as needed										
• Task at bench and hood	E_h and E_v @3' 6" AFF	T	500	1000	2000	Avg	R	250	500	1000	Avg
IT	See 22 | LIGHTING FOR COMMON APPLICATIONS										
JUDICIAL FACILITIES											
• Attorneys' Workroom											
• General	Eh @floor; Ev @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Table	Eh @2' 6"; Ev @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Attorney/Witness Room	Eh @2' 6"; Ev @4' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Cell	See CORRECTIONAL FACILITIES/Cells										
• Circulation Corridors	See TRANSITION SPACES/Circulation Corridors										

Table 23.2 | Courts and Correctional Facilities Illuminance Recommendations continued next page

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1		☀			■
	3:1		☀			■
	3:1					■
	3:1		☀	◪		■
	3:1		☀			■
	3:1		☀		■	
	3:1		☀		■	
		2:1	☀		■	
see Table 12.6			☀	◪	■	
	2:1		☀		■	
	4:1		☀			■
1.5:1	1.5:1		☀			■
1.5:1	1.5:1		☀		■	
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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
JUDICIAL FACILITIES	(continued)										
• Courtroom[m]											
• Art/Portraits	See ACCENTING										
• Attorneys' Tables	Eh @2' 6"; Ev @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• AV Presentation	Notetaking is intended										
• General	E_h @2' AFF; E_v @4' AFF	L	37.5	75	150	Avg	I	15	30	60	Avg
• Screen	Cited values are for screen or display monitor plane(s) when screen or display monitor(s) is in use										
◦ Front Projection	Over surface of screen							50	50	50	Max
◦ Video Displays or Monitors	Over front surface of display							200	200	200	Max
• Bailiff Station	Eh @2' 6"; Ev @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Bench and Clerks	Eh @2' 6"; Ev @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Evidence Table	Eh @2' 6"; Ev @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Jury Box	Eh @2' 6"; Ev @4' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Lectern or Podium	Eh @2' 6"; Ev @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Public Seating	Eh @2' 6"; Ev @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Witness Stand	Eh @2' 6"; Ev @4' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Document Handling	See TRANSITION SPACES/Elevators										
• Filing/Storage	E_h @2' 6" AFF; E_v at front face of filing cabinet over area from 1' AFF to top of filing cabinet or filing system.										
• Constant		P	150	300	600	Avg	O	100	200	400	Avg
• Intermittent		N	75	150	300	Avg	M	50	100	200	Avg
• Seldom		M	50	100	200	Avg	L	37.5	75	150	Avg
• Workroom	Eh @2' 6"; Ev @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Elevators	See TRANSITION SPACES/Elevators										
• Escalators/Moving Walkways	See TRANSITION SPACES/Escalators/Moving Walkways										
• Grand Jury Suite[m]											
• Hearing Room											
• AV Presentation	See JUDICIAL FACILITIES/Courtroom/AV Presentation										
• Exhibit Displays	Interactive use as part of hearings						P	150	300	600	Avg
• General	E_h @2' 6"; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Sound Lock	See JUDICIAL FACILITIES/Sound Lock Entrance										
• Toilets	See TOILETS/LOCKER ROOMS										
• Judges' Chambers Suite											
• Judge's Private Office	Desk illuminances accommodate intensive paperwork and CSA/ISO Types I and II positive polarity computer screens. Alternatively, See READING AND WRITING, establish tasks and normalize to illuminance of most important task or most common task; use controls to provide illuminance variability if tasks so demand										
• Art/Portraits	See ACCENTING										
• Bookshelves	See ACCENTING										
• General	E_h @floor; E_v @5' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• Desk	E_h @2' 6"; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg
• Judicial Assistant and Law Clerks	Desk illuminances accommodate intensive paperwork and CSA/ISO Types I and II positive polarity computer screens. Alternatively, See READING AND WRITING, establish tasks and normalize to illuminance of most important task or most common task; use controls to provide illuminance variability if tasks so demand										
• General	E_h @floor; E_v @5' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• Desk	E_h @2' 6"; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg

Table 23.2 | Courts and Correctional Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1		■		■	
	2:1					■
2:1					■	
2:1				■	■	
	2:1		■		■	
	2:1		■		■	
	2:1		■		■	
	2:1		■		■	
	2:1		■		■	
	2:1		■		■	
	2:1		■		■	
	see Table 12.6		■		■	
	3:1		■		■	
	3:1		■		■	
	3:1		■			■
	3:1		■	■	■	■
	3:1		■			■
	3:1		■			■
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	3:1		■			■
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b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 23.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches. A shaded icon indicates applications and tasks are sensitive to daylight and appropriate measures, including blackout capabilities, must be taken to limit daylight exposure, if daylight is deemed a suitable source of light.

g. Tasks with specular components, like object under glass or CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. Control architectural lighting with dimmers to accommodate varied needs.

j. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

k. Use lamps with CCTs of 5000 K and CRIs ≥85.

l. Illuminance targets cited are for target area so noted and achieved with a minimum of 3-level control, if not dimming control, of architectural lighting.

m. Use lamps with CRIs ≥85.

n. Equip physical analyses laboratories with adjustable portable luminaires for analysis efforts.

o. Make electrical provisions for portable work lights.

p. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 23.2 | Courts and Correctional Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
JUDICIAL FACILITIES	(continued)										
• Jury Pool Suite											
• Lounge and Assembly	Eh @2' 6"; Ev @4' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• Registration	Eh @2' 6"; Ev @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Toilets	See TOILETS/LOCKER ROOMS										
• Vending	E_h and E_v @3' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Law Library	See 29 | LIGHTING FOR LIBRARIES										
• Lobbies and Waiting Rooms	See TRANSITION SPACES/Lobbies and Waiting Rooms										
• Mail Facility	See SUPPORT SPACES/Mail Facility										
• News Media Room	Eh @2' 6"; Ev @4' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Offices	See 32 | LIGHTING FOR OFFICES										
• Receiving/Shipping	See SUPPORT SPACES/Receiving/Shipping										
• Sound Lock Entrance	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Toilets	See TOILETS/LOCKER ROOMS										
• Trial Jury Suite[m]											
• Jury Room											
• AV Presentation	See JUDICIAL FACILITIES/Courtroom/AV Presentation										
• General	E_h @2' 6"; E_v @4' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Perimeter Display Walls	Interactive use as part of deliberations						P	150	300	600	Avg
• Sound Lock	See JUDICIAL FACILITIES/Sound Lock Entrance										
• Toilets	See TOILETS/LOCKER ROOMS										
• Perimeter Display Walls	Interactive use as part of deliberations						P	150	300	600	Avg
• Vehicle Sally Port	See CORRECTIONAL FACILITIES/Vehicle Sally Port										
PARKING	See 26 | LIGHTING FOR EXTERIORS										
PEDESTRIAN WAYS	See 26 | LIGHTING FOR EXTERIORS										
SUPPORT SPACES											
• Barber Shop	See 28 | LIGHTING FOR HOSPITALITY/SPAS/Salon										
• Beauty Shop	See 28 | LIGHTING FOR HOSPITALITY/SPAS/Salon										
• Break Rooms/ Lunch Rooms	E_h @2' 6" AFF; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Coat Check or Coat Rooms	E_h @3' 0"; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Copy/Print Rooms											
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Machines	E_h and E_v @3' 6" AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Interstitial Space[o]	E_h @floor; E_v @4' AFF	I	15	30	60	Avg	G	7.5	15	30	Avg
• Janitor's Closet	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Mail Facility											
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	J	20	40	80	Avg
• Security Inspection	E_h and E_v @3' 6" AFF	T	500	1000	2000	Avg	P	150	300	600	Avg
• Sorting	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	L	37.5	75	150	Avg

Table 23.2 | Courts and Correctional Facilities Illuminance Recommendations continued next page

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1		☀			
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	3:1		☀			
	4:1		☀			
	3:1		☀			
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	3:1		☀			
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d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches. A shaded icon ☀ indicates applications and tasks are sensitive to daylight and appropriate measures, including blackout capabilities, must be taken to limit daylight exposure, if daylight is deemed a suitable source of light.

g. Tasks with specular components, like object under glass or CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◪ signals high likelihood; gray and white ◪ signals moderate likelihood; pale gray and white ◪ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. Control architectural lighting with dimmers to accommodate varied needs.

j. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

k. Use lamps with CCTs of 5000 K and CRIs ≥85.

l. Illuminance targets cited are for target area so noted and achieved with a minimum of 3-level control, if not dimming control, of architectural lighting.

m. Use lamps with CRIs ≥85.

n. Equip physical analyses laboratories with adjustable portable luminaires for analysis efforts.

o. Make electrical provisions for portable work lights.

p. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 23.2 | Courts and Correctional Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
SUPPORT SPACES	(continued)										
• Receiving/Shipping											
• Dock	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Receiving/Staging	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Storage	E_h @floor; E_v @4' AFF										
• Equipment		O	100	200	400	Avg	K	25	50	100	Avg
• Bulky items		K	25	50	100	Avg	H	10	20	40	Avg
• Medium items		M	50	100	200	Avg	I	15	30	60	Avg
• Small items		O	100	200	400	Avg	K	25	50	100	Avg
TOILETS/LOCKER ROOMS											
• Fixtures	E_h @top of plumbing fixture; E_v @3'-5' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• General	E_h @floor; E_v @3'-5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Lockers	E_h @floor; E_v @locker faces	K	25	50	100	Avg	K	25	50	100	Avg
• Showers	E_h @floor; E_v @3'-5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Vanities	E_h @3' AFF; E_v @3'-5' AFF	N	75	150	300	Avg	O	100	200	400	Avg
TRANSITION SPACES											
• Circulation Corridors	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• Public	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Secure	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Staff	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Elevators											
• Freight											
• Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Threshold											
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Public											
• Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Threshold											
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Secure											
• Cab interior	E_h @floor; E_v @3' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Threshold											
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg

Table 23.2 | Courts and Correctional Facilities Illuminance Recommendations continued next page

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1		■			■
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	3:1		■			■
	3:1		■			■
	3:1		■			■
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	2:1		■		■	
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g. Tasks with specular components, like object under glass or CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ■ signals high likelihood; gray and white ■ signals moderate likelihood; pale gray and white ■ signals some likelihood; and all-white signals little-to-no likelihood.

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j. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

k. Use lamps with CCTs of 5000 K and CRIs ≥85.

l. Illuminance targets cited are for target area so noted and achieved with a minimum of 3-level control, if not dimming control, of architectural lighting.

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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
TRANSITION SPACES	(continued)										
• Entries	See 22 | LIGHTING FOR COMMON APPLICATIONS										
• Escalators/Moving Walkways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Lobbies and Waiting Rooms											
• Circulation, Elevator Lobbies	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• General											
• At building entries	Close proximity to exterior. Lighting should be designed to assist with adaptation when passing to/from exterior.										
◦ Day	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
◦ Night	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Distant from entries	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Security Screening											
• Private Rooms	E_h @3' AFF; E_v @5' AFF	Q	200	400	800	Avg	O	100	200	400	Avg
• Public Lobbies	E_h @3' AFF; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Reading/Waiting Areas	E_h and E_v @2' 6" at sitting areas	P	150	300	600	Avg	N	75	150	300	Avg
• Reception	Such as visitor registration or informational/directional assistance.										
• Desk	Age determination may be as or more relevant with respect to visitors than staff.										
• Desk top	E_h @3' 6" AFF; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Focal wall behind desk	On wall plane							see Table 15.2			
• Stairs	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• High Activity[p]	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Live Surveillance	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Typical	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg

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	4:1		☀			■
	4:1					■
	4:1		☀			■
	2:1		☀		■	
	2:1		☀		■	
	4:1		☀		■	
see Table 12.6			☀		■	
			☀		■	
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p. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 23.3 | SI Dimensional Conversions

US Customary	SI
General	**Hard Conversion**
inches	mm [inches × 25.40]
feet	m [feet × 0.30]
Specific	**Convenient Conversions[a]**
2'	610 mm or 0.6 m
2' 6"	760 mm or 0.75 m
3'	915 mm or 0.9 m
3' 6"	1065 mm or 1.1 m
4'	1220 mm or 1.2 m
5'	1525 mm or 1.5 m

a. Hard conversions rounded for reporting convenience. Not to be confused with metric-sized luminaires or other building materials. Not for precision construction.

23.2.3 Atria and Courtyards

Lighting for atria and courtyards is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

23.2.4 Building Entries

Lighting for building entries is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

23.2.5 Circulation

Given varying security requirements, lighting for circulation is addressed in respective application areas of courts and correctional facilities.

23.2.6 Classrooms

Training and education are important components of the judicial and correctional fields. Lighting for classrooms is discussed in 24 | LIGHTING FOR EDUCATION.

23.2.7 Conferencing

Various forms of conferencing are used in courts and correctional facilities. Lighting for conferencing is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

23.2.8 Correctional Facilities

Incarceration is detention generally intended as punishment or deterrent. As such the criteria citations for some of the applications and tasks associated with correctional facilities identify illuminance criteria that are sensible and expedient, but not necessarily most appropriate. For example, a commissary is a retail application cited in Table 23.2. The designer could consider a more refined approach to retail lighting espoused in 34 | LIGHTING FOR RETAIL which may suit a specific type of commissary in a specific type of correctional facility for a specific owner. Yet, the commissary clientele or the authority funding a project for punishment or deterrence may not appreciate the lighting approach and techniques this degree of attention yields. The vendor running the commissary, however, may welcome some degree of retail lighting to assist sales in such a controlled market. Hence very straightforward criteria espousing a basic retail strategy are cited in Table 23.2 for the commissary. On applications or tasks where other and better detailed lighting criteria exist, such as chapels (Table 37.2), food service (Table 22.2), libraries (Table 29.2), and medical and dental (Table 27.2), the designer might review and propose criteria from the other application chapters, but recognizing the restrictive requirements of the project at hand.

Lighting effects and hardware styling and sizes in correctional facilities can contribute to a sense of calm and order. Daylighting is considered a significant benefit to those with little opportunity for outdoor activity. Electric lighting equipment must withstand the potential for intentional primary abuse or collateral damage. Review of the design program and consultation with the design team and client should provide insight to the degree and likelihood of such abuse and damage. Daylighting must be designed to prevent abuse of the daylight media and prevent methods of escape or impermissible communication with the outside community. Design techniques and hardware selections and detailing must be addressed accordingly by the lighting designer and team. Some key applications and tasks are discussed below.

Careful deliberation on lighting controls is necessary. Where these are located, what they control, who has access, which controls can be overridden, interaction with emergency and lock-down systems are among the variables to consider.

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23.2.8.1 Cells

General lighting should be commensurate with time of day and might be achieved with all daylight or some combination of daylight and electric light during daylight hours. Task lighting should be provided at one or several key task areas. Depending on the nature of the facility and degree of security, this might include the desk, head-of-bed, or grooming area. Figure 23.2 illustrates a technique. Luminaire construction needs to be rugged to withstand tampering and physical abuse. Lamps insensitive to sudden shock are appropriate. Special luminaire mountings often must be used to accommodate recessed lighting in security plaster ceilings or in concrete, or surface mounting to concrete. Generally, smaller apertures are preferable with heavy gauge back boxes or housings where these are not embedded in concrete. Equipment should be securely lensed. Concealed security screws in luminaire construction can preclude the hiding of contraband by inmates or disassembling components for use as weapons or in the construction of incendiary devices.

Lighting control varies for different security levels and may be based on specific client requirements. Lighting for medium- and maximum-security cells is typically controlled from the security control posts or a secure operations center. Minimum-security cell lighting may be controlled locally with a central override. Automated time clocks or photocells can be used to adjust day-to-night lighting, though automated systems must be highly secure electronically and electrically. Design programming for some facilities may require specific lock down switching schemes.



Figure 23.2 | Cell Lighting
A wall mounted luminaire exhibits an uplight and a downlight component. Versions are available where each distribution is separately lamped and switched to provide low-level ambient (uplight only), moderate ambient (uplight and downlight) or only task lighting (downlight only).
» Image ©Lizzie Himmel/Sygma/Corbis

23.2.8.2 Circulation Corridors

Corridors in correctional facilities consist of public (non secure), detention (secure), and staff areas. Corridors in detention areas are used for inmate traffic (both escorted and unescorted) and, depending on the facility, may serve as temporary holding. Corridor lighting must be adequate for both direct-view and video-view observations. Consultation with the design program and team and client is appropriate to establish the use of secure corridors and the desired degrees of direct- or video-viewing to and from these corridors. This must be coordinated with the control posts and their intended arrangement: as direct-view observation posts or as video-view observation posts. For direct-view observation posts, lighting within the post must be well-coordinated with that of the areas being viewed. Security glass and its finish, tint, and planar tilt, if any, influence the success of viewing conditions where the goal is to optimize outward view by security personnel and restrict inward view by detainees.

23.2.8.3 Control Posts

The lighting of control posts depends on the function of the posts and the required degree of security. Where security officers undertake anonymous direct-view observation in an enclosed room, lighting within the post must be very well controlled at the discretion of the officers to adjust for any change in lighting conditions of the areas being viewed and to limit direct-view into the control post by inmates. Low LRVs are best in this situation. Optically-controlled lighting positioned close the to surfaces intentionally deserving of light, such as floor or work surface, is best. This avoids the potential for floodlighting or spotlighting of security officers' heads and movements. If control panels are not electronic and require front lighting, optically-controlled and dimmable equipment should be used for the front lighting. Lighting of the area being observed must be addressed accordingly.

23.2.8.4 Vehicle Sally Ports

The secure movement of detainees or prisoners, protected witnesses, or even dignitaries requiring security protection is facilitated by a sally port where secure vehicles have access to secure entries to courts or correctional facilities. Sally ports are usually fully enclosed porte cocheres or garages. Lighting serves both an adaptation function as vehicles move from exterior to interior and vice versa and as a security function. Although daylighting can be used to limit energy use, its application must be made with great care. Daylight

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media must itself be secure of breach by people or gunfire and must prevent direct-view situations from any vantage point outside the sally port to limit identification and tracking of those inside.

23.2.9 Forensics Laboratories

Crime laboratories range from relatively basic setups to all-inclusive facilities, depending on the resources of the agency and the breadth and depth of crimes needing analysis. Labs fitted with electronic analyzers involving computer displays and digital readouts should be lighted to accommodate the dissection of physical samples, mixing of solutions, and insertion of materials of reading of the displays. Where more physical analysis is required, lighting must address the visual aspects of inspection, including that undertaken with microscopes. Some laboratory setups consist of both the electronic analyses and physical inspection side-by-side. All-inclusive facilities may have labs segregated based on the analyses. Controls for variability to accommodate a very wide range of visual tasks and portable task lighting for inspection are important. See Figures 23.3 and 23.4.

23.2.10 IT

Lighting for IT facilities is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

23.2.11 Judicial Facilities

Although judicial facilities encompass many applications, the most important and unique are the courtrooms, of which there may be several in one facility. Justice is a foundation of democracy. Lighting should serve to enhance the dignity of these facilities and support fair and speedy trials. Accenting is a functional and aesthetic necessity. Color rendering of electric light sources should be ≥85 CRI for purposes of rendering skin tones and clothing colors fully for purposes of inspection and identification of witnesses, defendants, and evidence, and self-confidence.

Courtrooms consist of two basic components: the audience and the area of proceedings. The area of proceedings includes the judge's bench, attorneys' tables, a lectern or podium, witness stand, court clerk, court recorder, and jury box. An evidence table may also be necessary, as may display easels and audiovisual equipment. Visual tasks are quite varied. Cameras may be involved for recording and security purposes. Lighting needs can be varied, but readily addressed with well-planned lighting layouts and control zones, dimmable sources, and controls. Controls must be simple for expedient application. Where these are located, what they control, who has access, which controls can be overridden, and interaction with emergency and lock-down systems are among the variables to consider. With the exception of AV requirements, vertical illuminances are relatively high, but readily achieved with diffuse lighting techniques. See Figure 23.1. For AV situations using front-projection systems, the position of the screen must be established and lighting controlled to limit illuminance over the surface of the screen. Illuminance criterion cited is maximum on the screen and can certainly be lower than this value. Uniformity over the screen is important to minimize distracting striations. Where video display monitors are used, these are generally much less forgiving than front-projection systems. However, some of these have highly specular screens and the position and tilt of the screen relative to energized lights must be considered.

Daylighting works well in courtrooms where very little, if any, AV is anticipated, such as might be expected in bankruptcy court. In other courts, daylighting must be designed to accommodate AV situations and this might involve automated shades adjusting to AV scene settings. Regardless, the security aspects of daylight media must be addressed. The design team must coordinate with the security consultant to establish appropriate daylight media, sizes, and orientations for the project's given locale.

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Figure 23.3 | Forensics Laboratory
Ambient lighting from linear indirect pendant luminaires accommodates electronic analyses. In multi-lamp pendants, switching can achieve a range of illuminances. Where physical analyses occur, portable task lights are used for inspection.
» Image ©Christopher Lark

23.2.12 Parking

Lighting for parking facilities is discussed in 26 | LIGHTING FOR EXTERIORS. In secure parking situations, lighting must accommodate camera and surveillance requirements.

23.2.13 Pedestrian Ways

Lighting for pedestrian ways is discussed in 26 | LIGHTING FOR EXTERIORS. In secure pedestrian-way situations, lighting must accommodate camera and surveillance requirements.

23.2.14 Support Spaces

Lighting for support spaces is briefly addressed in 22 | LIGHTING FOR COMMON APPLICATIONS. Barber and beauty shops are cited here since these amenities are likely a part of correctional facilities. Illuminance criteria are outlined in Chapter 28.

Coat rooms and copy centers are considered support spaces, though these may be decentralized. For example, a judge's chamber might need both a coat room and a copy center to address the volume of use and security requirements afforded by in-suite facilities.

Mail rooms may be relatively small, but there is likely need for an area and lighting to address sorting and to address security inspection. If inspection is an inherent part of sorting, then the security inspection criteria should be applied at all mail room work areas.

23.2.15 Toilets/Locker Rooms

Restrooms are best addressed by highlighting specific task areas. This offers energy efficiency while meeting the different illuminance criteria involved. Highlighting toilets, urinals, and vanities offers a more clean, crisp appearance than the haze of general diffuse lighting. Vanity positions require vertical illuminance on an imaginary facial plane (roughly a zone of sufficient size to encompass faces at standing or seated height) in front

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Figure 23.4 | Forensics Laboratory
Vehicle inspections require relatively high ambient illuminances with portable task lighting as needed. Here, direct/indirect linear pendants were determined most efficient in meeting illuminance criteria. Portable fluorescent studio lights are used for their intensity, efficiency, and minimal heat.
» Image ©Christopher Lark

of the mirror. Figure 22.7 identifies several methods of vanity lighting for non secure toilet facilities. Color of light is important for grooming. Lamps exhibiting 2700 K to 3500 K CCT and CRI ≥82, using triphosphor CFLs as benchmark, are appropriate.

23.2.16 Transition Spaces

How front-of-house transition spaces in many applications are designed and lighted defines the place and welcomes employees and guests. These spaces are transitions from exterior to interior and vice versa or from one kind of interior space to another. Illuminance criteria and accents are an important aspect of making comfortable and safe transitions.

Many of the public spaces in judicial facilities may be of a particular sequence of passage, ceremonial in nature, or of special importance. To appropriately serve these roles, subjective impressions outlined in Table 12.2 should guide the application of lighting effects. Illuminances associated with artwork and features that assist with these subjective impressions are outlined in Table 23.2.

Security screening areas in public spaces such as lobbies require some additional horizontal and vertical illuminance relative to the background lighting necessary for the normal space function. See Figure 25.1. Where special security procedures demand private screening, horizontal and vertical illuminance criteria should accommodate the situation. Illuminances and lighting hardware locations and light distributions must be coordinated with security cameras. Controls for these rooms may be purposely centralized or limited to motion sensors. The designer must coordinate requirements with the security consultant.

For purposes of visual consistency and of maintenance convenience, lamp types and color qualities should match those used elsewhere.

23.3 Illuminance Criteria

Illuminance criteria, when fully deployed, are a robust set of quantitative values that influence visibility, visual performance, and visual comfort and attention. Short-circuiting the criteria selection or designing to a single criterion value, such as horizontal illuminance, to address worst-case tasks will surely result in dissatisfaction. Even if clients accept the visual results, not getting the most from the energy expended or, worse, energy waste is a likely result. Following are notes related to various topics outlined in Table 23.2.

23.3.1 Applications and Tasks

Applications and tasks encountered on any given project may be different from those identified in Table 23.2 and may warrant different illuminance criteria. Cross-referencing closely-associated applications or tasks is appropriate. Sometimes naming trends or conventions for space types or functions change to conform to current practice, client programming, or architectural conventions, but the actual activities and tasks remain the same and this cross-referencing works. Failing this technique, reviewing the list in Table 36.2 may be in order to determine if any applications or tasks exhibit a similar visual-component to the unique applications or tasks. Otherwise, reviewing 4.12 An Illuminance Determination System and Table 4.1 is necessary to establish a task category based on the task characteristics or visual performance descriptions most closely associated with the unique applications or tasks. These exercises as well as any deviations from recommendations the designer intends to make should be carefully documented for the record.

23.3.2 Notes

The notes in Table 23.2 may refer to other task headings in the table or to other handbook chapters as appropriate. Where some degree of clarification is warranted, notes are made.

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23.3.3 Recommended Maintained Illuminance Targets

Values cited are maintained on the area of coverage for the task under consideration. Illuminance is additive. Where practical and without negatively affecting the intended application of light, target values are achieved with any combination of daylighting and/or electric lighting in whatever mix of ambient, task, and accent lighting is deemed appropriate to meet these and the other lighting goals established during design. See 12 | COMPONENTS OF LIGHTING DESIGN and see 10.7.1 Light Loss Factors.

With respect to light loss factors, account for anticipated losses through the point in time at which group relamping and cleaning should occur. Group relamping and cleaning should be standard practice, though these need not occur at the same frequency. Periodic cleaning and group relamping essentially maintain the illuminance at criteria and make the most efficient use of the installed equipment. For purposes of sustainability, cleaning and group relamping can no longer be presumed to be infrequent or unlikely. Maintenance procedures must be part of the design discussions with the client. See the IES document IESNA/NALMCO RP-36 Recommended Practice for Planned Indoor Lighting Maintenance for additional information. Where maintenance is deferred or practiced poorly or not at all, the actual illuminance values will fall below criteria targets. This is inefficient, unsustainable, and may be unsafe while adversely affecting users' quality of life or work. Ratcheting initial illuminances higher is poor practice and not recommended. Maintenance procedures may be especially problematic with LEDs where promises of extraordinarily long life may be offered, but usually with the caveat that lamp lumen depreciation (LLD) at that rated life is 70% or perhaps even as low as 50% of initial rating. If replacement cycles are presumed to be rated life, then LLD alone must be 0.7 or 0.5 or whatever lumen rating is certified by the LED vendor. See 13.3 Life and Lumen Maintenance.

Targets cited are consensus and recommended for respective functional activity. For some applications, IES recommendations are within 10% of code requirements. This apparently is an artifact of metrication. Footcandle conversions of any values cited in Table 23.2 should be made at 1 fc to 10 lx. This soft conversion avoids a redundant diminishing of illuminance values after multiple citations and conversions over time. This also eliminates a false sense of accuracy advanced by an ever-increasing number of decimal places and a false sense of urgency advanced by eccentric fractional values introduced by hard conversions. Nevertheless, a lighting design must meet code and the mechanics of which must be coordinated amongst the design team. The IES recommendations should not, do not, and cannot reflect all of the various code requirements in force in all jurisdictions at any given time.

Targets are intended to apply to the dominant plane of the task, typically, but not always, horizontal or vertical. In some situations, illuminance criteria are cited for one plane, such as the vertical plane for perimeter display walls in a trial jury suite, while the other plane is blank. The blank signifies that illuminance on that plane is unimportant and may be a consequence of the illuminance of other tasks within the vicinity or by whatever illuminance results from meeting the target illuminance for the prescribed plane of interest.

In some situations, no light is anticipated on at least one plane of a task, such as the vertical plane at 5' AFF for CORRECTIONAL FACILITIES/Control Posts/Direct-view Observation. A 0 indicates no light or zero light is recommended for the task or application.

23.3.3.1 Target Planes

Many, though certainly not all, tasks are performed with the task in roughly a horizontal orientation or vertical orientation. A dominant orientation must be assigned and the illuminance target determined accordingly. There may be situations where the IES recommended target relating to the typical planar mode of a task must be applied to a different plane.

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Nearly all tasks are expected to have both a horizontal illuminance component (E_h) and a vertical illuminance component (E_v). This allows some degree of task flexibility for off-plane viewing and accommodates various aspects of the task.

Where illuminance targets are intended at differing planar elevations, this is indicated under "Notes." Note the implication for observers' visual ages. Establishing and tracking task orientations and addressing both horizontal and vertical illuminance is necessary. If orientations in the project under consideration are programmed to be flipped from what might be considered normal-viewing, then criteria must be adjusted accordingly. If a task is scheduled to be oriented on some plane off axis from horizontal or vertical by more than 10°, say, then the illuminance criteria must be applied to that off-axis orientation. This is an important distinction for luminaire optical selection and aiming capabilities and for layout, calculations, and field measurements.

For planes related to vertical illuminance targets, some guidance is indicated under "Notes." However, the designer may elect to use alternate or multiple vertical planes. In some situations the vertical planes could be oriented in a number of directions and the designer must determine which are most appropriate for the situation.

23.3.3.2 Visual Ages of Observers

Illuminance criteria are based on the visual ages of more than half the intended observers. This aspect should be resolved during programming with the client. It may be determined that illuminance criteria for an age group other than that representing the majority of the intended observers is appropriate. However, this may result in overlighting, underlighting, harsh lighting, visual displeasure, or visual discomfort for many of the observers. See 12.5.5 Illuminance and 4.12 An Illuminance Determination System for additional information and guidance. In some situations, such as front projection AV presentations, lighting must meet the requirements of the screen technology to maximize visibility for all age groups and, therefore, is not tied to ages of observers.

23.3.3.3 Illuminance Categories

Illuminance categories are designated by letters A through Y. These are shown in Table 23.2 for more convenient reference to Table 4.1 | Recommended Illuminance Targets should the designer wish to explore other criteria targets or if applications or tasks on a specific project are not readily correlated to the table citations.

23.3.3.4 Gauge

The common gauge for determining illuminance target compliance is cited for each application. All gauges presume that point-by-point techniques are used for predictive calculations and presume that uniformity criteria are closely monitored. Where an average illuminance value over the area of coverage can satisfy target compliance, "Avg" is cited. In applications or tasks where a minimum or maximum target is necessary, the gauge for compliance is "Min" or "Max" respectively.

The designer may elect to use other methods to evaluate target compliance, such as criterion rating (CR) or coefficient of variation (C_v). See 4.12.4.5 Tasks at Uncertain Locations Over a Large Area.

In any event, once illuminance targets and uniformities are established, then any calculated deviation from them should be limited. Standard engineering allowance of ±10% might be acceptable for targets gauged as average unless contractual or code obligations demand otherwise. Minima and maxima must be achieved as intended.

Designs should be adjusted until predictions are within allowance for averages and meet minima and maxima. For additional information, see see 4.12.4.1 Recommended Illuminances at Design Time, 4.12.5 Illuminance Ratios, 9.15.1.1 Average Illuminance, and 10.8 Assessing Computed Results.

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23.3.4 Uniformity Targets

Illuminance uniformity targets work in conjunction with luminance uniformities and surface reflectances all of which must be addressed as part of the design to avoid visual discomfort, glare, and strain. Uniformity ratios are targets that define the widest recommended ranges. In many situations, uniformity ratio criteria are those between average values of an array of points and the minimum value in the same array of points. Uniformity targets apply to both horizontal and vertical illuminances over the area of coverage. Where horizontal uniformity criterion is different from vertical uniformity criterion, two ratios are reported with the first value for horizontal illuminance (E_h).

Generally the more important speed and accuracy and the more demanding the visual task, the tighter the ratio.

23.3.4.1 Maximum-to-average

This is the recommended ratio of maximum illuminance to the average illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations sensitive to even a relatively small degree of overlighting.

23.3.4.2 Average-to-minimum

This is the recommended ratio of average illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where illuminance too far below average conditions is noticeable and detrimental to task performance or inconsistent with normal expectations.

23.3.4.3 Maximum-to-minimum

This is the recommended ratio of maximum illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where too much variation in illuminance is considered undesirable and untenable from a performance or safety perspective.

23.3.5 Daylighting Advancement

Generally, design strategies should embrace any combination of daylighting and electric lighting to achieve target values during daylight hours. The preference is for daylighting to provide all or most of the recommended illuminance presuming that all aspects of daylighting are properly addressed. A sunburst icon depicts those applications and tasks where daylighting is considered a strategic candidate. Use photocells and stepped-dimming or continuous dimming to reduce or eliminate electric lighting during daylight hours. However, this may not be practical in courtrooms unless continuous dimming is used on slow response rates. See 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Even for those applications where daylighting is not traditionally a strategic candidate, it may be determined that very careful and coordinated design will offer great sustainability opportunities.

23.3.6 Veiling Reflections

Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper or, worse, both, are prone to veiling reflections. The likelihood of particular applications and tasks predisposed to veiling reflections is indicated by a "reflected light" icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood. Veiling reflections are minimized by controlling the overall amount and direction of light with respect to the task locations and orientations. Alternatively, tasks sensitive to veiling reflections can be screened or isolated. Effective strategies include employing indirect soft, diffuse electric lighting or direct electric lighting with multiple low-output luminaires, or positioning tasks and luminaires and luminance patterns to avoid harsh reflections from tasks. Addressing luminance

IESH/10e CSA/ISO

> 12.5 Task Factors
- for information on CSA/ISO computer screen qualities

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recommendations (see Table 12.4 | Default Luminance and Luminaire Intensity Recommendations for VDT Applications) minimizes veiling reflections. Changing the task will reduce or eliminate veiling reflections, such as use of CSA/ISO Type I or II computer screens and matte paper versus their specular counterparts.

23.3.7 Defining Areas of Coverage

In addition to establishing planes of task orientation, the areas of coverage to which targets apply must be determined. Typical areas of task illuminance coverage are identified here, but these may not be appropriate to specific project situations. One area of coverage is "task proper or task area." Here, the illuminance criteria are applied to the task itself or to a relatively small area to which the task is confined. See 12.5.5.1 Applications and Tasks and Figure 12.22 | Task Coverage Example. In some situations, such as accenting, the "task" area may consist of the entire wall when "feature wall" or "perimeter" accenting is desired. It is important to remember that illuminance is additive, that is, task illuminance can be achieved with some combination of ambient lighting, task lighting, and/or accent lighting, providing that the total illuminance on the task proper or task area meets the illuminance criteria outlined in Table 23.2.

Another area of coverage is "room or designated area." In this situation, illuminance criteria are applied to the room or an area of fairly substantive size representing the zone in which the applications and tasks are expected to occur. The designated area is typically established by the furniture layout, for example, or might be established by the design team or client. The area-of-coverage citations in Table 23.2 are based on traditional notions. So, for example, it may be determined that a "task proper or task area" coverage would result in some amount of LPD reduction when compared to "room or designated area" coverage. If the task can be confined to one area rather then multiple areas, if the room or area in which the task is located is itself relatively small, such as a single-occupant office, and if the other design goals and criteria outlined in 12 | COMPONENTS OF LIGHTING DESIGN are addressed, then this strategy of redefining area of coverage has merit.

An assessment and determination must be made on which area of coverage best satisfies the lighting goals on a particular project.

23.4 Designing

Information provided here is specific to courts and correctional facilities and should be used as part of the design and documentation processes outlined in Chapters 12, 15, and 20. Equipment selection and location strategies may need to address the possibility of lighting equipment abuse. For outdoor applications, lamps and ballasts, transformers, and drivers must be selected for ambient temperature conditions, some of which are extremely hot and others extremely cold. Dimming response to daylight may be impractical. See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY for additional information on respective aspects. Addressing all code requirements is a must. Energy efficient and sustainable practices are an integral part of all IES recommendations. Key design tenets include, but are not limited to:

- designing for the satisfaction of the observers of significance intended to use the project
- using baseline reflectances of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively) in interior production, holding, and work-oriented spaces
- using daylighting that meets luminance and illuminance criteria
- using highest-efficacy lamps that meet color, optical and electrical control, and output criteria

IESH/10e Economics Resources

> 15.3.3 Budgets
- for more on budgets and value engineering

> 18 | ECONOMICS
- for more on estimating costs
- for more on life cycle costs
- for more on paybacks and rates of return

IESH/10e Energy Efficiency Resources

> 17.2 New Construction
- for more on designing for daylighting
- for more on electric lighting equipment
- for more on lighting controls

> 17.4 Lighting Codes, Regulations and Standards
- for more on application standards
- for more on equipment regulations

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- using highest-efficiency luminaires that meet aesthetic, abuse, and luminance criteria
- using accenting to provide luminance balancing or improve brightness perceptions where necessary
- using controls liberally, preferably automated varieties such as presets, occupancy and vacancy sensors, astronomical time clocks, and photocells
- establishing IES-recommended illuminance criteria to meet programmed tasks
- establishing layouts that just meet IES-recommended illuminance criteria
- addressing outdoor environmental needs
- using calculations, photometrically-realistic renderings, and operational samples and mockups to prove concepts
- identifying and designing to code-specific requirements, if any, for ambient, task, and accent lighting
- documenting all code-, energy-, sustainability-, and IES-criteria compliance
- documenting criteria and design deviations and rationale and subsequent disposition by team, client, or AHJ
- documenting clearly the layouts, controls, and luminaire and lamp selections

Designing for the satisfaction of the observers of significance is the paramount design tenet and must be kept in perspective during all aspects of design. Here, the designer must establish the significant observers and their related lighting reqiurements. If the observers' expectations are not fulfilled, then how much energy could be saved is moot, as is how many fewer earth resources were spared, as is how much the whole affair cost or how much value engineering saved or the photogenic qualities of the project. See sidebar references for additional guidance on the key tenets. The design effort must be undertaken with coordinated and realistic expectations by all involved on initial and life cycle costs. Budgeting should include designer input and dialogue with the team and client at project commencement and design milestones. In other words, and paraphrasing Thomas Edison, genius is, indeed, just 1% inspiration and 99% perspiration.

23.5 References

[1] Mark S. Rea, ed. 2000. The IESNA lighting handbook: Reference and application. 9th edition. New York: IESNA. pp. 14-19:22.

IESH/10e Lighting Exteriors Resources

> 12.5.5.6 Nighttime Outdoor Illuminances
  - for more on lamp efficacies under mesopic adaptation

> 26 | LIGHTING FOR EXTERIORS
  - for more on criteria

IESH/10e Sustainability Resources

> 13.11 Sustainability
  - for more on lamps

> 19 | SUSTAINABILITY
  - for more on controls
  - for more on earth resources
  - for more on energy
  - for more on life cycle analyses
  - for more on lighting design
  - for more on recycling

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24 | LIGHTING FOR EDUCATION

Dwelling in the light, there is no occasion at all for stumbling, for all things are discovered in the light.
George Fox, 17th Century, Founder of the Quakers

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Knowledge acquisition and the process of learning involve the visual exploration of tangible forms and the discovery of concepts from written and graphical displays on paper, computer, and projection. Lighting's role is fundamental. However, lighting also sets the scene for listening, developing social skills, comprehending situations, and recognizing and understanding places. For the normal- and partial-sighted, lighting contributes to life and learning in ways that cannot be accounted in a conventional present worth analysis. Although electric lighting accounts for about 30% of the electricity used in K-12 schools (see Figure 24.1), this amounts to roughly ¾ of 1 percent of total expenditures [1] [2]. Addressing lighting-energy costs must not be allowed to compromise lighting for education. Proper use of daylight and efficient electric light enhance the learning environment. What follows is a discussion of the key aspects affecting lighting for people in educational facilities: project status; space types; activities; application-specific design goals, and illuminance criteria.

Comprehensive design efforts must also rely on material in 12 | COMPONENTS OF LIGHTING DESIGN, 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS, 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. The designer should have a thorough understanding of the design tenets outlined in those chapters, must identify those deemed appropriate and develop lighting goals and strategies accordingly. This chapter primarily addresses specifics related to lighting for education which should influence luminaire optical selections, lamping, and final layouts based on previously developed thought-starters (see 15.2 A Lighting Scheme). Use of the material in this chapter to the exclusion of material in Chapters 12, 13, 14, and 15 will likely lead to unsatisfactory results. Previous and current IES related documents serve as archival and reference sources [3] [4].

Deliberate thought must be given to details beyond the recommended illuminances in this chapter. For example, in art classrooms color quality of light is important. In some situations, very important. This information is usually available from project programming. Review relevant material in Chapter 12 and address the need by selecting lamps of a CCT and CRI deemed appropriate to the situation. Such specific details are not enumerated for all tasks. Table 24.1 offers a checklist of IES lighting topics and criteria. The design team is responsible for determining and addressing indoor and outdoor lighting and energy criteria set forth by authorities having jurisdiction (AHJ) which may be different from and supersede IES criteria. See also 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

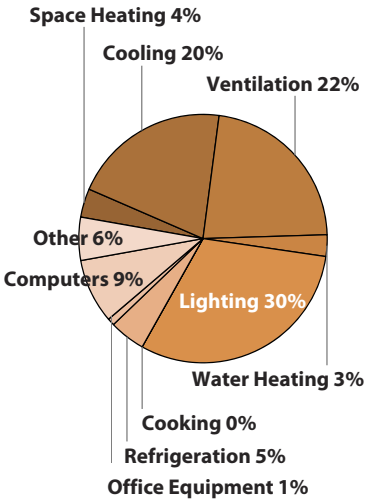


Figure 24.1 | Electricity Use of Education Buildings
Based on 2003 data from the US DOE's Energy Information Administration, lighting accounts for 30% of electricity use in education buildings (electricity use for Cooking rounds to 0%). Education buildings themselves account for about 10% of electricity use by all commercial and institutional buildings.

24.1 Project Type and Status

Before any design work, an understanding of the project type and scope is necessary. New, renovation, and restoration projects each offer varying opportunities. See 11.2 Planning, 11.3.1 Pre-design, and 11.3.2 Schematic Design. A clear understanding of the

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Table 24.1 | Education Lighting Checklist

Topics
✔ **Criteria and Design Resources**
Accenting
15.1.1.3 Accent Lighting
Table 12.2 | Subjective Impressions
Table 15.2 | Accent Illuminance Ratios
Table 22.2 | Common Applications Illuminance Recommendations
Appearance
12.2 Spatial Factors
Color
12.5.6 Color Considerations
Controls
16 | LIGHTING CONTROLS
Daylighting
14 | DESIGNING DAYLIGHTING
Electric Lighting
15 | DESIGNING ELECTRIC LIGHTING
Flicker
4.6 Flicker and Temporal Contrast Sensitivity
Glare
4.10.1 Discomfort Glare
4.10.2 Disability Glare
Illuminance
This Chapter: Table 24.2
12.5.5.1 Applications and Tasks
Table 12.6 | Default Illuminance Ratio Recommendations
Figure 12.22 | Task Coverage Example
Light Distribution
12.3.2 Subjective Impressions
Luminances
12.5.2 Luminance
Table 12.5 | Default Luminance Ratio Recommendations
Maintenance
15.4.4 Installation and Maintenance
Nighttime Outdoor Environment
Table 15.6 | Nighttime Operational Strategies for Improved Outdoor Environmental Regard
Systems Integration
12.6 Systems Factors
Veiling Reflections
This Chapter: Section 24.3.6
12.5.4 Veiling Reflections
Visual Tasks
This Chapter: Section 24.2
This Chapter: Table 24.2
Table 11.2 | Programming: Inventory Scope and Specific Examples
12.5.1 Visual Tasks
Table 12.3 | Sample Visual Task Survey

project type and scope will help establish the extent to which daylighting can address most or many or some of the lighting goals. At every opportunity the lighting designer should consider daylighting as a light source. Given hours of operation of at least K-12 schools, daylighting can be the primary light source. Critically, this means addressing the host of lighting design factors identified in 12 | COMPONENTS OF LIGHTING DESIGN. Daylight demands determined attention to address glare and balance visible and thermal energy.

24.2 Application Types

To develop lighting solutions that meet quality, quantity, and operational criteria, an inventory is made of the educational space types under consideration and the anticipated occupants, functions, and tasks (see Table 11.2 | Programming: Inventory Scope and Specific Examples and Table 12.3 | Sample Visual Task Survey). Otherwise, lighting cannot be best targeted to the users, their expectations, functions and tasks.

Space type definitions are required early in the project design in order to track design efforts that include inventorying the project knowns, anticipated functions, and tasks and calculating lighting, power, and energy compliance. Room names, from which functions can be deduced, and numbers for tracking should be clearly marked on architectural backgrounds. The applications and tasks cited in Table 24.2 | Educational Facilities Illuminance Recommendations should be reviewed against the project knowns and correlated with the named space types and functions to establish recommended illuminance criteria. Seek clarification with the client where discrepancies occur between programming information, the list of room names, and the available application and task citations in Table 24.2.

The following discussion is keyed to major application headings in Table 24.2. Couple this with topics in Table 24.1 for comprehensive qualitative and quantitative criteria.

24.2.1 Accenting

Accenting affects people's brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. Default accent lighting criteria are discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. Also see 15.1.1.3 Accent Lighting.

24.2.2 Administration

Lighting for administrative areas is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. The architectural scheme and even task specifics may vary based on the associated educational facility, from K-12 to vocational technology to community college to college and university to adult education. These distinctions may affect the lighting design by influencing the kinds of lighting effects, the lighting equipment styling, and the luminances and illuminances.

The administrative areas may be dispersed throughout an educational facility or campus or may be centralized into a single area, wing, or building. Depending on client wishes and architectural desires, this centralization or decentralization may affect the degree to which the lighting design in administrative areas is sympathetic to or different from that of the other applications and tasks at the educational facility in question.

24.2.3 Auditoria

Auditoria are typified by their flexibility in use. Functions are quite varied even within designations as lecture halls or multipurpose or performance spaces. This usually requires design of a controls system that may demand operators instructed in the use

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of the system. Additionally, in more intimate auditoria, simplified controls for speakers and students may be appropriate to accommodate small sessions without the need for additional staff.

Challenges include aisle lighting during dark-house performances as well as sound and light lock lighting. *Sound and light locks* serve as transitions from the auditorium to the adjacent lobby, concourse, or other transition space. The aisle lighting must function appropriately during various kinds of performances and their intermissions and pre- and post-performances. For example, during dark-house performances, people leaving or entering the auditorium should not create a visual distraction. Sound and light lock lighting should be designed to manage the luminance change from the auditorium aisles to the adjacent spaces. This may involve adjusting floor reflectances and illuminances between aisles, sound and light locks, and lobbies. Dimmed decorative lighting or optically-controlled architectural lighting or localized lighting from steplights or handrails are typically options. See also 28.2.7 Control Booths and 28.2.19 Theaters.

Sound and light lock is a reference to a doored room with no daylight access and which separates a light sensitive space, such as a darkened auditorium, dining room, or theater, from an active space where relatively higher illuminances are necessary, such as a daylit lobby, kitchen, or foyer. The lock acts like a sound and light baffle so that as people enter and exit the light sensitive space no extraneous sound or light from the brighter active space disrupts people's experience in the light sensitive space. See Figure 24.2.

24.2.4 Building Entries

Lighting for building entries is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. For educational facilities one distinct variable is time of need. Other variables include anticipated levels of activity and the nighttime outdoor lighting zone. Nighttime activity levels may vary by type of educational facility, such as primary versus secondary, and by specific schedules, such as extra-curricular activities, sports, social, or other events. All of this may demand a control system capable of addressing various settings on various evenings through manual intervention, automated time clock, and photocell functions.

The nighttime outdoor lighting zone within which the facility is located or to which the team and client elect to design affects the illuminance criteria for outdoor tasks. Nighttime outdoor lighting zone designations vary by local ordinance, sustainability guides, or the team's own definition of place. These are discussed in 26 | LIGHTING FOR EXTERIORS. Also see Table 15.6 | Nighttime Operational Strategies for Improved Outdoor Environmental Regard.

After-hours security needs, such as on-site or remote monitoring or recording, may require that some luminaires at building entries remain energized through the night or placed on motion sensors or interconnected with camera operations. Control zones and time clock functions must be designed accordingly. Where remote monitoring is done with infrared cameras, lighting may be unnecessary.



Figure 24.2 | Sound and Light Lock
This sound and light lock separates a daylit lobby (out of view to the left, but the effect of which is visible through an open door) from a large auditorium (through the door to the right).

At pre- and post-performance times and during intermission, electric lighting is set to the levels seen here. At actual performance and lecture times, the overhead luminaires are extinguished and steplights are dimmed. Note how even the door to the auditorium is hinged on the far side to further baffle extraneous light from the unseen and possibly opened door along the left wall to the brighter lobby.

» Image ©Balthazar Korab Photography Ltd.

24.2.5 Classrooms

In addition to task visibility and visual performance, classroom lighting influences attention. Here, it is necessary to define and address all anticipated visual tasks—many of which are vertically-oriented. Although lighting effects should not be the focus of attention, lighting should be developed that helps the eye maintain focus and user maintain attention on specific task areas as the pedagogy requires.

Ages of observers must be deliberated with care in classrooms. A sense of comfort and place as well as appropriate energy use can only be achieved if illuminance levels are targeted for the intended audience. Illuminance criteria are presented based on age groupings associated with at least half the observers in a particular application. The designer is always at liberty to reselect criteria based on her own experience or on client direction. Where age groupings conflict, such as might happen with day classes in primary or secondary schools for the children and adolescents and night classes in the same facilities for adults, lighting controls allow for appropriate and efficient lighting to address both situations.

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Table 24.2 | Educational Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
ACCENTING	Accenting influences observers' overall brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. See 22 | LIGHTING FOR COMMON APPLICATIONS/ACCENTING for default accenting criteria for consideration in any application.											
ADMINISTRATION	See 22 | LIGHTING FOR COMMON APPLICATIONS											
AUDITORIA												
• Circulation	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.											
• AV or performance	E_h @floor; E_v @5' AFF		2	2	2	Min	F	5	10	20	Avg	
• All-but-AV-or-performance	E_h @floor; E_v @5' AFF		10	10	10	Min	I	15	30	60	Avg	
• Control Booths	See 28 | LIGHTING FOR HOSPITALITY AND ENTERTAINMENT											
• Lecture Hall	Dedicated to lectures (likely fixed seating)											
• Audience	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.											
• AV and notes	Notetaking is intended. E_h @2' AFF; E_v @4' AFF	K	25	50	100	Avg	G	7.5	15	30	Avg	
• AV and no notes	No notetaking is intended. E_h @floor; E_v @4' AFF	F	5	10	20	Avg	D	3	6	12	Avg	
• Feature presentation	E_h @floor; E_v @4' AFF	F	5	10	20	Avg	D	3	6	12	Avg	
• No AV	E_h @2' AFF; E_v @4' AFF	M	50	100	200	Avg	J	20	40	80	Avg	
• Demonstration	E_h @3' AFF; E_v @4' 6" AFF	T	500	1000	2000	Avg	R	250	500	1000	Avg	
• Screen (front projection)	Cited values are intended for screen plane when screen is in use											
• Feature presentation								10	10	10	Max	
• Periodic reference								50	50	50	Max	
• Speaker/Panel	Lighting at the speaker or panel of speakers											
• AV												
◦ Face(s)	E_v @4' AFF							Avg ≤3 times audience task E_h				
◦ Task surface	E_h @2' 6" AFF			Avg ≤3 times audience task E_h								
• No AV	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
• Multipurpose	High degree of flexibility (likely loose seating)											
• Assembly	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.											
• Audience												
◦ AV and notes	Notetaking is intended. E_h @2' AFF; E_v @4' AFF	K	25	50	100	Avg	G	7.5	15	30	Avg	
◦ AV and no notes	No notetaking is intended. E_h @floor; E_v @4' AFF	F	5	10	20	Avg	D	3	6	12	Avg	
◦ Feature presentation	E_h @floor; E_v @4' AFF	F	5	10	20	Avg	D	3	6	12	Avg	
◦ No AV	E_h @2' AFF; E_v @4' AFF	M	50	100	200	Avg	J	20	40	80	Avg	
• Screen (front projection)	Cited values are for screen plane when screen is in use											
◦ Feature presentation								10	10	10	Max	
◦ Periodic reference								50	50	50	Max	
• Speaker/Panel	Lighting at the speaker or panel of speakers											
◦ AV												
Face(s)	E_v @4' AFF							Avg ≤3 times audience task E_h				
Task surface	E_h @2' 6" AFF			Avg ≤3 times audience task E_h								
◦ No AV	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	

Table 24.2 | Educational Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	5:1/3:1					
	10:1/3:1					
	2:1					
	2:1					
	2:1					
	3:1					
	3:1					
2:1						
2:1						
	2:1					
	2:1					
	3:1					
	2:1					
	2:1					
	2:1					
	3:1					
2:1						
2:1						
	2:1					
	2:1					
	3:1					

Notes for Table 24.2

The table column headings are discussed in detail in 24.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 24.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 24.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Exterior tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 24.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. Alternatively, design to specific tasks, if known, from READING AND WRITING.

j. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

k. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

l. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 24.2 | Educational Facilities Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
AUDITORIA	(Multipurpose continued)										
• Dancing (Social)	E_h @dance floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Exhibition	E_h @2' 6" AFF; E_v @5' AFF	P	150	300	600	Avg	O	100	200	400	Avg
• Study	Typical paper and/or laptop	P	150	300	600	Avg	M	50	100	200	Avg
• Testing	E_h @2' 6" AFF; E_v @4' AFF										
◦ Combination	Typical paper and/or laptop	P	150	300	600	Avg	M	50	100	200	Avg
◦ Laptop only	CSA/ISO Type I and II negative polarity screens.[i]	N	75	150	300	Avg	K	25	50	100	Avg
◦ Paper only	Variety of paper tasks[i]	Q	200	400	800	Avg	N	75	150	300	Avg
• Performance	Dedicated to artistic performances (likely fixed seating); For dedicated theaters see 28 | LIGHTING FOR HOSPITALITY AND ENTERTAINMENT										
• House	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
◦ During event	E_h @floor; E_v @4' AFF		2	2	2	Min	F	5	10	20	Avg
◦ Pre/Post event	E_h @floor; E_v @5' AFF	L	37.5	75	150	Avg	K	25	50	100	Avg
• Stage											
◦ Access ramps/stairs	See AUDITORIA/Circulation										
◦ Amateur productions											
▪ Dance (performance)	E_h and E_v @5' AFF	P	150	300	600	Avg	R	250	500	1000	Avg
▪ Demonstration	E_h @3' AFF; E_v @4' 6" AFF	T	500	1000	2000	Avg	R	250	500	1000	Avg
▪ Music	E_h and E_v @4' AFF	P	150	300	600	Avg	R	250	500	1000	Avg
▪ Theater	Simple, no stage lighting cues.. E_h and E_v @5' AFF	P	150	300	600	Avg	P	150	300	600	Avg
◦ Professional productions	Stage lighting as determined by production crew; See IES DG-20 | Stage Lighting **A Guide to the Planning of Theatres and Auditoriums** for guidance on architectural and electrical infrastructure										
• Prefunction	Anteroom or transition space adjoining auditorium										
• During event	E_h @floor; E_v @4' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Pre/Post event, intermission	E_h @floor; E_v @5' AFF	N	75	150	300	Avg	L	37.5	75	150	Avg
• Sound and light lock	Transition from lobby or foyer space adjoining auditorium										
• During event	E_h @floor; E_v @5' AFF		2	2	2	Min	I	15	30	60	Avg
• Pre/Post event, intermission	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
BUILDING ENTRIES	See 22 | LIGHTING FOR COMMON APPLICATIONS										
CLASSROOMS											
• Arts											
• Art Studios	E_h @2' 6"; E_v @4' AFF	R	250	500	1000	Avg	P	150	300	600	Avg
• Graphic Arts											
◦ Displays											
▪ Fine art	See 21 | LIGHTING FOR ART										

Table 24.2 | Educational Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1		☀			■
	3:1		☀			■
	3:1		☀	↶		■
	2:1		☀	↶		■
	2:1		☀	↶		■
	2:1		☀	↶		■
	5:1/3:1					■
	3:1		☀			■
	1.5:1				■	
	3:1				■	
	2:1				■	
	2:1				■	
	3:1		☀			■
	3:1		☀			■
	5:1/3:1					■
	3:1		☀			■
	3:1		☀	↶		■

Notes for Table 24.2

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a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 24.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Exterior tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 24.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ↶ signals high likelihood; gray and white ↶ signals moderate likelihood; pale gray and white ↶ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. Alternatively, design to specific tasks, if known, from READING AND WRITING.

j. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

k. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

l. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 24.2 | Educational Facilities Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
CLASSROOMS	(Graphic Arts continued)										
◦ Permanent/Temporary	Awards, student art, plaques										
Dimensional	E_h and E_v @artworks										
Dark finish	<50% reflectance	Avg = 5 times E_h of surrounding space					Avg = 5 times E_h of surrounding space				
Light finish	≥50% reflectance	Avg = 3 times E_h of surrounding space					Avg = 3 times E_h of surrounding space				
Flat											
Horizontal	E_h and E_v @artworks										
Dark finish	<50% reflectance	Avg = 5 times E_h of surrounding space									
Light finish	≥50% reflectance	Avg = 3 times E_h of surrounding space									
Vertical	E_h and E_v @artworks										
Dark finish	<50% reflectance						Avg = 5 times E_h of surrounding space				
Light finish	≥50% reflectance						Avg = 3 times E_h of surrounding space				
• Drafting and Design	On drafting board or table										
◦ Blueline blueprint	Also see READING AND WRITING/Xerograph	R	250	500	1000	Avg	M	50	100	200	Avg
◦ CAD (exclusively)	See READING AND WRITING/VDT Screen and Keyboard										
◦ CAD/paper mixed	See READING AND WRITING, establish tasks and normalize to illuminance of most important task or most common task; use controls to provide illuminance variability if tasks so demand.										
• Light table	On light table	M	50	100	200	Avg	I	15	30	60	Avg
• Photographs (inspection)											
◦ Color and B+W prints	E_h @2' 6"; E_v @4' AFF	R	250	500	1000	Avg	M	50	100	200	Avg
◦ Negative lightbox	Architectural lighting illuminances on front of backlit light box	K	25	50	100	Max	K	25	50	100	Max
• Kiln Room	E_h @2' 6"; E_v @4' AFF	R	250	500	1000	Avg	P	150	300	600	Avg
• Music Room	E_h and E_v @4' AFF	P	150	300	600	Avg	O	100	200	400	Avg
• General Classrooms											
• Learning/teaching	Interactive experience										
• AV (dedicated AV viewing)	E_h @2' 6"; E_v @4' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Chalkboard							Q	200	400	800	Avg
• Dedicated VDT screens	CSA/ISO Type I and II negative polarity screens.[i] E_h @2' 6"; E_v @4' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• Hardcopy and writing	Variety of paper tasks.[i] E_h @2' 6"; E_v @4' AFF	Q	200	400	800	Avg	N	75	150	300	Avg
• Tack board							N	75	150	300	Avg
• White board							P	150	300	600	Avg
• Home Economics	At all food prep and detailed work areas		500	500	500	Min	O	100	200	400	Avg
• Lecture Halls	See AUDITORIA/Lecture Hall										
• Science Lab											
• Bench	E_h @3'; E_v @4' 6" AFF	R	250	500	1000	Avg	P	150	300	600	Avg
• Demonstration Area	E_h @3' AFF; E_v @4' 6" AFF	T	500	1000	2000	Avg	R	250	500	1000	Avg
• Seminar Rooms	See 22 | LIGHTING FOR COMMON APPLICATIONS/CONFERENCING/Meeting										

Table 24.2 | Educational Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	4:1					
	4:1					
	4:1					
	4:1					
	4:1					
	4:1					
	see Table 12.6					
	2:1					
	see Table 12.6					
2:1	see Table 12.6					
	3:1					
	2:1					
	2:1					
	3:1					
	2:1					
	2:1					
	3:1					
	3:1					
	see Table 12.6					
	see Table 12.6					
	3:1					

Notes for Table 24.2

The table column headings are discussed in detail in 24.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 24.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 24.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Exterior tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 24.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. Alternatively, design to specific tasks, if known, from READING AND WRITING.

j. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

k. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

l. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 24.2 | Educational Facilities Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
CLASSROOMS	(continued)										
• Shops	E_h @3' AFF; E_v @4' AFF. Also see 30 | LIGHTING FOR MANUFACTURING.										
• Assembly	Difficult process	T	500	1000	2000	Avg	R	250	500	1000	Avg
• Inspection	Difficult process	T	500	1000	2000	Avg	R	250	500	1000	Avg
• Machining	Medium benchwork	T	500	1000	2000	Avg	R	250	500	1000	Avg
• Woodworking	Fine process	T	500	1000	2000	Avg	R	250	500	1000	Avg
• Study Halls		P	150	300	600	Avg	O	100	200	400	Avg
CONFERENCING	See 22 | LIGHTING FOR COMMON APPLICATIONS										
DORMITORIES											
• Circulation	See TRANSITION SPACES/Circulation Corridors										
• Dorm Room											
• Casual Reading	E_h @2' AFF; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Desk	E_h @2' 6" AFF; E_v @4' AFF	Q	200	400	800	Avg	N	75	150	300	Avg
• General	E_h @floor; E_v @5' AFF	J	20	40	80	Avg	G	7.5	15	30	Avg
• Elevators	See TRANSITION SPACES/Elevators										
• Entries	See 22 | LIGHTING FOR COMMON APPLICATIONS/BUILDING ENTRIES										
• Escalators/Moving Walkways	See TRANSITION SPACES/Escalators/Moving Walkways										
• Gallery (student work)	E_h and E_v @artworks	P	150	300	600	Avg	P	150	300	600	Avg
• Game Room											
• Electronic	E_h @2' 6" AFF; E_v @4' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Traditional	E_h @tables; E_v @4' AFF	P	150	300	600	Avg	K	25	50	100	Avg
• Kitchen											
• In-suite	E_h and E_v @3' AFF	R	250	500	1000	Avg	L	37.5	75	150	Avg
• Institutional	See 22 | LIGHTING FOR COMMON APPLICATIONS/Food Service										
• Student-use	E_h and E_v @3' AFF	R	250	500	1000	Avg	L	37.5	75	150	Avg
• Laundry	E_h and E_v @3' AFF	P	150	300	600	Avg	K	25	50	100	Avg
• Living Room	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	K	25	50	100	Avg
• Lobbies	See TRANSITION SPACES/Lobbies										
• Mailboxes	E_h @floor; E_v @mailbox faces	K	25	50	100	Avg	M	50	100	200	Avg
• Media Lounge	E_h @2' 6" AFF; E_v @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Multipurpose	E_h @2' 6" AFF; E_v @display walls	P	150	300	600	Avg	M	50	100	200	Avg
• Toilets	See TOILETS/LOCKER ROOMS										
FOOD SERVICE	See 22 | LIGHTING FOR COMMON APPLICATIONS										
IT	See 22 | LIGHTING FOR COMMON APPLICATIONS										
LIBRARIES	See 29 | LIGHTING FOR LIBRARIES										
PARKING	See 26 | LIGHTING FOR EXTERIORS										
PEDESTRIAN WAYS	See 26 | LIGHTING FOR EXTERIORS										

Table 24.2 | Educational Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
		see Table 12.6				
		see Table 12.6				
		see Table 12.6				
		see Table 12.6				
		2:1				
		see Table 12.6				
		see Table 12.6				
		4:1				
		3:1				
		3:1				
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e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

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j. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

k. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

l. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 24.2 | Educational Facilities Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
READING AND WRITING												
• Computer	See READING AND WRITING/VDT Screen and Keyboard											
• Electronic Readers												
• Electronic Ink Devices	E_h and E_v @height of device	P	150	300	600	Avg	N	75	150	300	Avg	
• LCD or LED Devices	E_h and E_v @height of device	N	75	150	300	Avg	K	25	50	100	Avg	
• Facsimile												
• Analog	E_h @2' 6" AFF; E_v @4' AFF[k]	R	250	500	1000	Avg	M	50	100	200	Avg	
• Digital	E_h @2' 6" AFF; E_v @4' AFF[k]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Handwritten Work	Based on fair-to-good penmanship/hand print on white or canary paper											
• Pencil												
• Graphite/HB	E_h @2' 6" AFF; E_v @4' AFF[k]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Red	E_h @2' 6" AFF; E_v @4' AFF[k]	R	250	500	1000	Avg	M	50	100	200	Avg	
• Ballpoint/Rollerpoint/Felt-tip												
• Black	E_h @2' 6" AFF; E_v @4' AFF[k]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Red, Green, Blue	E_h @2' 6" AFF; E_v @4' AFF[k]	Q	200	400	800	Avg	L	37.5	75	150	Avg	
• Laptop	See READING AND WRITING/VDT Screen and Keyboard											
• Microforms (Projected)		L	37.5	75	150	Avg	I	15	30	60	Avg	
• Print Media	Digital-printing-press-generated, white paper											
• 6-pt Font												
• Matte paper and ink	E_h @2' 6" AFF; E_v @4' AFF[k]	R	250	500	1000	Avg	L	37.5	75	150	Avg	
• Specular paper and ink	E_h @2' 6" AFF; E_v @4' AFF[k]	R	250	500	1000	Avg	L	37.5	75	150	Avg	
• 8- and 10-pt Font												
• Matte paper and ink	E_h @2' 6" AFF; E_v @4' AFF[k]	P	150	300	600	Avg	K	25	50	100	Avg	
• Specular paper and ink	E_h @2' 6" AFF; E_v @4' AFF[k]	P	150	300	600	Avg	K	25	50	100	Avg	
• 12-pt Font												
• Matte paper and ink	E_h @2' 6" AFF; E_v @4' AFF[k]	O	100	200	400	Avg	K	25	50	100	Avg	
• Specular paper and ink	E_h @2' 6" AFF; E_v @4' AFF[k]	O	100	200	400	Avg	K	25	50	100	Avg	
• VDT Screen and Keyboard												
• CSA/ISO Types I and II	See Figure 12.16 | CSA/ISO Computer Screen Qualities											
• Positive polarity	E_h @2' 6" AFF; E_v @4' AFF[k]	P	150	300	600	Avg	N	75	150	300	Avg	
• Negative polarity	E_h @2' 6" AFF; E_v @4' AFF[k]	N	75	150	300	Avg	K	25	50	100	Avg	
• CSA/ISO Type III	See Figure 12.16 | CSA/ISO Computer Screen Qualities											
• Positive polarity	E_h @2' 6" AFF; E_v @4' AFF[k]	N	75	150	300	Avg	K	25	50	100	Avg	
• Negative polarity	E_h @2' 6" AFF; E_v @4' AFF[k]	L	37.5	75	150	Avg	I	15	30	60	Avg	
• White Board												
• Analog or Digital												
• Reading (reference)							N	75	150	300	Avg	
• Reading (with presenter)	Presenter at white board						P	150	300	600	Avg	
• Xerograph	Copier- and printer-generated on white paper											
• ≥8-pt type, common graphics	Select progressively next-higher letter category of illuminance for each 2-point-type decrease in fonts/graphics)											
• Color												
◦ Analog	E_h @2' 6" AFF; E_v @4' AFF[k]	R	250	500	1000	Avg	M	50	100	200	Avg	
◦ Digital	E_h @2' 6" AFF; E_v @4' AFF[k]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Grayscale and/or B+W Print												
◦ Analog	E_h @2' 6" AFF; E_v @4' AFF[k]	P	150	300	600	Avg	L	37.5	75	150	Avg	
◦ Digital	E_h @2' 6" AFF; E_v @4' AFF[k]	O	100	200	400	Avg	K	25	50	100	Avg	

Table 24.2 | Educational Facilities Illuminance Recommendations continued next page

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	see Table 12.6				[j]	[j]
	3:1					
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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
SPORTS												
• Competitive Sports	See 35 | LIGHTING FOR SPORTS AND RECREATION											
• Fieldhouse	E_h @2' 6"; E_v @5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Gymnasia												
• Assembly	E_h @2' 6"; E_v @5' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• Competitive Sports	See 35 | LIGHTING FOR SPORTS AND RECREATION											
• Exhibition/General Activities	E_h @2' 6"; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Physical Education	E_h @2' 6"; E_v @5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Locker Room	See TOILETS/LOCKER ROOMS											
• Pool	See 35 | LIGHTING FOR SPORTS AND RECREATION											
SUPPORT SPACES												
• Coat Check or Coat Rooms	Eh @3'; Ev @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Copy/Print Rooms												
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Machines	E_h and E_v @3' 6" AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Janitor's Closet	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Receiving/Shipping												
• Dock	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Receiving/Staging	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Storage												
• Food	See 22 | LIGHTING FOR COMMON APPLICATIONS/Food Service											
• Frequent Use	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Infrequent Use	E_h @floor; E_v @4' AFF	K	25	50	100	Avg	H	10	20	40	Avg
TOILETS/ LOCKER ROOMS	See 22 | LIGHTING FOR COMMON APPLICATIONS											
TRANSITION SPACES												
• Circulation Corridors	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.											
• Adjacency Passageways	E_h @floor; E_v @5' AFF	Avg ≥0.3 times task E_h of adjacent space or as cameras require, but with min ≥10 lx					Avg ≥0.3 times task E_v of adjacent space or as cameras require					
• Breakout-study/Passageways	E_h @floor; E_v @4' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
• Independent Passageways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• With Lockers	E_v on locker face @4' AFF						K	25	50	100	Avg
• Elevators												
• Freight												
• Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Threshold												
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg

Table 24.2 | Educational Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1		☀			
	3:1		☀			
	3:1		☀			
	3:1		☀			
	3:1		☀			
	3:1		☀			
	3:1		☀			
	3:1		☀			
	2:1		☀			
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	2:1		☀			
	2:1		☀			

Notes for Table 24.2

The table column headings are discussed in detail in 24.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 24.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 24.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Exterior tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 24.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. Alternatively, design to specific tasks, if known, from READING AND WRITING.

j. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

k. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

l. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 24.2 | Educational Facilities Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
TRANSITION SPACES	(Elevators continued)											
• Passenger												
• Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
• Threshold												
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
• Entries	See 22 | LIGHTING FOR COMMON APPLICATIONS/Building Entries											
• Escalators/Moving Walkways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
• Lobbies												
• Circulation, Elevator Lobbies	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.											
• At building entries	Close proximity to exterior. Lighting should assist with adaptation when passing to/from exterior..											
◦ Day	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg	
◦ Night	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg	
• Distant from entries	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg	
• Displays												
• Awards/Trophy cases	See CLASSROOMS/Arts/Graphic Arts/Displays											
• Posting boards							N	75	150	300	Avg	
• Information Desk		P	150	300	600	Avg	M	50	100	200	Avg	
• Lounges												
• Pleasure Reading		O	100	200	400	Avg	M	50	100	200	Avg	
• Social		M	50	100	200	Avg	K	25	50	100	Avg	
• Reception/Waiting Areas												
• Reception Desk		Q	200	400	800	Avg	N	75	150	300	Avg	
• Waiting Areas		O	100	200	400	Avg	M	50	100	200	Avg	
• Stairs	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.											
• High activity[l]	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg	
• Live-surveillance	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg	
• Typical	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1		☀			
	2:1		☀			
	2:1		☀			
	2:1		☀			
	3:1		☀			
	3:1					
	3:1		☀			
	3:1		☀	◪		
	see Table 12.6		☀			
	see Table 12.6		☀			
	3:1		☀			
	see Table 12.6		☀			
	3:1		☀			
	2:1		☀			
	2:1		☀			
	2:1		☀			

Notes for Table 24.2

The table column headings are discussed in detail in 24.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 24.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 24.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Exterior tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 24.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◪ signals high likelihood; gray and white ◪ signals moderate likelihood; pale gray and white ◪ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. Alternatively, design to specific tasks, if known, from READING AND WRITING.

j. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

k. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

l. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 24.3 | SI Dimensional Conversions

US Customary	SI
General	**Hard Conversion**
inches	mm [inches × 25.40]
feet	m [feet × 0.30]
Specific	**Convenient Conversions[a]**
2'	610 mm or 0.6 m
2' 6"	760 mm or 0.75 m
3'	915 mm or 0.9 m
3' 6"	1065 mm or 1.1 m
4'	1220 mm or 1.2 m
5'	1525 mm or 1.5 m

a. Hard conversions rounded for reporting convenience. Not to be confused with metric-sized luminaires or other building materials. Not for precision construction.

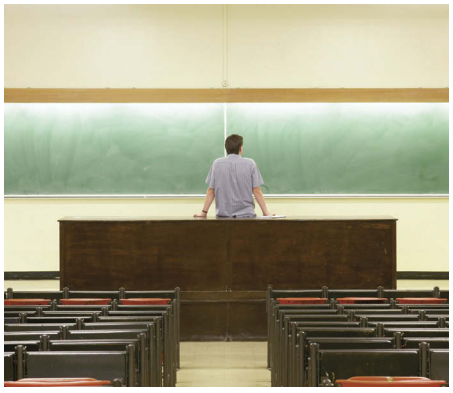


Figure 24.3 | Chalkboards
Lighting chalkboards greatly improves their visibility and better maintains observer attention. Grazing light creates strong luminance near the source of light. Placement of room lighting to brighten the bottom portion of the board can balance this effect.

Luminaires cantilevered from the wall or ceiling or recessed in the ceiling at some distance from the board are most effective when optics provide an asymmetric distribution of relatively diffuse light oriented toward the board (see wallwash lighting on the white boards in Figure 24.4)

» Image ©Peter M. Fisher/CORBIS

IESH/10e CSA/ISO

> 12.5 Task Factors
- for information on CSA/ISO computer screen qualities

Lighting for audiovisual presentations depends largely on the presentation media and the intended use. Most available display systems exhibit luminances and resolutions that make for readily visible presentations under many classroom lighting conditions. If dedicated electronic-display presentations, that is, exclusive viewing of the display, are part of the pedagogy, then provisions should be made to meet the criteria cited in Table 24.2 for CLASSROOMS/General Classrooms/Learning/teaching/AV (dedicated AV viewing). This may necessitate a separate preset scene and the deployment of daylight shades.

Daylighting success is facilitated where seamless, simple-for-the-instructor operation of electric and daylighting mechanisms, such as shades, occurs. Functional variation, including room-darkening for AV, must be easily available to the instructor. For classrooms, these aspects deserve particular attention:

1. Automate dimming or brief client on stepped-dimming functionality
2. Avail instructors of simple dimming overrides to brighten or darken rooms on demand
3. Care in the design of any east- and west-elevation daylighting relative to glare
4. Automate window treatment or avail instructors of convenient manual operation and expected time of use
5. Introduce daylight apertures on orientations different from primary or secondary instruction positions or display/presentation positions
6. Arrange glazing to allow sufficient wall space for posting teaching aids, student work, etc.
7. Maintain some degree of exterior view
8. Avoid daylight designs requiring near-continual or complete shade deployment
9. Perform daylight simulations to limit areas of overlighting and assist with glazing transmittance and shading treatment selections [5] [6] [7] [8]

Laboratories, industrial and electronics shops, and art studios may have special requirements related to the kinds of light necessary for processes and viewing and related to the kinds of luminaires appropriate to the hazards of the environment. Such special requirements should be identified in programming and researched during design. This may involve vendors of special equipment, rooms, or booths, which are many times purchased as turnkey packages. Determination of lighting needs requires close coordination amongst the design team, client, and turnkey-package vendors. Some examples and related lighting needs are:

1. Fume hoods and paint and finishing booths: Where fume hood or paint or finishing booth packages do not include integral lighting, design of lighting for the hazardous location is necessary. See Table 25.4 | Hazardous Location Classifications.
2. Motor and motor vehicle servicing, prototyping, and experimentation: Design of lighting for the hazardous location is necessary. See Table 25.4 | Hazardous Location Classifications.
3. Lab experiment stations and observation booths: Where equipment or booth vendors do not provide integral lighting, lighting needs must be established. Where processes involve hazardous chemicals, design of lighting for hazardous locations is necessary. Where processes are spectrally sensitive, such as some curing procedures, select lamps accordingly. Where processes are spectrally and intensity sensitive, such as plant-growth, select lamps accordingly. In some situations the luminaires may need to accommodate directed water spray or wash down procedures in which case wet-rated luminaires are necessary and which should carry IP ratings specific to the situation. See 15.1.2.1 Luminaires.

Maintenance and cleaning of the lighting equipment must be well considered in process areas. Where wash-down is convenient or necessary due to task processes, then lighting equipment must be specified accordingly. Where color discrimination is important to

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Figure 24.4 | Electric and Daylighting
The continuous clerestory offers an opportunity to harvest daylight along the half of the classroom closest to the exterior wall. The linear pendant luminaires in the classroom exhibit two lamps in cross section. At the perimeter luminaire ❶ the rows of lamps are wired for two zones of control. The outboard lamp row (the row of lamps closest to the exterior) is switched separately from the inboard row. When a photocell senses that enough daylight is present, one row is automatically extinguished. Which zone is extinguished can be alternated on a daily basis to equalize and extend in-service life of the ballasts and lamps. If not considered too disruptive, both lamp rows could be extinguished when sufficient daylight is available, and this is the typical approach. No window treatment can be a successful approach on north facades and where T_{vis} is of moderate value, but which depends on geographic location, typical sky conditions, and reviews of daylight simulations. Otherwise, automated shades are best.

Wallwashers are used to highlight white boards ❷. Controls establish preset scenes that extinguish these luminaires during AV presentations.

Present-day projection systems are sufficiently powerful to permit view during full-light conditions. This is useful when the presentation is mixed with traditional reading and writing tasks. However, to optimize viewing conditions and maximize energy savings, staff instruction on the use of controls is necessary.

High-reflectance matte wall and ceiling finishes greatly improve the effectiveness of daylight and electric light ❸.

» Image ©Bill Lindhout Photography

the task process, such as assessing chemical reactions in experiments or paint color and matching or finish quality in shops, CRI may need to be ≥90 and CCT may need to be 5000 K or 6500 K. Also see Table 6.1 | Color-related Design Questions.

In any of the classroom applications, control systems are key to providing the functional variation, daylight integration, and simple-for-the-instructor operation.

Figures 24.3, 24.4, and 24.5 illustrate some classroom lighting techniques

24.2.6 Conferencing

The lighting of conferencing facilities is addressed in 22 | LIGHTING FOR COMMON APPLICATIONS. Where conferencing facilities are essentially multipurpose meeting rooms, controls are used to establish appropriate settings for various tasks. Figure 24.6 illustrates a dedicated video conference classroom.

24.2.7 Dormitories

Lighting for living is as much about visual comfort, sense of place, and distinction from classroom and administrative settings as it is about illuminance values. Much of the lighting for dormitory applications is task-oriented or relatively low-level ambient. This more discrete approach to lighting combined with the typical age groupings has additional advantage in low connected load. With occupancy sensors this yields low energy use.

Depending on the nature of the dormitory facilities, criteria cited in 28 | LIGHTING FOR HOSPITALITY AND ENTERTAINMENT may be suitable. For example, dorms may be used as housing for business executives on multi-week training and education missions. Some school and academy markets expect and will bear the cost of upscale housing.

24.2.8 Food Service

Lighting for food service is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

24.2.9 IT

Lighting for IT tasks is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

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Figure 24.5 | Science Lab
Ambient and task lighting systems combine to achieve horizontal and vertical illuminances at tables and faces. Lensed task lighting is integrated into overhead lab utility carriers. For lab work, tables are reconfigured to be directly centered below the overhead lab utility carriers. Ambient lighting consists of lensed 1x4 luminaires. Outside row is strategically positioned (near clerestory at top of image) to illuminate glass-front storage cabinets. Accenting of the white boards is achieved with ceiling-recessed rectilinear wallwashers lamped with long compact fluorescent lamps. Each of these three lighting systems is separately controlled to accommodate a number of teaching situations.
» Image ©Bill Lindhout Photography

24.2.10 Libraries

Lighting for libraries is discussed in 29 | LIGHTING FOR LIBRARIES.

24.2.11 Parking

Lighting for parking facilities is discussed in 26 | LIGHTING FOR EXTERIORS.

24.2.12 Pedestrian Ways

Lighting for pedestrian ways is discussed in 26 | LIGHTING FOR EXTERIORS.

24.2.13 Reading and Writing

Reading and writing tasks occur within various applications. Familiarity with these tasks will aid with assessment of specific application tasks and activities. This may result in the recommendation of illuminance criteria different than that proposed in Table 24.2 for a particular application. For example, if the computer tasks in AUDITORIA/Multipurpose/Testing or those in CLASSROOMS/General Classroom/Dedicated VDT Screens are known to involve CSA/ISO Type III negative-polarity screens, then the task citation under READING AND WRITING/VDT Screen and Keyboard/CSA/ISO Type III/Negative Polarity is an appropriate recommendation and should be deliberated with the client. Figure 24.7 illustrates a computer lab application with CSA/ISO Type I positive-polarity screens.

24.2.14 Sports

Depending on the size and extent of sports programs, if any, the lighting designer may find more appropriate criteria discussed in 36 | LIGHTING FOR SPORTS AND RECREATION. Recommendations are made in Table 24.2 where a basic fieldhouse is programmed or where a gymnasium is used for assembly and physical education classes.

24.2.15 Support Spaces

These relatively back-of-house citations are self-explanatory.

24.2.16 Toilets/Locker Rooms

Lighting for toilets and locker rooms is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. Addressing the fixture functional areas, such as toilets, urinals, vanities, will provide sufficient light where needed without overlighting the entire toilet room. Vanities are problematic when little or no vertical illuminance is designed to illuminate an imaginary facial plane (roughly a zone of sufficient size to encompass faces) in front of the mirrors. Wall slot details illuminating light-colored upper walls above the mirror or discrete, lensed ceiling-recessed luminaires or some combination are appropriate techniques here.

Vertical light on the faces of lockers will assist with locker use.

24.2.17 Transition Spaces

Most of these spaces are self-explanatory, but one deserves discussion. Adjacency passageways refer to a condition where circulation areas are encompassed by larger work or task areas. Given their adjacency to the open and visually accessible work or task areas, their illuminances, confined to the passageway proper, should be ratios of the nearby task illuminances. This avoids annoying contrasts within the work setting.

For purposes of maintenance convenience, lamp types and color qualities should match those used elsewhere. Figure 24.8 illustrates benefits of daylighting. Figure 24.9 identifies some lighting aspects associated with stairs.

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24.3 Illuminance Criteria

Illuminance criteria, when fully deployed, are a robust set of quantitative values that influence visibility, visual performance, and visual comfort and attention. Short-circuiting the criteria selection or designing to a single criterion value, such as horizontal illuminance, to address worst-case tasks will surely result in dissatisfaction. Even if clients accept the visual results, not getting the most from the energy expended or, worse, energy waste is a likely result. Following are notes related to various topics outlined in Table 24.2.

24.3.1 Applications and Tasks

Applications and tasks encountered on any given project may be different from those identified in Table 24.2 and may warrant different illuminance criteria. Cross-referencing closely-associated applications or tasks is appropriate. Sometimes naming trends or conventions for space types or functions change to conform to current practice, client programming, or architectural conventions, but the actual activities and tasks remain the same and this cross-referencing works. Failing this technique, reviewing the list in Table 24.2 may be in order to determine if any applications or tasks exhibit a similar visual-component to the unique applications or tasks. Otherwise, reviewing 4.12 An Illuminance Determination System and Table 4.1 is necessary to establish a task category based on the task characteristics or visual performance descriptions most closely associated with the unique applications or tasks. These exercises as well as any deviations from recommendations the designer intends to make should be carefully documented for the record.

24.3.2 Notes

Notes may refer to other application and task headings in the table or to other handbook chapters as appropriate. Where some degree of clarification is warranted, notes are made.

24.3.3 Recommended Maintained Illuminance Targets

Values cited are maintained on the area of coverage for the task under consideration. Illuminance is additive. Where practical and without negatively affecting the intended application of light, target values are achieved with any combination of daylighting and/or electric lighting in whatever mix of ambient, task, and accent lighting is deemed appropriate to meet these and the other lighting goals established during design. See 12 | COMPONENTS OF LIGHTING DESIGN and see 10.7.1 Light Loss Factors.

With respect to light loss factors, account for anticipated losses through the point in time at which group relamping and cleaning should occur. Group relamping and cleaning should be standard practice, though these need not occur at the same frequency. Periodic cleaning and group relamping essentially maintain the illuminance at criteria and make the most efficient use of the installed equipment. For purposes of sustainability, cleaning and group relamping can no longer be presumed to be infrequent or unlikely. Maintenance procedures must be part of the design discussions with the client. See the IES document IESNA/NALMCO RP-36 Recommended Practice for Planned Indoor Lighting Maintenance for additional information. Where maintenance is deferred or practiced poorly or not at all, the actual illuminance values will fall below criteria targets. This is inefficient, unsustainable, and may be unsafe while adversely affecting users' quality of life or work. Ratcheting initial illuminances higher is poor practice and not recommended. Maintenance procedures may be especially problematic with LEDs where promises of extraordinarily long life may be offered, but usually with the caveat that lamp lumen depreciation (LLD) at that rated life is 70% or perhaps even as low as 50% of initial rating. If replacement cycles are presumed to be rated life, then LLD alone must be 0.7 or 0.5 or whatever lumen rating is certified by the LED vendor. See 13.3 Life and Lumen Maintenance.



Figure 24.6 | Video Conference
Present-day video systems and large-format flat screens are available with matte screens and exhibit sufficient brightness to work well even when illuminances are relatively high and diffuse. These relatively high and diffuse illuminances accommodate recording/transmission of high quality images of facial detail, clothing, and tasks.
» Image ©Bryan Denton/Corbis

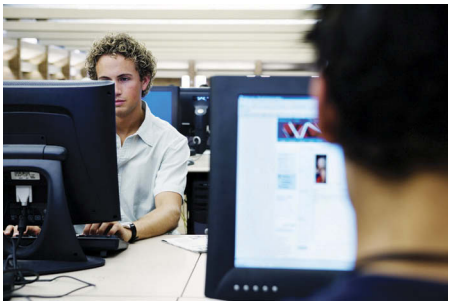


Figure 24.7 | VDT Screens
CSA/ISO Type I and II positive-polarity screens offer excellent inherent contrast. Indirect or direct/indirect lighting typically yields glare-free viewing conditions for these screens and results in no veiling reflections. The indirect lighting component reflects diffuse light from the ceiling which produces vertical illuminances that facilitate facial recognition.
» Image ©Anderson Ross/Blend Images/Corbis

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Figure 24.8 | Daylighting
Code interpretation permitting, daylight can exclusively meet illuminance criteria during daylight hours. In some applications, such as circulation areas, daylight illuminances exceeding IES recommendations are acceptable, even desirable providing glare is addressed. However, where transition is made to dark spaces, such as a performance auditorium, overlighting adjacent circulation areas is problematic.
» Image ©Emely/Corbis

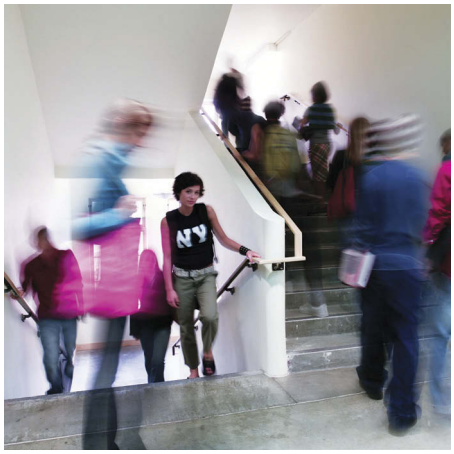


Figure 24.9 | Stairs
Highly-loaded stairs, typically encountered during class change, require higher illuminance than normal-situation counterparts. Controls, such as time clocks synchronized with class change or occupancy sensors are used to adjust lighting according to use patterns.
» Image ©Ocean/Corbis

Targets cited are consensus and recommended for respective functional activity. For some applications, IES recommendations are within 10% of code requirements. This apparently is an artifact of metrication. Footcandle conversions of any values cited in Table 24.2 should be made at 1 fc to 10 lx. This soft conversion avoids a redundant diminishing of illuminance values after multiple citations and conversions over time. This also eliminates a false sense of accuracy advanced by an ever-increasing number of decimal places and a false sense of urgency advanced by eccentric fractional values introduced by hard conversions. Nevertheless, a lighting design must meet code and the mechanics of which must be coordinated amongst the design team. The IES recommendations should not, do not, and cannot reflect all of the various code requirements in force in all jurisdictions at any given time.

Targets are intended to apply to the dominant plane of the task, typically, but not always, horizontal or vertical. In some situations, illuminance criteria are cited for one plane, such as the vertical plane for perimeter lighting in indoor retailing situations, while the other plane is blank. The blank signifies that illuminance on that plane is unimportant and may be a consequence of the illuminance of other tasks within the vicinity or by whatever illuminance results from meeting the target illuminance for the prescribed plane of interest.

In some situations, no light is anticipated on at least one plane of a task. A 0 indicates no light or zero light is recommended for the task or application.

24.3.3.1 Target Planes

Many, though certainly not all, tasks are performed with the task in roughly a horizontal orientation or vertical orientation. A dominant orientation must be assigned and the illuminance target determined accordingly. There may be situations where the IES recommended target relating to the typical planar mode of a task must be applied to a different plane. For example, if an art studio is intended to be used exclusively for easel painting, then the illuminance target cited in Table 24.2, which is for a dominant horizontal orientation, must be applied to the plane of the easels. This, however, pressures the designer to attend to glare issues associated with higher vertical illuminances.

Nearly all tasks are expected to have both a horizontal illuminance component (E_h) and a vertical illuminance component (E_v). This allows some degree of task flexibility for off-plane viewing and accommodates various aspects of the task. In some applications, like conventional art studios accommodating a variety of media, art forms, and genres, horizontal- and vertical-plane illuminances address the common studio situation where simultaneously some work or some portion of the work is on horizontal planes while other work or portion is on vertical planes.

Where illuminance targets are intended at differing planar elevations, this is indicated under "Notes." For example, for most corridors (TRANSITION SPACES/Circulation Corridors), horizontal illuminances apply to the floor plane while vertical illuminances apply to standing-face-plane height of 5' AFF oriented in the two main directions of travel. In primary schools, the designer may elect to set the elevation for vertical illuminance at 3' AFF. Establishing and tracking task orientations and addressing both horizontal and vertical illuminance is necessary. If orientations in the project under consideration are programmed to be flipped from what might be considered normal-viewing, then criteria must be adjusted accordingly. If a task is scheduled to be oriented on some plane off axis from horizontal or vertical by more than 10°, say, then the illuminance criteria must be applied to that off-axis orientation. This is an important distinction for luminaire optical selection and aiming capabilities and for layout, calculations, and field measurements.

For planes related to vertical illuminance targets, some guidance is indicated under "Notes." However, the designer may elect to use alternate or multiple vertical planes. In some situations the vertical planes could be oriented in a number of directions and the designer must determine which are most appropriate for the situation. For example, in a dormitory kitchen, E_v at preparation surfaces, the number and orientation of vertical planar points assessed depends on the preparation surface. On a counter against a full-height

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wall, the vertical planes of most interest are the one facing the preparer and the two planes perpendicular to the preparer (one oriented toward the right and one toward the left). So, the criteria apply to these three planes. On an island or peninsula which may be used from more than one side, however, four planes are of interest.

24.3.3.2 Visual Ages of Observers

Illuminance criteria are based on the visual ages of more than half the intended observers. In many education settings, more than half the total observers are under 25 years of age. Although implications to energy use are significant, this alone should not predetermine illuminance targets. More than half the instructors, administrators, and staff are likely to be in the 25-to-65 age group and their visual tasks encompass a broader array of reading and writing tasks. Further, their ability to read facial features and the mouthing of words is important to assessing and directing student achievement. The designer must work to reconcile the task, age, and subsequent illuminance differences. In some situations, it might be acceptable to the client to select illuminance targets for people under 25 years of age. In other situations, the client might demand illuminance targets for people ranging from 25 to 65 years of age. In still other situations, it may be desirable to light student areas to illuminance targets for people under 25 years of age while lighting instructor areas to illuminance targets for people between 25 to 65 years of age. For a classroom setting, this age-and-task-driven lighting approach has the benefit of directing students' attention to the instructor area. In any event, the aspect of observers' ages, task sets for age groups, and illuminance targets should be resolved during programming with the client. See 12.5.5 Illuminance and 4.12 An Illuminance Determination System for additional information and guidance.

24.3.3.3 Illuminance Categories

Illuminance categories are designated by letters A through Y. These are shown in Table 24.2 for more convenient reference to Table 4.1 | Recommended Illuminance Targets should the designer wish to explore other criteria targets or if applications or tasks on a specific project are not readily correlated to the table citations.

24.3.3.4 Gauge

The common gauge for determining illuminance target compliance is cited for each application. All gauges presume that point-by-point techniques are used for predictive calculations and presume that uniformity criteria are closely monitored. Where an average illuminance value over the area of coverage can satisfy target compliance, "Avg" is cited. In applications or tasks where a minimum or maximum target is necessary, the gauge for compliance is "Min" or "Max" respectively.

The designer may elect to use other methods to evaluate target compliance, such as criterion rating (CR) or coefficient of variation (C_v). See 4.12.4.5 Tasks at Uncertain Locations Over a Large Area.

In any event, once illuminance targets and uniformities are established, then any calculated deviation from them should be limited. Standard engineering allowance of ±10% might be acceptable for targets gauged as average unless contractual or code obligations demand otherwise. Minima and maxima must be achieved as intended.

Designs should be adjusted until predictions are within allowance for averages and meet minima and maxima. For additional information, see 4.12.4.1 Recommended Illuminances at Design Time, 4.12.5 Illuminance Ratios, 9.15.1.1 Average Illuminance, and 10.8 Assessing Computed Results.

24.3.4 Uniformity Targets

Illuminance uniformity targets work in conjunction with luminance uniformities and surface reflectances all of which must be addressed as part of the design to avoid visual discomfort, glare, and strain. Uniformity ratios are targets that define the widest recommended ranges. In many situations, uniformity ratio criteria are those between average

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values of an array of points and the minimum value in the same array of points. Uniformity targets apply to both horizontal and vertical illuminances over the area of coverage. Where horizontal uniformity criterion is different from vertical uniformity criterion, two ratios are reported with the first value for horizontal illuminance (E_h). In some situations, notably those with regard to exterior illuminances, two uniformity values are cited. The first value addresses the primary cited application or task. The parenthetical value references the parenthetical application or task, such as a curfew situation associated with nighttime outdoor lighting.

Generally the more important speed and accuracy and the more demanding the visual task, the tighter the ratio.

24.3.4.1 Maximum-to-average

This is the recommended ratio of maximum illuminance to the average illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations sensitive to even a relatively small degree of overlighting.

24.3.4.2 Average-to-minimum

This is the recommended ratio of average illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where illuminance too far below average conditions is noticeable and detrimental to task performance or inconsistent with normal expectations.

24.3.4.3 Maximum-to-minimum

This is the recommended ratio of maximum illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where too much variation in illuminance is considered undesirable and untenable from a performance or safety perspective.

24.3.5 Daylighting Advancement

Generally, design strategies should embrace any combination of daylighting and electric lighting to achieve target values during daylight hours. The preference is for daylighting to provide all or most of the recommended illuminance presuming that all aspects of daylighting are properly addressed. A sunburst icon depicts those applications and tasks where daylighting is considered a strategic candidate. Use photocells and stepped-dimming or continuous dimming to reduce or eliminate electric lighting during daylight hours. See 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Even for those applications where daylighting is not traditionally a strategic candidate, it may be determined that very careful and coordinated design will offer great sustainability opportunities along with positive influences associated with daylight and views.

24.3.6 Veiling Reflections

Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper or, worse, both, are prone to veiling reflections. The likelihood of particular applications and tasks predisposed to veiling reflections is indicated by a "reflected light" icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood. Veiling reflections are minimized by controlling the overall amount and direction of light with respect to the task locations and orientations. Alternatively, tasks sensitive to veiling reflections can be screened or isolated. Effective strategies include employing indirect soft, diffuse electric lighting or direct electric lighting with multiple low-output luminaires, or positioning tasks and luminaires and luminance patterns to avoid harsh reflections from tasks. Addressing luminance recommendations (see Table 12.4 | Default Luminance and Luminaire Intensity Recommendations for VDT Applications) minimizes veiling reflections. Changing the task will reduce or eliminate veiling reflections, such as use of CSA/ISO Type I or II computer screens and matte paper versus their specular counterparts.

IESH/10e CSA/ISO

> 12.5 Task Factors
- for information on CSA/ISO computer screen qualities

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24.3.7 Defining Areas of Coverage

In addition to establishing planes of task orientation, the areas of coverage to which targets apply must be determined. Typical areas of task illuminance coverage are identified here, but these may not be appropriate to specific project situations. One area of coverage is "task proper or task area." Here, the illuminance criteria are applied to the task itself or to a relatively small area to which the task is confined. See 12.5.5.1 Tasks and Applications and Figure 12.22 | Task Coverage Example. In some situations, such as accenting, the "task" area may consist of the entire wall when "feature wall" or "perimeter" accenting is desired. It is important to remember that illuminance is additive, that is, task illuminance can be achieved with some combination of ambient lighting, task lighting, and/or accent lighting, providing that the total illuminance on the task proper or task area meets the illuminance criteria outlined in Table 24.2.

Another area of coverage is "room or designated area." In this situation, illuminance criteria are applied to the room or an area of fairly substantive size representing the zone in which the applications and tasks are expected to occur. The designated area is typically established by the furniture layout, for example, or might be established by the design team or client. The area-of-coverage citations in Table 24.2 are based on traditional notions. So, for example, it may be determined that a "task proper or task area" coverage would result in some amount of LPD reduction when compared to "room or designated area" coverage. If the task can be confined to one area rather then multiple areas, if the room or area in which the task is located is itself relatively small, such as a single-occupant office, and if the other design goals and criteria outlined in 12 | COMPONENTS OF LIGHTING DESIGN are addressed, then this strategy of redefining area of coverage has merit.

Figure 24.5 illustrates a science lab where task and ambient lighting systems are applied. The task area is considered the lab table zone, designed to a "demonstration area" illuminance criteria. The ambient coverage area is the entire room.

An assessment and determination must be made on which area of coverage best satisfies the lighting goals on a particular project.

24.4 Designing

Information provided here is specific to educational facilities and should be used as part of the design and documentation processes outlined in Chapters 12, 15, and 20. For outdoor applications, lamps and ballasts, transformers, and drivers must be selected for ambient temperature conditions, some of which are extremely hot and others extremely cold. See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY for additional information on respective aspects. Addressing all code requirements is a must. Energy efficient and sustainable practices are an integral part of all IES recommendations. Key design tenets include, but are not limited to:

- designing for the satisfaction of the observers intended to use the project
- using baseline reflectances of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively) in interior production and work-oriented spaces
- using daylighting that meets luminance and illuminance criteria
- using highest-efficacy lamps that meet color, optical and electrical control, and output criteria
- using highest-efficiency luminaires that meet aesthetic and luminance criteria
- using accenting to provide luminance balancing or improve brightness perceptions where necessary
- using controls liberally, preferably automated varieties such as presets, occupancy and vacancy sensors, astronomical time clocks, and photocells

IESH/10e Economics Resources

> 15.3.3 Budgets
  - for more on budgets and value engineering

> 18 | ECONOMICS
  - for more on estimating costs
  - for more on life cycle costs
  - for more on paybacks and rates of return

IESH/10e Energy Efficiency Resources

> 17.2 New Construction
  - for more on designing for daylighting
  - for more on electric lighting equipment
  - for more on lighting controls

> 17.4 Lighting Codes, Regulations and Standards
  - for more on application standards
  - for more on equipment regulations

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IESH/10eLightingExteriorsResources

> 12.5.5.6 Nighttime Outdoor Illuminances
- for more on lamp efficacies under mesopic adaptation

> 26 | LIGHTING FOR EXTERIORS
- for more on criteria

IESH/10e Sustainability Resources

> 13.11 Sustainability
- for more on lamps

> 19 | SUSTAINABILITY
- for more on controls
- for more on earth resources
- for more on energy
- for more on life cycle analyses
- for more on lighting design
- for more on recycling

- establishing IES-recommended illuminance criteria to meet programmed tasks
- establishing layouts that just meet IES-recommended illuminance criteria
- addressing outdoor environmental needs
- using calculations, photometrically-realistic renderings, and operational samples and mockups to prove concepts
- identifying and designing to code-specific requirements, if any, for ambient, task, and accent lighting
- documenting all code-, energy-, sustainability-, and IES-criteria compliance
- documenting criteria and design deviations and rationale and subsequent disposition by team, client, or AHJ
- documenting clearly the layouts, controls, and luminaire and lamp selections

Designing for the satisfaction of the observers is the paramount design tenet and must be kept in perspective during all aspects of design. If the observers' expectations are not fulfilled, then how much energy could be saved is moot, as is how many fewer earth resources were spared, as is how much the whole affair cost or how much value engineering saved or the photogenic qualities of the project. See sidebar references for additional guidance on the key tenets. The design effort must be undertaken with coordinated and realistic expectations by all involved on initial and life cycle costs. Budgeting should include designer input and dialogue with the team and client at project commencement and design milestones. In other words, and paraphrasing Thomas Edison, genius is, indeed, just 1% inspiration and 99% perspiration.

24.5 References

[1] [DOE] US Department of Energy, Energy Information Administration. Table E5A. In: Electricity Consumption (kWh) by End Use for All Buildings, 2003 [Internet]. 2003. DOE. [cited December 23, 2008]. Available from: http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html#enduse03.

[2] [EPA] US Evironmental Protection Agency. High performance schools [Internet]. EPA. [cited August 22, 2010]. Available from: http://www.epa.gov/iaq/schooldesign/high-performance.html.

[3] Mark S. Rea, ed. 2000. The IESNA lighting handbook: Reference and application. 9th edition. New York: IESNA. Ch 12.

[4] [IESNA] Illuminating Engineering Society. Lighting for Educational Facilities. RP-3-00(R2006). New York: IESNA. 47 p.

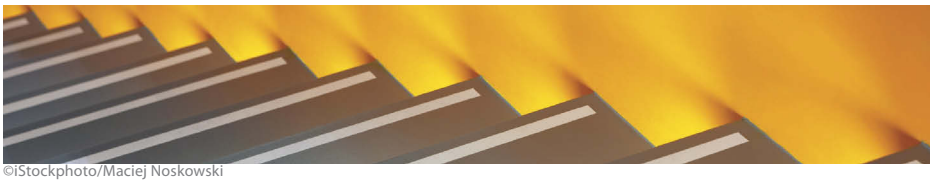
[5] ASERTTI. 2010. Daylighting in schools, Zach Elementary School, Fort Collins, CO [Internat]. ASERTTI. [cited August 21, 2010]. Available from: http://www.asertti.org/programs/schools/daylighting/projects/zach.htm.

[6] ASERTTI. 2010. Daylighting in schools, Solon High School, Solon, IA [Internet]. ASERTTI. [cited August 21, 2010]. Availble from: http://www.asertti.org/programs/schools/daylighting/projects/solon.htm.

[7] ASERTTI. 2010. Daylighting in schools, Georgina Blach Intermediate School, Los Altos, CA [Internet]. ASERTTI. [cited August 21, 2010]. Available from: http://www.asertti.org/programs/schools/daylighting/projects/georgina.htm.

[8] ASERTTI. 2010. Daylighting in schools, Congress Elementary School, Milwaukee, WI [Internet]. ASERTTI. [cited August 21, 2010]. Available from:http://www.asertti.org/programs/schools/daylighting/projects/congress.htm.

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25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY

I not only use all of the brains I have, but all I can borrow.
Woodrow Wilson, 28th President of the United States

Contents

25.1 Project Type and Status. . . 25.1
25.2 Application Types 25.1
25.3 Illuminance Criteria 25.12
25.4 Designing. 25.16
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Collaboration on architectural lighting is a must as borne out in the other application and design chapters. The designer of the architectural lighting (aka lighting designer) must work with designers of the architecture, interiors, and landscape to achieve project success. If the lighting designer is not an electrical engineer, then collaboration between the two may benefit the project on matters of at least emergency lighting and perhaps safety and security lighting. The topics discussed in this chapter are by nature quite analytic, though some discussion outlines aesthetic aspects and IES criteria in context with some code-mandated criteria related to emergency lighting. Lighting for safety and security are also addressed.

Comprehensive design efforts involve the information in this chapter combined with material in 12 | COMPONENTS OF LIGHTING DESIGN, 14 | DESIGNING DAYLIGHTING, 15 | DESIGNING ELECTRIC LIGHTING, and respective application chapters relevant to the project at hand. Design tenets deemed appropriate from those chapters must be identified and lighting goals and strategies developed accordingly. This chapter primarily addresses illuminance specifics related to Lighting for Emergency, Safety, and Security which should influence illuminance criteria, luminaire ratings, lampings, and final layouts based on design thought-starters (see 15.2 A Lighting Scheme). Use of the material in this chapter to the exclusion of material in Chapters 12, 14, 15, and relevant application chapters will likely lead to unsatisfactory results. That is, even though the application may be considered code compliant, safe, and secure, the users may find its utility for the intended functions inappropriate or unacceptable. Previous IES related documents serve as archival reference sources [1].

Table 25.1 offers a checklist of IES lighting topics and criteria related to emergency, safety, and security lighting.

25.1 Project Type and Status

Before any design work, an understanding of the project type and scope is necessary. The scope and work assignments associated with lighting for emergency, safety, and security should be clearly understood prior to project commencement. New, renovation, and restoration projects each offer varying challenges. See 11.2 Planning, 11.3.1 Pre-design, and 11.3.2 Schematic Design.

25.2 Application Types

Emergency, safety, and security lighting are perhaps the design team's greatest challenges. Codes, ordinances, and mandates establish the minimum requirements of construction to protect public health, safety, and welfare. What follows is indicative rather than exhaustive.

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Table 25.1 | Emergency, Safety, and Security Lighting Checklist

Topics
✔ **Criteria and Design Resources**
Codes
Table 12.9 | Typical Prescribed Lighting Design Factors
Color
12.5.6 Color Considerations
Controls
16 | LIGHTING CONTROLS
Daylighting
14 | DESIGNING DAYLIGHTING
Electric Lighting
15 | DESIGNING ELECTRIC LIGHTING
Flicker
4.6 Flicker and Temporal Contrast Sensitivity
Glare
4.10.1 Discomfort Glare
4.10.2 Disability Glare
Illuminance
This Chapter: Table 25.2
4.12 An Illuminance Determination System
12.5.5.6 Nighttime Outdoor Illuminances
Table 22.2 (BUILDING ENTRIES)
Table 22.2 (TRANSITION SPACES/ Circulation Corridors)
Table 22.2 (TRANSITION SPACES/Elevators)
Table 22.2 (TRANSITION SPACES/Escalators)
Table 22.2 (TRANSITION SPACES/ Security Screening)
Table 22.2 (TRANSITION SPACES/Stairs)
Light Distribution
8.2.2.4 IES Distribution Classification of Outdoor Luminaires
Maintenance
15.4.4 Installation and Maintenance
Systems Integration
12.6 Systems Factors
Veiling Reflections
This Chapter: Section 25.3.6
12.5.4 Veiling Reflections

The lighting recommendations throughout this handbook are made on the basis of effective visual performance for the intended application and task situations. The Safety and Security Illuminance Recommendations in Table 25.2 should be reviewed against the project knowns and an assessment should be made on their relevance to the various application and task situations on the project. Codes, ordinances, or mandates may supersede any of the IES criteria cited throughout this handbook for any of the application and task situations and the designer must design accordingly or seek variance from the appropriate authority having jurisdiction (AHJ). This should be documented.

25.2.1 Codes, Ordinances, and Mandates

A rigorous review by the design team is necessary to identify all codes and ordinances that affect lighting on every project. The requirements of these codes, ordinances, and mandates must be identified and defined by the registered and licensed professionals. Regardless which design team members ultimately address these citations, they *must* all be addressed. The designs to address them must be coordinated amongst the design team and are likely to involve architecture, interior finishes, materials, and contrasts, landscape, electrical engineering, and lighting. What follows is discussion on some code- and ordinance-related topics and on some common practices related to lighting for emergency, safety, and security. This is not and cannot be a complete recitation and review of all codes, ordinances, and mandates that might be applicable on any and every project at the time of project design.

The work by installers and licensed and registered architects and engineers must conform to electrical and life safety codes. Where the designer of the lighting is not one of these professionals, then he or she should have some familiarity with the electrical and life safety codes. This familiarity will help on collaborative design efforts and will minimize the likelihood of the lighting designer developing impractical, impossible, or inappropriate design layouts or luminaire selections or, in the case of emergency lighting of the egress paths, may help minimize the need for an egress lighting system entirely independent of the *normal power* architectural lighting system. There are typically economic and aesthetic advantages to connecting some of the architectural lighting system equipment to the *emergency power* system.

Relevant codes, ordinances, and mandates (legal requirements) are defined and enforced at the discretion of the AHJ and may be different from project to project and locale to locale. It is not uncommon for different versions of the same code to be required on different projects. These should be identified and their implications reviewed and documented by the design team early in the project. Work scopes should be clearly delineated at that time to avoid later confusion or the potential of non-compliance issues.

Table 12.9 | Typical Prescribed Lighting Design Factors offers a short list of some relevant codes, ordinances, and mandates along with some certification programs. This is a tentative list and should not be considered exhaustive or even complete. See Section 12.7 Prescribed Factors.

In the United States there is a proliferation of legal requirements. Some of these conflict with each other. Some conflict with sustainable practices. The design team must identify all codes, ordinances, and mandates that apply to a project, identify conflicts and determine resolution. The team should subsequently identify any that are deemed unnecessarily restrictive to the project goals, develop proposed resolution and consult with the AHJ. Where more than one AHJ is involved, a determination will need to be made on which authority and code takes precedent. Typically codes involving life safety override conflicting requirements of other codes, ordinances, and mandates.

25.2.1.1 Code Prescriptions for Lighting Equipment

All lighting equipment, including, but not limited to ballasts, drivers, transformers, and lamps, and the luminaires which combine these components into light-producing containers suitable for installation in their intended application and lighting controls should or must

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meet basic safety and operational expectations. Underwriters Laboratories (UL) in the United States, Canadian Standards Association (CSA) in Canada, and Norma Oficial Mexicana (NOM) in Mexico have defined standards to which lighting equipment should be certified for their respective markets of use. In each North American Country, government authorized certification bodies test and certify lighting equipment to the respective standards for various applications, such as a wet location application. For example, in the United States Nationally Recognized Testing Laboratories (NRTLs) perform certification testing to the UL standards. A successful certification results in listing and labeling to the UL standards, evidenced by labeling on the respective component or luminaire. Although exceptions are possible and sometimes warranted, generally the listing and labeling should not be waived. UL/CSA/NOM is used as a generic catch-all reference throughout this handbook to related standards and certifications and the associated testings, listings, and labelings for lighting equipment in respective countries. UL/NRTL is a catch-all reference to the procedure in the U.S. whereby one of many testing labs test, list, and label products to the UL standards.

In addition to basic safety and operational expectations, lighting equipment must meet criteria for its application or use. The National Electrical Code (NEC) in the U.S., the Canadian Electrical Code (CEC), and the Mexican Electrical Code (MEC) establish lighting equipment application requirements.

Normal power is a reference to the electricity normally used when the premises are occupied. When this normal power flows to the architectural lighting equipment, normal power architectural lighting results.

Emergency power is a reference to the electricity provided for use when the normal power supply fails. When this emergency power flows to architectural lighting equipment or emergency lighting equipment or some combination, emergency lighting results.

Hazardous Location Applications

Equipment safety criteria are different for different applications. Where the design program, the licensed and registered architect or engineer, or the AHJ identify applications as hazardous, the lighting equipment and controls must be specified accordingly. Table 25.4 identifies the matrix of hazardous location categories from NFPA 70 (National Electrical Code), a United States code. The lighting designer must seek specific direction from the licensed and registered team professionals on the appropriate hazardous categories for a given application, room, or area. For example, a Class I, Division 2, Group D, T1 hazardous location requires lighting equipment exhibiting those ratings.

Other Location Applications

Equipment for all other locations should be appropriately tested, listed, and labeled for those respective applications. Reference guides to the available listing markings for luminaires for many applications are available [3] [4]. The designer must track, for example, if the intended application is dry, damp, or wet. If wet, is the luminaire likely to receive direct water spray or be submersed? If submersed, to what depth and will this be sustained for the life of the installation except for maintenance or will there be extended periods of dryness, but where the luminaire is expected to continue to operate or where operation is to cease? There are numerous subcategories and branches of testing and rating procedures. The designer must determine the intended application and research product requirements. Luminaires must be specified accordingly.

Required or Desired Luminaire Ratings

The designer must review programming against code, ordinance, and mandated requirements for lighting equipment safety and against client-, team-, or non-lighting-industry-practice requirements or suggestions. It is not uncommon to design lighting to also meet other standards for such applications as clean rooms, containment areas, pharmaceutical research and development and production, and food processing. Some of these standards might be codified by the AHJ while others may be imposed or suggested with good intentions, but unknown lighting provenance. The designer should identify those considered valid to the tasks and lighting involved and review with the team and client. Where conflicts arise with legal requirements or good lighting judgement, these must be resolved with the relevant parties.

Installation

The contractor is expected to follow installation requirements set forth by codes and manufacturers. Although not a responsibility of the designer, some familiarity with installation

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Table 25.2 | Safety and Security Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d] Horizontal (E_h) Targets — Visual Ages of Observers (years) where **at least half** are <25	25-65	>65	Vertical (E_v) Targets — Visual Ages of Observers (years) where **at least half** are <25	25-65	>65
		Category ▼		Gauge ▼	Category ▼		Gauge ▼
SAFETY, BASIC	Default illuminance criteria solely for basic safe circulation typically in interior situations not sensitive to light. See SAFETY, DARK for light-sensitive situations.						
• **High Degree of Hazards**	High degree of visual detection necessary. Typified by small or low-contrast or inconsistent objects or surface or planar changes.						
• **High Circulation Activity**[i]	Typified by periods of high people counts. E_h @floor.						
• **High Surface Reflectances**	LRVs 90%-60%-20% (ceilings-walls-floors)	40	40	40 Min			
• **Medium Surface Reflectances**	LRVs 60%-40%-10% (ceilings-walls-floors)	50	50	50 Min			
• **Low Surface Reflectances**	LRVs 30%-20%-5% (ceilings-walls-floors)	75	75	75 Min			
• **Medium Circulation Activity**[i]	Typified by periods of medium people counts. E_h @floor.						
• **High Surface Reflectances**	LRVs 90%-60%-20% (ceilings-walls-floors)	20	20	20 Min			
• **Medium Surface Reflectances**	LRVs 60%-40%-10% (ceilings-walls-floors)	30	30	30 Min			
• **Low Surface Reflectances**	LRVs 30%-20%-5% (ceilings-walls-floors)	40	40	40 Min			
• **Low Circulation Activity**[i]	Typified by periods of low people counts. E_h @floor.						
• **High Surface Reflectances**	LRVs 90%-60%-20% (ceilings-walls-floors)	10	10	10 Min			
• **Medium Surface Reflectances**	LRVs 60%-40%-10% (ceilings-walls-floors)	20	20	20 Min			
• **Low Surface Reflectances**	LRVs 30%-20%-5% (ceilings-walls-floors)	30	30	30 Min			
• **Low Degree of Hazards**	Low degree of visual detection necessary. Typified by large or high-contrast or consistent objects or surface or planar changes.						
• **High Circulation Activity**[i]	Typified by periods of high people counts. E_h @floor.						
• **High Surface Reflectances**	LRVs 90%-60%-20% (ceilings-walls-floors)	8	8	8 Min			
• **Medium Surface Reflectances**	LRVs 60%-40%-10% (ceilings-walls-floors)	10	10	10 Min			
• **Low Surface Reflectances**	LRVs 30%-20%-5% (ceilings-walls-floors)	15	15	15 Min			
• **Medium Circulation Activity**[i]	Typified by periods of medium people counts. E_h @floor.						
• **High Surface Reflectances**	LRVs 90%-60%-20% (ceilings-walls-floors)	6	6	6 Min			
• **Medium Surface Reflectances**	LRVs 60%-40%-10% (ceilings-walls-floors)	8	8	8 Min			
• **Low Surface Reflectances**	LRVs 30%-20%-5% (ceilings-walls-floors)	10	10	10 Min			
• **Low Circulation Activity**[i]	Typified by periods of low people counts. E_h @floor.						
• **High Surface Reflectances**	LRVs 90%-60%-20% (ceilings-walls-floors)	4	4	4 Min			
• **Medium Surface Reflectances**	LRVs 60%-40%-10% (ceilings-walls-floors)	6	6	6 Min			
• **Low Surface Reflectances**	LRVs 30%-20%-5% (ceilings-walls-floors)	8	8	8 Min			
SAFETY, DARK	Default illuminance criteria solely for safe circulation typically in interior light-sensitive situations such as photographic film handling and auditoria, ballrooms, classrooms, lecture halls, and theaters during focused-light presentations or performances.						
• **Low Degree of Hazards**	Dark default situation is based on low degree of visual detection necessary and low circulation activity regardless surface reflectances. Otherwise see SAFETY, BASIC.						
• **Low Circulation Activity**[i]	Typified by periods of low pedestrian traffic. E_h @floor.	2	2	2 Min			
SECURITY	See IESNA G-1 | Guideline for Security Lighting for People, Property, and Public Spaces for criteria when security lighting is deemed necessary. Typically addressing interior and exterior situations.						

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1	10:1				
	2:1	10:1				
	2:1	10:1				
	2:1	10:1				
	2:1	10:1				
	2:1	10:1				
	2:1	10:1				
	2:1	10:1				
	2:1	10:1				
	2:1	10:1				
	2:1	10:1				
	2:1	10:1				
	2:1	10:1				
	2:1	10:1				
	2:1	10:1				
	2:1	10:1				
	2:1	10:1				
	2:1	10:1				
	5:1	20:1				

Notes for Table 25.2

The table column headings are discussed in detail in 25.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 25.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 25.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 25.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours.

g. Tasks with specular components, like some stone floors, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 25.3 | SI Dimensional Conversions

US Customary	SI
General	**Hard Conversion**
inches	mm [inches × 25.40]
feet	m [feet × 0.30]
Specific	**Convenient Conversions[a]**
2'	610 mm or 0.6 m
2' 6"	760 mm or 0.75 m
3'	915 mm or 0.9 m
3' 6"	1065 mm or 1.1 m
4'	1220 mm or 1.2 m
5'	1525 mm or 1.5 m

a. Hard conversions rounded for reporting convenience. Not to be confused with metric-sized luminaires or other building materials. Not for precision construction.

aspects is recommended. The designer of the lighting, if not also the designated licensed and registered architect or engineer on the project, must coordinate luminaire specifications with respect to any installation and other application requirements as directed by the licensed and registered professionals. For example, this can include earthquake clips and safety cables or other such items affecting equipment safety and that can be specified as part of the luminaires.

Junction boxes supporting luminaires weighing 50 pounds or less must be rated and properly installed to support the weight of the luminaire. Otherwise the luminaire must be independently supported. For chandeliers over 50 pounds, for example, independent support is needed as is additional independent support to accommodate one or several safety cables. This structural support work must be coordinated by the registered professionals with the installer and may involve structural engineers. Coordination with the manufacturer of the specified lighting equipment may also be necessary.

25.2.1.2 Code Prescriptions for Illuminance

Illuminances for a number of applications are now prescribed by a variety of codes, ordinances, and mandates. The design team must coordinate and reconcile with the AHJ any instances where codes, mandates, standards, and green ratings conflict. The illuminance values and the number of applications vary by jurisdiction and change from time to time. Some illuminance mandates are accompanied by uniformities. Application examples, which vary by code and jurisdiction, include, but are not limited to:

Normal Power Prescriptions

Subject to the design team's and AHJ's interpretation, these prescriptions are for the noted application during normal power (non-emergency) situations.

- Barber shops
- Beauty salons
- Classrooms
- Facilities for the disabled
- Egress (designated exit circulation) paths
- New egress stairs
- Old egress stairs
- Elevator landing sills or thresholds on both sides of elevator door
- Escalator treads and landings
- Food service areas
- Machine rooms
- Moving walkways
- Occupied spaces with limited or no daylight
- Pools and Spas
- Restrooms

Emergency Power Prescriptions

Subject to the design team's and AHJ's interpretation, these prescriptions are for the noted application during emergency situations.

- Egress paths
- Egress stairs
- Outdoor paths to some safe distance

Most of these prescriptions involve illuminance minima. At this writing, some of the minima prescribed for normal power situations, are high. This results in relatively significant average illuminance values that require relatively large proportions of the project's available energy. Typically, average illuminances are two to three times greater than minima, which for corridors in the vicinity of elevator landing sills as well as for new stairs might need to be as high as 200 to 300 lx. Additionally, the resulting surface luminances in these normal power situations may be disturbingly greater than those of adjacent areas. With-

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Table 25.4 | Hazardous Location Classifications[a]

Category	Definition
Class	**Type of explosive danger in the area**
	• Class I: Flammable gases or vapors
	• Class II: Combustible dusts
	• Class III: Combustible fibers or flyings
Division	**Likelihood of a hazardous atmosphere**
	• Division 1: Flammable or combustible concentrations likely under normal operating conditions
	• Division 2: Flammable or combustible concentrations unlikely under normal operating conditions
Group	**Rating of the fire and explosion characteristics of a material**
	• Groups A, B, C, and D: Flammable gases and vapors
	• Groups E, F, and G: Combustible dusts
Temperature	**Maximum safe equipment operating temperature allowed for the hazardous atmosphere**
	• T1 to T6 (highest to lowest) temperature classifications

a. See NFPA 70 National Electrical Code Article 500 [2].

out code rewrites, the best alternatives to such high normal power illuminance situations are seeking documented variances to code prescriptions in favor of the normal power IES criteria cited throughout the handbook for various applications and tasks or design to code and make and document the required design and power budget adjustments. Regardless, all must be reviewed by the team and agreed upon by the licensed and registered professionals and client and accepted by the AHJ.

Early in project planning, the design team must at least identify where collaborative techniques may be beneficial in addressing emergency lighting. Benefits might include cost efficiencies, improved architectural and equipment integration, improved aesthetics, and improved maintenance where normal power architectural lighting can partially or wholly address emergency lighting. The lighting designer supports the engineer and architect and may be directed to adjust architectural lighting equipment specifications or even layouts to accommodate their interpretation of codes and, ultimately, that of the AHJ on emergency lighting requirements.

25.2.1.3 Beyond Code Prescriptions

Code prescriptions aside, the project program or local AHJ may require that provisions be made for sufficient illumination for specific processes or functions such as security, hazardous processes, or the continuity of critical operations. Such applications include, but are not limited to:

- Health care critical care areas
- Security centers
- Gatehouses
- First aid areas
- Critical mechanical, electrical, IT, and communications rooms
- Control rooms
- Hazardous material processing areas
- Other areas deemed critical to the viability of the operation and safety of personnel

The designer of the lighting must coordinate with the electrical engineer, if not one in the same, to establish what constitutes "sufficient illumination" and then lighting and controls and power should be planned accordingly by the respective responsible parties.

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The normal power may fail due to a number of situations, and the design team should consider the implications of these when designing the normal power and emergency power lighting, control, and power distribution. This may affect all or selective normal power architectural lighting luminaire and lamp selections, layouts, optional auxiliary power devices within luminaires, and their proposed control. An emergency may include any, several, or all of the following:

- Utility power failure
- Utility power voltage reduction (brownout) potentially negatively affecting lamp, ballast, driver, or transformer operation
- Power interruption within the premises including total power loss or individual phase or branch circuit failures
- Fire and/or smoke
- Earthquake, flood, hurricane, tornado, or other natural disaster.

25.2.2 IES Safety Lighting

Safe conditions are essential to any inhabited space and the effect of light on safety must be considered. The environment should be designed to help compensate for the limitations of human capability. Any factor that aids visual effectiveness increases the probability that a person will detect a hazard and take appropriate action. In many instances where illumination is associated with accidents, the cause may be attributed to inadequate illuminance levels or poor quality of illumination. All of which can result in poor visibility. However, there are other factors associated with poor visibility which may contribute to accidents. Some of these are: low contrast, direct glare, reflected glare, and harsh shadows. Visual fatigue itself may be an element contributing to accidents. Accidents may also be prompted by delayed adaptation a person experiences when moving from bright settings into dark ones and vice versa.

Visibility for safety is affected by lighting as well as architectural planning, finishes and contrasts, and layouts. Hazards such as curbs, steps, and sloped walkways, for example, should be visible. Where these occur in a consistent or regular fashion with appropriately contrasting finishes and detailing such that they are considered slight hazards, little light is needed for detection. Where hazards occur in an inconsistent or irregular manner, where contrasts are low or nonexistent, or where their sizes and contrasts may be variable such that they are considered high hazards, more light is needed for detection. Where finishes are coordinated to assist visibility, lamps with CRI ≥80 are recommended to improve color contrast.

Where illuminances or luminances are very low or designed to create a special effect or scene, such as in auditoria, clubs, hotels, museums, restaurants, theaters, and the like, care must be taken to identify changes in elevation and direction without detracting from the visual effectiveness of the architectural lighting. These situations are typically considered dark and where low activity occurs.

Table 25.2 identifies IES illuminance criteria related to safety. [5] Baseline criteria address most indoor situations and might be deemed appropriate for some outdoor situations. A citation for dark situations is appropriate where dark settings are expected as a part of the overall function or activity of the application.

In situations where safety lighting is considered appropriate, uniformities contribute significantly to the overall effectiveness. Maximum-to-minimum uniformities for basic safety situations should be no greater than 10-to-1 (10:1).

25.2.3 Security Lighting

Establish the rationale for a need for security lighting. Implementing security lighting will likely involve an increase in illuminance and lighting power densities of at least 50%.

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Issues of unwanted attention from higher illuminances, glare, accommodating additional hardware, and, in outdoor settings, light trespass and light pollution must be addressed. Security lighting should be applied in a limited and strategic manner and only where normal application illuminances are considered inadequate. Refer to other application illuminance tables where some references to security illuminance criteria are made, such as Table 22.2 | Common Applications Illuminance Recommendations/TRANSITION SPACES/Lobbies/Security Screening. See Figure 25.1.

In security situations where color recognition is important, lamps should exhibit CRIs ≥ 80. This will assist with the distinguishing of vehicular colors, skin tonal differences, and clothing colors.

Where lighting is deemed necessary for security and no criteria is available in other application chapters, check the bookstore at www.ies.org for updates on security lighting dated 2011 or later. If no updates are available, then document criteria using the procedure outlined below based on IES G-1-03 | Guideline for Security Lighting for People, Property, and Public Spaces. Alternatively, establish and document criteria using the procedure below based on Table 4.1 | Recommended Illuminance Targets. Regardless, at the designer's discretion, adjustments may be deemed appropriate to account for activity levels, nighttime outdoor lighting zones, and mesopic adaptation. Age determination should be well-deliberated and based on anticipated use. All adjustments should be documented and the recommended criteria reviewed with the team and client. BUG ratings may be mandated and must be addressed during development of design techniques and selection of luminaires.

Document the following procedure to establish recommended security lighting illuminance criteria to review with the team and owner for the project at hand.

1. Review Section 4.12 An Illuminance Determination System.
2. Establish an illuminance category for each security activity and task appropriate to the level of activity, the nighttime outdoor lighting zone, and background ambient.
3. Assess observers' ages and determine appropriate horizontal and vertical illuminance targets.
4. Determine design gauge (average, minimum, maximum) and uniformities.
5. Determine if mesopic multipliers are appropriate.
6. Finalize recommended security illuminance criteria for the project.

An Illuminance Determination System

Section 4.12 outlines the latest IES system for determining illuminance criteria. Illuminance categories are identified in Table 4.1 | Recommended Illuminance Targets. Security situations may involve interior and exterior settings during daytime or nighttime hours or both. Precedent suggests illuminance categories that increase normal application illuminances by between 50% and 100% make an appropriate pool from which to determine security illuminance criteria. There are situations where less light is appropriate for enhanced security, such as in control rooms and one-way-viewing situations. However, the designer must assess these criteria in the context of activity level and lighting zone.

Activities and Tasks

Outline the various activities and tasks to be addressed with security lighting. This may be a lifting, extension, or modification of those activities and tasks cited in other application illuminance tables or a completely different assessment by the designer based on a task survey (see Table 12.3 | Sample Visual Task Survey). Some activities and tasks addressed in other chapters, such as stairs or elevator lobbies (see Table 22.2 | Common Applications Illuminance Recommendations), may be deemed appropriate. In any event, most, if not all, activities and tasks will have a need for horizontal and vertical illuminance criteria.

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Figure 25.1 | Security Screening
Here additional lighting was used to define a security task zone consisting of an X-ray machine to the far left and an adjacent metal detector. Horizontal illuminance assists in the event of a search of a purse, brief case, or other personal belonging. Vertical illuminance assists with overall visual assessment of approaching visitors (see TRANSITION SPACES/Lobbies/Security Screening in Table 22.2)
» Image ©Photographer: James Haefner

The designer must define and track these planar requirements. For security situations, horizontal illuminance criteria are at the plane of particular interest, many times pavement or floor plane or desk, counter, or transaction height. Vertical illuminance criteria are related to seated, standing, or walking face height. The designer must establish which viewing directions are most important with a minimum of two directions of travel and sometimes up to four when walking is involved. This depends on the intended perspective or points of observation and whether observation is live-on-site or monitored or recorded.

Preliminary Illuminance Categories
For each of the activities and tasks and planes of interest, identify a preliminary illuminance category based on experience, IES precedent, or study of the categories' typical application and task characteristics and the visual performance description in Table 4.1. Developing a table outlining criteria for all three methods would allow the designer to use averaging or at least understand the extent of the variances. The goal is to establish the lowest illuminance criteria appropriate to the security need. Overlighting as a convenience is inappropriate.

Activity Level
For some indoor and many nighttime outdoor applications, activity levels influence illuminance criteria. Nighttime outdoor high activity levels, for example, demand greatest illuminances to address the volumes of vehicular and pedestrian traffic. From Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions, identify the anticipated activity level. For those activities and tasks where vehicles are involved or where vehicles and pedestrians interact, use the outdoor activity level category. For those activities and tasks where only people are involved, use the indoor activity level category. If the activity level is expected to change according to time of day, identify the various activity levels and their durations. Generally, a "high activity" level gives merit to the highest illuminance under consideration. A "medium activity" level gives merit to the moderate illuminance under consideration. A "low activity" level gives merit to the lowest illuminance under consideration.

Nighttime Outdoor Lighting Zone
In outdoor situations, lighting zones influence illuminance criteria. Lighting zones in more urban areas require greater illuminances given densities of nighttime activity and a need to maintain states of adaptation consistent with surroundings. If not codified as part of an ordinance, code, or sustainable initiative, then from Table 26.4 | Nighttime Outdoor Lighting Zone Definitions determine the most appropriate lighting zone descriptor

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for the environmental setting within which the project is located. Generally, Z4 and Z3 give merit to the highest illuminance under consideration. For each step reduction in lighting zone, a concomitant step reduction in illuminance category is merited. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits. This typically precludes the use of adjustable spot or flood lights and restricts the wattage and output of shielded and optically-controlled area luminaires.

Background Ambient

Where security lighting is intended to accentuate an area for purposes of visual surveillance, the immediate background brightnesses affects the security illuminance. Higher security illuminances are necessary where backgrounds are brighter. Similarly, darker immediate backgrounds require lower security illuminances.

Assess Observers' Ages

The illuminance categories outlined in Table 4.1 each consist of a range of three illuminance targets with: a low value associated with situations where the visual ages of at least half the observers are less than 25 years old; a middle value associated with situations where the visual ages of at least half the observers are between 25 and 65 years old; and a high value associated with situations where the visual ages of at least half the observers are greater than 65 years old. Deliberation might include the hours of operation and the security personnel demographics at various times of day and night. Where observers' visual ages are equally split among the three age groups, the designer must establish recommendations based on other techniques, such as combining two groups to establish a majority and using the older group's illuminance criteria or using the 25-65 age group's illuminance criteria, and reviewing the outcome with the team and client. Once visual ages are established, the designer can identify recommended illuminance targets for the security activity and task.

Design Gauges and Uniformities

Security illuminance targets must be calculated and measured against a gauge of average, minimum, or maximum. Using average as a gauge is recommended along with a uniformities of average-to-minimum and of maximum-to-minimum defines the upper and lower limits on illuminance. This assures some minimal illuminance for detection and adaptation purposes while also minimizing the detrimental effects of overlighting were no maximum to be set. Uniformities vary greatly depending on the kind of surveillance. Average-to-minimum ratios for live, on-site surveillance may be as great as 8-to-1 (8:1). Remote monitoring and recording with cameras may demand tighter uniformities to meet the capabilities of the cameras. The tighter the maximum-to-minimum uniformity ratio, the more consistent the illuminance.

Mesopic Multipliers

As identified in 4.12.3 Spectral Effects, an additional modifier for low luminance situations accounts for users' adaptation states. Adaptation state is important in developing recommended illuminance criteria for low-light activities and tasks which may correspond to nighttime outdoor or indoor patrol.

Generally, as eyes adapt to the lower luminances experienced in low-illuminance settings, mesopic adaptation occurs, typically at or below 3 cd/m^2. See Table 2.1 | Vision Adaptation States. These are luminances that might be experienced in low-light situations with moderate-to-low surface reflectances or in very-low-light situations with moderate-to-high reflectances. Such as might occur in some security situations. Under mesopic adaptation, lamps with spectra exhibiting shorter wavelengths (cooler-toned color quality) are more efficacious than longer wavelength (warmer-toned counterparts). It is quite possible, especially where illuminances are less than 10 lx, to find a specific design situation where an assessment of background luminance shows, for example, that a lighting system using standard 2000 K HPS lamps is 13 percent less efficacious than one using 3000 K CMH lamps or 19 percent less efficacious than one using 4000 K CMH

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lamps. See Table 12.7 | Pedestrian Way Mesopic Multiplier Example Worksheet and Table 26.6 | Parking Deck Mesopic Multiplier Example Worksheet. Both examples outline steps involved in determining if observers are likely to be in the mesopic adaptation state and, if so, the affect of various lamping options on illuminance criteria for the example.

Using the method outlined in 4.12.3 and Figure 4.27, mesopic multipliers adjust the illuminance criteria to account for the anticipated photopic background luminance and the spectra of the lamps under consideration. In the example in Table 26.6, in the design phase, this means illuminance criteria would need to be increased if HPS lamps are under consideration for the specific design situation discussed here or decreased if CMH lamps are under consideration. This can affect lamp wattages or luminaire layouts or both and may greatly affect connected loads or control schemes for night operation and curfew situations.

Finalize Recommended Illuminance Criteria
Itemize nighttime and daytime horizontal and vertical security illuminance and uniformity criteria.

25.3 Illuminance Criteria

Illuminance criteria, when fully deployed, are a robust set of quantitative values that influence visibility, visual performance, and visual comfort and attention. Short-circuiting the criteria selection or designing to a single criterion value, such as horizontal illuminance, to address worst-case tasks or simply overlighting areas for convenience of design will surely result in dissatisfaction. Even if clients accept the visual results, not getting the most from the energy expended or, worse, energy waste is a likely result. Following are notes related to various aspects outlined in Table 25.2.

25.3.1 Applications and Tasks

Applications and tasks encountered on any given project may be different from those identified in Table 25.2 and may warrant different illuminance criteria. Cross-referencing closely-associated applications or tasks is appropriate. Sometimes naming trends or conventions for space types or functions change to conform to current practice, client programming, or architectural, landscape, or civil engineering conventions, but the actual activities and tasks remain the same and this cross-referencing works. Failing this technique, reviewing the list in Table 25.2 or those in other application chapters may be in order to determine if any applications or tasks exhibit a similar visual-component to the unique applications or tasks. Otherwise, reviewing 4.12 An Illuminance Determination System and Table 4.1 is necessary to establish a task category based on the task characteristics or visual performance descriptions most closely associated with the unique applications or tasks. These exercises as well as any deviations from recommendations the designer intends to make should be carefully documented for the record.

25.3.2 Notes

Notes may refer to other application and task headings in the table or to other handbook chapters as appropriate. Where some degree of clarification is warranted, notes are made.

25.3.3 Recommended Maintained Illuminance Targets

Values cited are maintained on the area of coverage for the task under consideration. Illuminance is additive. Where practical and without negatively affecting the intended application of light, target values are achieved with any combination of daylighting and/or electric lighting in whatever mix of functional and accent lighting techniques is deemed appropriate to meet these and the other lighting goals established during design. See 12 | COMPONENTS OF LIGHTING DESIGN and see 10.7.1 Light Loss Factors. Lighting for emergency and lighting for safety is tested periodically, at least as frequently as code requires.

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With respect to light loss factors, account for anticipated losses through the point in time at which group relamping and cleaning should occur. Group relamping and cleaning should be standard practice, though these need not occur at the same frequency. Periodic cleaning and group relamping essentially maintain the illuminance at criteria and make the most efficient use of the installed equipment. For purposes of sustainability, cleaning and group relamping can no longer be presumed to be infrequent or unlikely. Maintenance procedures must be part of the design discussions with the client. See the IES document IESNA/NALMCO RP-36 Recommended Practice for Planned Indoor Lighting Maintenance for additional information. Where maintenance is deferred or practiced poorly or not at all, the actual illuminance values will fall below criteria targets. This is inefficient, unsustainable, and may be unsafe while adversely affecting users' quality of life or work. Ratcheting initial illuminances higher is poor practice, will result in excess energy use and in many exterior situations, will result in more significant glare, light pollution, and light trespass. Ratcheting illuminances is not recommended. Maintenance procedures may be especially problematic with LEDs where promises of extraordinarily long life may be offered, but usually with the caveat that lamp lumen depreciation (LLD) at that rated life is 70% or perhaps even as low as 50% of initial rating. If replacement cycles are presumed to be rated life, then LLD alone must be 0.7 or 0.5 or whatever lumen rating is certified by the LED vendor. See 13.3 Life and Lumen Maintenance.

Targets are consensus and recommended for respective functional activity. For some applications, IES recommendations are within 10% of code requirements. This apparently is an artifact of metrication. Footcandle conversions of any values cited in Table 25.2 should be made at 1 fc to 10 lx. This soft conversion avoids a redundant diminishing of illuminance values after multiple citations and conversions over time. This also eliminates a false sense of accuracy advanced by an ever-increasing number of decimal places and a false sense of urgency advanced by eccentric fractional values introduced by hard conversions. Nevertheless, a lighting design must meet code and the mechanics of which must be coordinated amongst the design team. The IES recommendations should not, do not, and cannot reflect all of the various code requirements in force in all jurisdictions at any given time.

Targets are intended to apply to the dominant plane of the task, typically, but not always, horizontal or vertical. In some situations, illuminance criteria are cited for one plane, such as the horizontal plane for safe circulation. The blank signifies that illuminance on that plane is unimportant and may be a consequence of the illuminance of other applications or tasks within the vicinity or by whatever illuminance results from meeting the target illuminance for the prescribed plane of interest.

25.3.3.1 Target Planes

Many, though certainly not all, tasks are performed with the task in roughly a horizontal orientation or vertical orientation. A dominant orientation must be assigned and the illuminance target determined accordingly. There may be situations where the IES recommended target relating to the typical planar mode of a task must be applied to a different plane.

Nearly all tasks are expected to have both a horizontal illuminance component (E_h) and a vertical illuminance component (E_v). This allows some degree of task flexibility for off-plane viewing and accommodates various aspects of the task. In many exterior pedestrian applications, horizontal- and vertical-plane illuminances address the common situation where simultaneously walkway pavement visibility is related to horizontal illuminance while facial recognition is related to vertical illuminance.

Some illuminance targets, such as those for some security situations where task visibility and facial recognition are intended at differing planar elevations and must be deliberated and established by the designer. For criteria purposes, standing face height is defined by an imaginary vertical plane oriented perpendicular to the primary direction of travel and centered at 5' above finished grade (AFG). Illuminance criteria are applied to one

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or both sides of this plane at consistent spacing increments along the length of the area under surveillance, for example, depending on the direction of observation. Establishing and tracking task orientations and addressing both horizontal and vertical illuminance is necessary. In some security situations involving pedestrians, at least two vertical planes are of interest, both perpendicular to the direction of main travel on the path, one opposing the other. This is an important distinction for luminaire optical selection and orientation capabilities and for layout, calculations, and field measurements.

25.3.3.2 Visual Ages of Observers

Illuminance criteria are based on the visual ages of more than half the intended observers. The designer must coordinate with the design team and client to establish the age group of the intended observers. During deliberations, the designer and client should review precedents as well as implications of tentative criteria proposals on infrastructure, cost, and user performance. The aspects of observers' ages and illuminance targets should be resolved during programming with the client. See 12.5.5 Illuminance and 4.12 An Illuminance Determination System for additional information and guidance.

25.3.3.3 Illuminance Categories

Illuminance categories are designated by letters A through Y. These are shown in Table 25.2 for more convenient reference to Table 4.1 | Recommended Illuminance Targets should the designer wish to explore other criteria targets or if applications or tasks on a specific project are not readily correlated to the table citations.

25.3.3.4 Gauge

The common gauge for determining illuminance target compliance is cited for each application. All gauges presume that point-by-point techniques are used for predictive calculations and presume that uniformity criteria are closely monitored. Where an average illuminance value over the area of coverage can satisfy target compliance, "Avg" is cited. In applications or tasks where a minimum or maximum target is necessary, the gauge for compliance is "Min" or "Max" respectively.

The designer may elect to use other methods to evaluate target compliance, such as criterion rating (CR) or coefficient of variation (C_v). See 4.12.4.5 Tasks at Uncertain Locations Over a Large Area.

In any event, once illuminance targets and uniformities are established, then any calculated deviation from them should be limited. Standard engineering allowance of ±10% might be acceptable for targets gauged as average unless contractual or code obligations demand otherwise. Minima and maxima must be achieved as intended.

Designs should be adjusted until predictions are within allowance for averages and meet minima and maxima. For additional information, see 4.12.4.1 Recommended Illuminances at Design Time, 4.12.5 Illuminance Ratios, 9.15.1.1 Average Illuminance, and 10.8 Assessing Computed Results.

25.3.4 Uniformity Targets

Illuminance uniformity targets work in conjunction with luminance uniformities and surface reflectances all of which must be addressed as part of the design to avoid visual discomfort, glare, and strain. Uniformity ratios are targets that define the widest recommended ranges. In many situations, uniformity ratio criteria are those between average values of an array of points and the minimum value in the same array of points. Uniformity targets apply to both horizontal and vertical illuminances over the area of coverage. Where horizontal uniformity criterion is different from vertical uniformity criterion, two ratios are reported with the first value for horizontal illuminance (E_h). In some situations, notably those with regard to exterior illuminances, two uniformity values are cited. The first value addresses the primary cited application or task. The parenthetical value references the parenthetical application or task, such as a curfew situation associated with nighttime outdoor lighting.

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Generally the more important speed and accuracy and the more demanding the visual task, the tighter the ratio.

25.3.4.1 Maximum-to-average

This is the recommended ratio of maximum illuminance to the average illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations sensitive to even a relatively small degree of overlighting.

25.3.4.2 Average-to-minimum

This is the recommended ratio of average illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where illuminance too far below average conditions is noticeable and detrimental to task performance or inconsistent with normal expectations.

25.3.4.3 Maximum-to-minimum

This is the recommended ratio of maximum illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where too much variation in illuminance is considered undesirable and untenable from a performance or safety perspective.

25.3.5 Daylighting Advancement

Generally, design strategies should embrace any combination of daylighting and electric lighting to achieve target values during daylight hours. The preference is for daylighting to provide all or most of the recommended illuminance presuming that all aspects of daylighting are properly addressed. A sunburst icon depicts those applications and tasks where daylighting is considered a strategic candidate. Use photocells and stepped-switching, stepped-dimming, or continuous dimming to reduce or eliminate electric lighting when not needed during daylight hours. See 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Even for those applications where daylighting is not traditionally a strategic candidate, it may be determined that very careful and coordinated design will offer great sustainability opportunities along with positive influences associated with daylight and views.

25.3.6 Veiling Reflections

Tasks with specular components, which in exterior settings include glossy metal, stone, or glass surfaces as might be found on facades, walls, or artworks and wet or dry pavement, are prone to specular reflections. Where such reflections veil important task information, such as grade changes, then these are known as veiling reflections. Diffuse-optic, low-wattage, and multiple luminaires can minimize the effects of veiling reflections, but not eliminate them. Diffuse-finish materials for walls, flooring, pavements, facades, and the like are helpful.

25.3.7 Defining Areas of Coverage

In addition to establishing planes of task orientation, the areas of coverage to which targets apply must be determined. Typical areas of task illuminance coverage are identified here, but these may not be appropriate to specific project situations. One area of coverage is “task proper or task area.” Here, the illuminance criteria are applied to the task itself or to a relatively small area to which the task is confined. In some situations, such as accenting, the “task” area may consist of the entire wall when “feature wall” or “perimeter” accenting is desired.

Another area of coverage is “room or designated area.” In this situation, illuminance criteria are applied to the room or an area of fairly substantive size representing the zone in which the applications and tasks are expected to occur. The designated area is typically established by the functional layout, such as that for a parking deck, but should be scrutinized by the design team. An assessment and determination must be made on which area of coverage best satisfies the lighting goals on a particular project.

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IESH/10e Economics Resources

> 15.3.3 Budgets
- for more on budgets and value engineering

> 18 | ECONOMICS
- for more on estimating costs
- for more on life cycle costs
- for more on paybacks and rates of return

IESH/10e Energy Efficiency Resources

> 17.2 New Construction
- for more on designing for daylighting
- for more on electric lighting equipment
- for more on lighting controls

> 17.4 Lighting Efficiency Codes, Regulations and Standards
- for more on application standards
- for more on equipment regulations

IESH/10eLightingExteriorsResources

> 12.5.5.6 Nighttime Outdoor Illuminances
- for more on lamp efficacies under mesopic adaptation

> 26 | LIGHTING FOR EXTERIORS
- for more on criteria

IESH/10e Sustainability Resources

> 13.11 Sustainability
- for more on lamps

> 19 | SUSTAINABILITY
- for more on controls
- for more on earth resources
- for more on energy
- for more on life cycle analyses
- for more on lighting design
- for more on recycling

25.4 Designing

Information provided here is specific to emergency, safety, and security and should be used as part of the design and documentation processes outlined in Chapters 12, 15, and 20. Coordinate this emergency, safety, and security lighting with that criteria selected from other application chapters. Addressing all code requirements is a must. For outdoor applications, lamps and ballasts, transformers, and drivers must be selected for ambient temperature conditions, some of which are extremely hot and others extremely cold. Energy efficient and sustainable practices are an integral part of all IES recommendations. Key design tenets include, but are not limited to:

- designing for the satisfaction of the observers intended to use the project
- using baseline reflectances of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively) in interior production, circulation, and work-oriented spaces
- using daylighting that meets luminance and illuminance criteria
- using highest-efficacy lamps that meet color, optical and electrical control, and output criteria
- using highest-efficiency luminaires that meet aesthetic and luminance criteria
- using accenting to provide luminance balancing or improve brightness perceptions where necessary
- using controls liberally, preferably automated varieties such as presets, occupancy and vacancy sensors, astronomical time clocks, and photocells
- establishing IES-recommended illuminance criteria to meet programmed tasks
- establishing layouts that just meet IES-recommended illuminance criteria
- addressing outdoor environmental needs
- using calculations, photometrically-realistic renderings, and operational samples and mockups to prove concepts
- identifying and designing to code-specific requirements, if any, for ambient, task, and accent lighting
- documenting all code-, energy-, sustainability-, and IES-criteria compliance
- documenting criteria and design deviations and rationale and subsequent disposition by team, client, or AHJ
- documenting clearly the layouts, controls, and luminaire and lamp selections

Designing for the satisfaction of the observers is the paramount design tenet and must be kept in perspective during all aspects of design. If the observers' expectations are not fulfilled, then how much energy could be saved is moot, as is how many fewer earth resources were spared, as is how much the whole affair cost or how much value engineering saved or the photogenic qualities of the project. See sidebar references for additional guidance on the key tenets. The design effort must be undertaken with coordinated and realistic expectations by all involved on initial and life cycle costs. Budgeting should include designer input and dialogue with the team and client at project commencement and design milestones. In other words, and paraphrasing Thomas Edison, genius is, indeed, just 1% inspiration and 99% perspiration.

25.5 References

[1] Mark S. Rea, ed. 2000. The IESNA lighting handbook: Reference and application. 9th edition. New York: IESNA. Ch 29.

[2] [NFPA] National Fire Protection Association. 2011. Article 500. In: NFPA 70 National Electrical Code. 12th Edition. Quincy: National Fire Protection Association.

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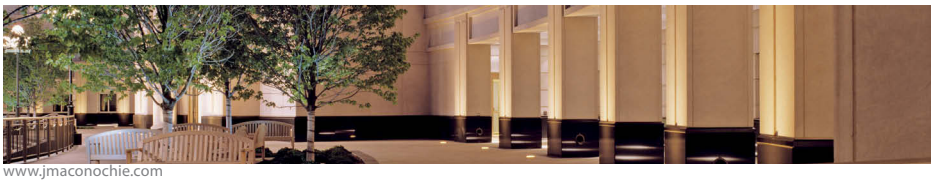
[3] [UL] Underwriters Laboratories. 2010. Underwriters Laboratories marking guide luminaires [Internet]. UL. [cited March 13, 2011]. Available from: http://www.ul.com/global/eng/pages/offerings/perspectives/regulator/publications (under Luminaires Marking Guide) LuminairesMG_April2006_Final.pdf.

[4] [UL] Underwriters Laboratories. 2010. Underwriters Laboratories marking guide swimming pool equipment, spas, fountains hydromassage bathtubs [Internet]. UL. [cited March 13, 2011]. Avilable from: http://www.ul.com/global/eng/pages/offerings/perspectives/regulator/publications (under Swimming Pool and Spa Equipment Marking Guide) SwimmingPoolSpaMG.pdf.

[5] Kaufman JE. 1973. Lighting for safety. LD+A. March, 1973. 14(3): 6-8.

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26 | LIGHTING FOR EXTERIORS

Discontent is the first necessity of progress.
Thomas Alva Edison, 19th and 20th Century Inventor, Scientist, and Businessman

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Any lighting of any exterior demands a disciplined procedure equal that known to be successful for interior lighting applications. Illuminances and luminances must be carefully determined to advance commerce, culture, satisfactory perceptions of safety and security, and nighttime enjoyment of the natural and built scenery which is quite different from that experienced under daylight. All of this must be balanced with minimal energy use and respect for the natural night environment and fellow humans. What follows is a discussion of the key aspects affecting lighting for people in exterior applications: project status; space types; activities; application-specific design goals, and, where available, illuminance criteria.

Comprehensive design efforts must also rely on material related to outdoor settings in 12 | COMPONENTS OF LIGHTING DESIGN, 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS, 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. The designer should have a thorough understanding of the design tenets outlined in those chapters, must identify those deemed appropriate for outdoor settings, and develop lighting goals and strategies accordingly. This chapter primarily addresses specifics related to lighting for exteriors which should influence luminaire optical selections, lamping, and final layouts based on previously developed thought-starters (see 15.2 A Lighting Scheme). Using material in this chapter to the exclusion of material in Chapters 12, 13, 14, and 15 will likely lead to unsatisfactory results. Previous and current IES related documents serve as archival references [1] [2] [3].

Considerable deliberation is in order for many of the exterior applications outlined in this chapter. The application-specific interior and exterior illuminance recommendations outlined in other chapters of this handbook are based on the current IES illuminance determination procedure [4]. Exterior illuminance criteria related to parking lot, parking structure, pedestrian sidewalks and paths, and street and roadway are not yet aligned with this procedure and remain under development at this writing. For these applications, and until appropriate updates are available, reference to archival information and to 4.12 An Illuminance Determination System are resources.

Table 26.1 offers a checklist of IES lighting topics and criteria related to outdoor lighting. The design team is responsible for determining and addressing outdoor lighting and energy criteria set forth by authorities having jurisdiction (AHJ) which may be different from and supersede IES criteria. See also 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

26.1 Project Type and Status

Before any design work, an understanding of the project type and scope is necessary. New, renovation, and restoration projects each offer varying opportunities. See 11.2 Planning, 11.3.1 Pre-design, and 11.3.2 Schematic Design. A clear understanding of the project type and scope will help establish the extent to which daylighting can address most or many or some of the lighting goals for parking garages. At every opportunity the lighting designer should consider daylighting as a light source.

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Table 26.1 | Exterior Lighting Checklist

Topics
✔ Criteria and Design Resources
Accenting
15.1.1.3 Accent Lighting
Table 15.2 | Accent Illuminance Ratios
Appearance
12.2 Spatial Factors
Table 12.1a | Spatial Factors: Part One/ Pleasantness/Luminaires
Table 12.1b | Spatial Factors: Part Two
Color
12.5.6 Color Considerations
Controls
16 | LIGHTING CONTROLS
Daylighting
14 | DESIGNING DAYLIGHTING
Electric Lighting
15 | DESIGNING ELECTRIC LIGHTING
Flicker
4.6 Flicker and Temporal Contrast Sensitivity
Glare
4.10.1 Discomfort Glare
4.10.2 Disability Glare
Illuminance
This Chapter: Table 26.2
4.12 An Illuminance Determination System
12.5.5.6 Nighttime Outdoor Illuminances
Table 22.2 (BUILDING ENTRIES)
Table 27.2 (AMBULATORY CARE/Porte Cochere)
Table 28.2 (FITNESS CENTER/Pools/Outdoor)
Table 29.2 (EXTERIORS)
Table 33.2 (RESIDENTIAL EXTERIORS)
Table 34.2 (RETAILING, OUTDOOR)
Light Distribution
8.2.2.4 IES Distribution Classification of Outdoor Luminaires
Maintenance
15.4.4 Installation and Maintenance
Systems Integration
12.6 Systems Factors
Veiling Reflections
This Chapter: Section 26.3.6
12.5.4 Veiling Reflections
Visual Tasks
This Chapter: Section 26.2
This Chapter: Table 26.2
Table 11.2 | Programming: Inventory Scope and Specific Examples
12.5.1 Visual Tasks
Table 12.3 | Sample Visual Task Survey

26.2 Application Types

To develop lighting solutions that meet quality, quantity, and operational criteria, an inventory is made of the exterior space, area, or feature types under consideration and the anticipated users, functions, and tasks (see Table 11.2 | Programming: Inventory Scope and Specific Examples and Table 12.3 | Sample Visual Task Survey). Otherwise, lighting cannot be best targeted to the users, their expectations, functions and tasks.

Outdoor application definitions are required early in the project design in order to track design efforts that include inventorying the project knowns, anticipated functions, and tasks and calculating lighting, power, energy, and night-environment compliance. Area names, from which functions can be deduced, and boundaries for tracking should be clearly marked on architectural, landscape, or civil engineering backgrounds. The applications and tasks cited in Table 26.2 | Exterior Illuminance Recommendations should be reviewed against the project knowns and correlated with the named space types and functions to establish recommended illuminance criteria. Seek clarification with the client where discrepancies occur between programming information, the list of outdoor areas, and the available application and task citations in Table 26.2.

Outdoor lighting, unlike indoor lighting, has no built architectural enclosure to contain, capture, and redistribute the light. Any and all outdoor lighting should be employed only when deemed necessary and applied with great care. See Table 15.6 | Nighttime Operational Strategies for Improved Outdoor Environmental Regard. Otherwise, energy waste and light pollution are likely. Where outdoor lighting is deemed necessary, attend to the following:

- Establish and confirm the need for light
- Carefully define areas of application and the application itself
- Establish the lowest illuminance criteria appropriate to the need
- Independently address unique areas of interest
- Design lighting layouts to address only those areas of interest
- Select equipment with distribution and optical control to address criteria
- Use controls to energize, dim, and extinguish lighting to address activity levels

Establish and confirm the need for light. Although convenient to apply lighting to many, every, or most situations, this may be quite unnecessary. For example, on a corporate or college campus pedestrian paths may evolve over time. Some are paved, some are gravel, and others may simply be well-worn earth. It is not necessary or even desirable to illuminate all of these paths, if any of them. Based on programming, determine the typical activity levels of the project. After dusk and before dawn, few if any people may use the paths or a reasonable number of people may use a few key paths. Additionally, project administrators or design team members may determine that a single path or perhaps just a few paths should be designated as the most appropriate for nighttime outdoor circulation. Lighting all paths would likely result in the following: visual clutter with too many luminaires on crisscrossed layouts; some energy waste; some unnecessary light pollution; and some unnecessary initial and operational costs. Lighting one or a few paths in a complete and appropriate manner is a much better result than just meeting horizontal illuminance criteria on pavement for miles of pavement.

Defining finite areas to be illuminated is critical to an efficient and cost-effective design. Assessing how much, if any, light spills beyond those defined areas is a necessary part of the design process. It is unacceptable to define the edges of parking lot pavement, for example, in a calculation study and only assess criteria compliance on the parking lot pavement. An equally important part of the assessment is reviewing illuminances beyond the pavement and limiting these as much as practical.

The application must be well defined. For example, is the parking lot used at night? If so, until what time? What is its busiest time of use and what level of activity is involved? What ages are the majority of drivers at that time?

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The IES Illuminance Determination System discussed in Section 4.12 requires the designer to make many judgments. A single-value illuminance for all tasks and all activity levels and all populations in all situations is generally not appropriate. The designer must make every effort to establish the lowest illuminance criteria appropriate to the need.

Independently addressing unique areas of interest with layouts addressing only those areas helps target lighting energy and coincidentally creates a more visually interesting setting. For example, parking lots, pedestrian paths, plazas, and circulation drives and streets, even where the architectural landscape plans promote compact adjacencies, should not be illuminated to a common-denominator illuminance that conveniently "blankets all of them" using tall poles and high-wattage floodlights. More task-oriented approaches unique to each application should be considered.

Outdoor situations are typically unlike interior situations where background luminance from walls and ceilings helps mitigate glare and helps contain light within close proximity to the luminaires. Luminaires must be selected on the basis of optical control. Floodlights and luminaires that direct light outward and upward should be selected as exceptions for feature accenting and extinguished at mandated or client-imposed curfew. In any event, indiscriminate floodlighting or spotlighting techniques involving the aiming of the photometric-maximum-candlepower (the main beam of light) outward or upward into free air without benefit of louvers or snoots or shields, where no vertical or overhead horizontal surfaces are the intentional targets, and to illuminate distant ground-plane surfaces is inappropriate. Using high-wattage wide-beam (flood-distribution) equipment to illuminate a focal or task area instead of low-wattage targeted-beam equipment is also inappropriate.

Controls alone can save significant amounts of energy and greatly reduce light pollution. Switching all or step-switching some lights off or dimming them at curfew times is appropriate and effective. Programming information should indicate hours of operation and the need, if any, for patrol surveillance lighting. Pending the team's review of reliability for specific applications, motion sensors may offer a means to meet illuminance criteria over limited areas for limited times when activity levels are extremely low.

Color rendering and color temperature for outdoor lamping have a strong influence on users' sense of normalcy and impressions of visual attraction and visual aesthetic of the setting. Operational mockups of lamps under consideration on a project should be reviewed in nighttime outdoor settings similar to those under design. This is especially important where lamp CRIs dip below 80 and where CCTs extend outside the range of 2700 K to 4100 K.

Outdoor lighting, regardless of the illuminance, will not *necessarily* reduce or eliminate crime [5]. However, lighting that addresses normal criteria appropriate for public nighttime activity may be a potential deterrent to criminal activity and provide pedestrians with a sense of security (and a sense of safety). Lamps with CRIs ≥80 help people better identify and distinguish colors. It is also important that the lighting is tuned to the nighttime outdoor lighting zone to avoid adaptation issues. Addressing CRI, nighttime outdoor lighting zones, and normal criteria enable users to see and identify surroundings and potential perpetrators. It is this identification that serves to indirectly deter criminal activity. Perpetrators will learn that their risk of exposure and identification is greater in such well-designed areas. Adding high-wattage, wide-area floodlights and tripling or quadrupling illuminances is generally counter-productive. Where additional lighting at entries or public pedestrian areas is deemed necessary for purposes of security surveillance, this should be relatively low-wattage equipment directing light down and across the limited area of coverage and contributing an average of 10 lx, 25 lx, and 50 lx on the ground plane respectively in rural, suburban, and urban areas [6]. See Figure 22.4.

The following sections are keyed to the major application and task headings in Table 26.2. These discussions, those identified in Table 26.1, and the material in Table 26.2 offer comprehensive qualitative and quantitative criteria.

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Table 26.2 | Exterior Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b,c,d] Horizontal (E_h) Targets — Visual Ages of Observers (years) where **at least half** are <25	25-65	>65	Vertical (E_v) Targets — Visual Ages of Observers (years) where **at least half** are Category	Gauge	<25	25-65	>65	Gauge
ACCENTING	Accenting influences observers' overall brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. See 15.1.1.3 Accent Lighting. These are criteria for consideration in any application. Extinguish at curfew.									
• Art	On artwork plane (typically vertical)				see Table 15.2 (typically "Moderate" or "Soft")					
• Feature	On wall plane or trees				see Table 15.2 (typically "Moderate")					
• Important Focal Point	On focal point plane (typically vertical)				see Table 15.2 (typically "Strong" to "Moderate")					
• Performance Areas	E_h @pavement; E_v @5' AFG	see Table 15.2 (typically "Moderate")			see Table 15.2 (typically "Strong" to "Moderate")					
• Perimeter	On wall plane or trees				see Table 15.2 (typically "Soft")					
BUILDING ENTRIES	See 22 | LIGHTING FOR COMMON APPLICATIONS									
FACADES										
• Facade Details or Features	Key elements or details. Apply strategically to ≤25% of area of building facade. Uniformity ratios are cited here as guides when relatively uniform appearance is desired over the area of application.									
• With Surface Reflectance ≥0.5	Lighter-toned facade materials									
• High Activity[i]										
◦ LZ4[j]	Apply strategically to ≤25% of area of building facade.				O	100	200	400	Max	
◦ LZ3[j] (and LZ4 curfew)	Apply strategically to ≤20% of area of building facade.				N	75	150	300	Max	
◦ LZ2[j] (and LZ3 curfew)	Apply strategically to ≤15% of area of building facade.				M	50	100	200	Max	
◦ LZ1[j] (and LZ2 curfew)	Apply strategically to ≤10% of area of building facade.				L	37.5	75	150	Max	
◦ LZ0[j] (and LZ1 curfew)					-	0	0	0		
• Medium Activity[i]										
◦ LZ4[j]	Apply strategically to ≤25% of area of building facade.				M	50	100	200	Max	
◦ LZ3[j] (and LZ4 curfew)	Apply strategically to ≤20% of area of building facade.				L	37.5	75	150	Max	
◦ LZ2[j] (and LZ3 curfew)	Apply strategically to ≤15% of area of building facade.				K	25	50	100	Max	
◦ LZ1[j] (and LZ2 curfew)	Apply strategically to ≤10% of area of building facade.				J	20	40	80	Max	
◦ LZ0[j] (and LZ1 curfew)					-	0	0	0		
• Low Activity[i]										
◦ LZ4[j]	Apply strategically to ≤25% of area of building facade.				K	25	50	100	Max	
◦ LZ3[j] (and LZ4 curfew)	Apply strategically to ≤20% of area of building facade.				J	20	40	80	Max	
◦ LZ2[j] (and LZ3 curfew)	Apply strategically to ≤15% of area of building facade.				I	15	30	60	Max	
◦ LZ1[j] (and LZ2 curfew)	Apply strategically to ≤10% of area of building facade.				H	10	20	40	Max	
◦ LZ0[j] (and LZ1 curfew)					-	0	0	0		
• With Surface Reflectance <0.5	Darker-toned facade materials									
◦ LZ4[j]	Apply strategically to ≤25% of area of building facade.				Q	200	400	800	Max	
◦ LZ3[j] (and LZ4 curfew)	Apply strategically to ≤20% of area of building facade.				P	150	300	600	Max	
◦ LZ2[j] (and LZ3 curfew)	Apply strategically to ≤15% of area of building facade.				O	100	200	400	Max	
◦ LZ1[j] (and LZ2 curfew)	Apply strategically to ≤10% of area of building facade.				N	75	150	300	Max	
◦ LZ0[j] (and LZ1 curfew)					-	0	0	0		
• Medium Activity[i]										
◦ LZ4[j]	Apply strategically to ≤25% of area of building facade.				O	100	200	400	Max	
◦ LZ3[j] (and LZ4 curfew)	Apply strategically to ≤20% of area of building facade.				N	75	150	300	Max	
◦ LZ2[j] (and LZ3 curfew)	Apply strategically to ≤15% of area of building facade.				M	50	100	200	Max	
◦ LZ1[j] (and LZ2 curfew)	Apply strategically to ≤10% of area of building facade.				L	37.5	75	150	Max	
◦ LZ0[j] (and LZ1 curfew)					-	0	0	0		

Table 26.2 | Exterior Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f] [g] Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min	Task Proper or Task Area	Room or Designated Area

Notes for Table 26.2

The table column headings are discussed in detail in 26.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 26.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 26.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 26.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some general retail sales, the typical area of coverage is "Room or Designated Area" at the planar elevations noted. For applications where task position is known, such as fixed displays or specific gondola layouts, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area" and which may involve different planar elevations that the designer must accommodate.

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Table 26.2 | Exterior Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d] Horizontal (E_h) Targets — Visual Ages of Observers (years) where **at least half** are <25	25-65	>65	Vertical (E_v) Targets — Visual Ages of Observers (years) where **at least half** are <25	25-65	>65
		Category		Gauge	Category		Gauge
FACADES	Facade Details or Features (continued)						
• Low Activity[i]							
◦ LZ4[j]	Apply strategically to ≤25% of area of building facade.	M	50	100	200		Max
◦ LZ3[j] (and LZ4 curfew)	Apply strategically to ≤20% of area of building facade.	L	37.5	75	150		Max
◦ LZ2[j] (and LZ3 curfew)	Apply strategically to ≤15% of area of building facade.	K	25	50	100		Max
◦ LZ1[j] (and LZ2 curfew)	Apply strategically to ≤10% of area of building facade.	J	20	40	80		Max
◦ LZ0[j] (and LZ1 curfew)		-	0	0	0		
• Facade Fields	Relatively large areas of facade or entire facade. Uniformity ratios are cited here as guides when relatively uniform appearance is desired over the area of application.						
• With Surface Reflectance ≥0.5	Lighter-toned facade materials						
• High Activity[i]							
◦ LZ4[j]		L	37.5	75	150		Avg
◦ LZ3[j] (and LZ4 curfew)		K	25	50	100		Avg
◦ LZ2[j] (and LZ3 curfew)		J	20	40	80		Avg
◦ LZ1[j] (and LZ2 curfew)		I	15	30	60		Avg
◦ LZ0[j] (and LZ1 curfew)		-	0	0	0		
• Medium Activity[i]							
◦ LZ4[j]		J	20	40	80		Avg
◦ LZ3[j] (and LZ4 curfew)		I	15	30	60		Avg
◦ LZ2[j] (and LZ3 curfew)		H	10	20	40		Avg
◦ LZ1[j] (and LZ2 curfew)		G	7.5	15	30		Avg
◦ LZ0[j] (and LZ1 curfew)		-	0	0	0		
• Low Activity[i]							
◦ LZ4[j]		H	10	20	40		Avg
◦ LZ3[j] (and LZ4 curfew)		G	7.5	15	30		Avg
◦ LZ2[j] (and LZ3 curfew)		F	5	10	20		Avg
◦ LZ1[j] (and LZ2 curfew)		E	4	8	16		Avg
◦ LZ0[j] (and LZ1 curfew)		-	0	0	0		
• With Surface Reflectance <0.5	Darker-toned facade materials						
◦ LZ4[j]		N	75	150	300		Avg
◦ LZ3[j] (and LZ4 curfew)		M	50	100	200		Avg
◦ LZ2[j] (and LZ3 curfew)		L	37.5	75	150		Avg
◦ LZ1[j] (and LZ2 curfew)		K	25	50	100		Avg
◦ LZ0[j] (and LZ1 curfew)		-	0	0	0		
• Medium Activity[i]							
◦ LZ4[j]		L	37.5	75	150		Avg
◦ LZ3[j] (and LZ4 curfew)		K	25	50	100		Avg
◦ LZ2[j] (and LZ3 curfew)		J	20	40	80		Avg
◦ LZ1[j] (and LZ2 curfew)		I	15	30	60		Avg
◦ LZ0[j] (and LZ1 curfew)		-	0	0	0		
• Low Activity[i]							
◦ LZ4[j]		J	20	40	80		Avg
◦ LZ3[j] (and LZ4 curfew)		I	15	30	60		Avg
◦ LZ2[j] (and LZ3 curfew)		H	10	20	40		Avg
◦ LZ1[j] (and LZ2 curfew)		G	7.5	15	30		Avg
◦ LZ0[j] (and LZ1 curfew)		-	0	0	0		

Table 26.2 | Exterior Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1	10:1				
	3:1	10:1				
	3:1	10:1				
	3:1	10:1				
	3:1	10:1				
	3:1	10:1				
	3:1	10:1				
	3:1	10:1				
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b. Values cited are to be maintained over time on the area of coverage.

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d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some general retail sales, the typical area of coverage is "Room or Designated Area" at the planar elevations noted. For applications where task position is known, such as fixed displays or specific gondola layouts, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area" and which may involve different planar elevations that the designer must accommodate.

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Table 26.2 | Exterior Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d] Horizontal (E_h) Targets — Visual Ages of Observers (years) where **at least half** are: <25 (Category)	25-65	>65 (Gauge)	Vertical (E_v) Targets — Visual Ages of Observers (years) where **at least half** are: <25 (Category)	25-65	>65 (Gauge)
FOUNTAINS	See 26.2.4 for discussion.						
PARKING DECKS	Covered parking facilities. See PARKING LOTS for top of deck lighting. See 26.2.5 for discussion. A checklist of probable application tasks and areas follows for which illuminance criteria should be established.						
• **Dedicated Corners/Ramps**	Lighting should address corners and ramps dedicated primarily, if not exclusively, to vehicular activity with no adjoining parking. E_h @finished floor; E_v @5' AFF in at least the two primary directions of travel. The face is defined by an imaginary vertical plane oriented perpendicular to the primary direction of travel. Illuminances on both sides of the plane are assessed. Coordinate illuminance criteria with observers' ages and high, medium, or low activity level.[i]						
• **Drive Aisles/Parking Areas**	Lighting should address drive aisles and adjacent parking with mixed pedestrian and vehicular activity. E_h @finished floor; E_v @5' AFF in at least the two primary directions of travel. The face is defined by an imaginary vertical plane oriented perpendicular to the primary direction of travel. Illuminances on both sides of the plane are assessed. Coordinate illuminance criteria with observers' ages and high, medium, or low activity level.[i]						
• **Drop-off/Pickup Areas, Interior Vehicle Transaction Areas and Valets**	Lighting should address courtesy drop-off and pickup areas and valets with mixed pedestrian and vehicular activity. Lighting should address vehicle transaction areas distant from covered entry/exit portals. E_h @finished floor; E_v @5' AFF in at least the two primary directions of travel. The face is defined by an imaginary vertical plane oriented perpendicular to the primary direction of travel. Illuminances on both sides of the plane are assessed. Coordinate illuminance criteria with observers' ages and high, medium, or low activity level.[i]						
• **Elevator Lobbies, Pedestrian Transaction Areas, and Stairways**	Lighting should address the lobby proper and pedestrian parking-fee transaction areas. E_h @finished floor; E_v @5' AFF in at least the two primary directions of travel. The face is defined by an imaginary vertical plane oriented perpendicular to the primary direction of travel. Illuminances on both sides of the plane are assessed. Coordinate illuminance criteria with observers' ages and high, medium, or low activity level.[i]						
• **Vehicular Entries and Exits**	Lighting should address vehicular entries and exits and adjacent parking and pedestrian areas. E_h @finished floor; E_v @5' AFF in at least the two primary directions of travel. The face is defined by an imaginary vertical plane oriented perpendicular to the primary direction of travel. Illuminances on both sides of the plane are assessed. Coordinate illuminance criteria with observers' ages and high, medium, or low activity level.[i]						
PARKING LOTS	Open parking facilities, including tops of parking decks. See 26.2.6 for discussion. A checklist of probable application tasks and areas follows for which illuminance criteria should be established.						
• **Drive Aisles/Parking Areas**	Lighting should address drive aisles and adjacent parking with mixed pedestrian and vehicular activity. E_h @grade; E_v @5' AFG in at least the two primary directions of travel. The face is defined by an imaginary vertical plane oriented perpendicular to the primary direction of travel. Illuminances on both sides of the plane are assessed. Coordinate illuminance criteria with observers' ages and high, medium, or low activity level.[i]						
• **Pedestrian Transaction Areas**	Lighting should address pedestrian parking-fee transaction areas. E_h @grade; E_v @5' AFG in at least the two primary directions of travel. The face is defined by an imaginary vertical plane oriented perpendicular to the primary direction of travel. Illuminances on both sides of the plane are assessed. Coordinate illuminance criteria with observers' ages and high, medium, or low activity level.[i]						
• **Vehicle Transaction Areas and Vehicular Entries/Exits**	Lighting should address vehicle transaction areas and vehicular entries and exits.. E_h @grade; E_v @5' AFG in at least the two primary directions of travel. The face is defined by an imaginary vertical plane oriented perpendicular to the primary direction of travel. Illuminances on both sides of the plane are assessed. Coordinate illuminance criteria with observers' ages and high, medium, or low activity level.[i]						
PEDESTRIAN MALLS	See Table 34.2 | Retail Illuminance Recommendations/CENTERS, OUTDOOR						
PEDESTRIAN STAIRS	See Table 34.2 | Retail Illuminance Recommendations/CENTERS, OUTDOOR						

Table 26.2 | Exterior Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
			☀		■	
			☀			■
			☀		■	
			☀		■	
			☀		■	

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d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◥ signals high likelihood; gray and white ◥ signals moderate likelihood; pale gray and white ◥ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

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j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

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Table 26.2 | Exterior Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]					
		Horizontal (E_h) Targets			Vertical (E_v) Targets		
		Visual Ages of Observers (years) where **at least half** are			Visual Ages of Observers (years) where **at least half** are		
		<25	25-65	>65	<25	25-65	>65
		Category		Gauge	Category		Gauge
PEDESTRIAN WAYS AND BIKE WAYS	Outdoor pedestrian and bike circulation paths. See 26.2.9 for discussion. A checklist of probable application tasks and areas follows for which illuminance criteria should be established.						
• **Street-adjacent**	Lighting should address the street-adjacent pedestrian or bike way pavement (sidewalks). See PEDESTRIAN AND BIKE WAYS/Underpass-street-adjacent for discussion related to sidewalks adjacent to streets in underpasses. E_h @grade; E_v @5' AFG in at least the two primary directions of travel. The face is defined by an imaginary vertical plane oriented perpendicular to the primary direction of travel. Illuminances on both sides of the plane are assessed. Coordinate illuminance criteria with observers' ages and high, medium, or low activity level.[i]						
• **Street-distant**	Lighting should address street-distant pedestrian or bike way pavement (paths and walkways including pedestrian- and bike-exclusive bridges and underpasses). E_h @grade; E_v @5' AFG in at least the two primary directions of travel. The face is defined by an imaginary vertical plane oriented perpendicular to the primary direction of travel. Illuminances on both sides of this plane are assessed. Coordinate illuminance criteria with observers' ages and high, medium, or low activity						
• **Underpass-street-adjacent**	Lighting should address the street-adjacent pedestrian or bike way pavement in underpasses. (street sidewalks in underpasses). E_h @grade; E_v @5' AFG in at least the two primary directions of travel. The face is defined by an imaginary vertical plane oriented perpendicular to the primary direction of travel. Illuminances on both sides of this plane are assessed. Coordinate illuminance criteria with observers' ages and high, medium, or low activity level.[i]						
PLAZAS	See Table 34.2 | Retail Illuminance Recommendations/CENTERS, OUTDOOR/Plazas and Town Squares						
POOLS, OUTDOOR	See 28 | LIGHTING FOR HOSPITALITY AND ENTERTAINMENT						
RESIDENTIAL EXTERIORS	See 33 | LIGHTING FOR RESIDENCES						
RETAILING, OUTDOOR	See 34 | LIGHTING FOR RETAIL						
ROADWAYS	See IES RP-8 | Roadway Lighting for criteria for these vehicular-based tasks.						
ROUNDABOUTS	See IES DG-19 | Design Guide for Roundabout Lighting for criteria for these vehicular-based tasks.						
TUNNELS	See IES RP-22 | IESNA Recommended Practice for Tunnel Lighting for criteria for these vehicular-based tasks.						

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Uniformity Targets[e] Over Area of Coverage 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f] [g] Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min	Task Proper or Task Area	Room or Designated Area

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j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some general retail sales, the typical area of coverage is "Room or Designated Area" at the planar elevations noted. For applications where task position is known, such as fixed displays or specific gondola layouts, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area" and which may involve different planar elevations that the designer must accommodate.

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Table 26.3 | SI Dimensional Conversions

US Customary	SI
General	**Hard Conversion**
inches	mm [inches × 25.40]
feet	m [feet × 0.30]
Specific	**Convenient Conversions[a]**
2'	610 mm or 0.6 m
2' 6"	760 mm or 0.75 m
3'	915 mm or 0.9 m
3' 6"	1065 mm or 1.1 m
4'	1220 mm or 1.2 m
5'	1525 mm or 1.5 m

a. Hard conversions rounded for reporting convenience. Not to be confused with metric-sized luminaires or other building materials. Not for precision construction.

26.2.1 Accenting

Accenting affects people's brightness perceptions and provides visual relief and can be used for visual attraction and wayfinding. Accenting illuminance criteria are based on the intended significance of the accented feature and the horizontal illuminance in the locale of observers. Also see 15.1.1.3 Accent Lighting. See Figure 26.1.

26.2.2 Building Entries

Lighting for building entries is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

For building entries, variables affecting recommended illuminance criteria include anticipated levels of activity and the nighttime outdoor lighting zone. Nighttime activity levels may vary by type of facility, by neighborhood, by specific schedules, such as which night of the week, and by other events or activities, such as holidays or overtime work schedules. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions. All of this may demand a control system capable of addressing various settings on various evenings through manual intervention, automated time clock, and photocell functions.

The nighttime outdoor lighting zone within which the facility is located establishes the categories of illuminance for outdoor tasks. Nighttime outdoor lighting zones vary by local ordinance, sustainability guides, or the team's own definition of place. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions.

Business- and after-hours security needs, such as on-site or remote monitoring or recording, may require specific luminaire placement and specific illuminances coordinated with security cameras, and, after hours, may require that some luminaires at building entries remain energized through the night or placed on motion sensors or interconnected with camera operations. Control zones and time clock functions must be designed accordingly. Where remote monitoring is done with infrared cameras, lighting may be unnecessary.

Entry lighting should transition between the indoor and outdoor lighting condition. Both interior and exterior entry illuminances, uniformities, and luminances are important. Entries should be inviting and reflect the indoor setting. Unless a distinct design "break" is part of the scheme, lamp CCTs and CRIs should be based on indoor lamping color. This can even extend to parking and driveway lamp selections.

Figure 26.1 | Accenting
Flags and fountain features are dramatic focal points (see Table 15.2) and designed to 200 lx average (using an assumption of 10 lx for street illuminance [behind the camera]). The trees were considered moderate focal points with canopy illuminance designed to 100 lx average. The tree lighting establishes a visual outdoor perimeter, avoids a black hole effect, and serves as a backdrop for silhouetting effective for security surveillance.

Wet/dry-rated luminaires fitted with 250W/PAR38/SP quartz halogen lamps exhibiting 40,000 cd center beam are centered under each water feature.

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Table 26.4 | Nighttime Outdoor Lighting Zone Definitions

Zone	Outdoor Lighting Situation	Definition
LZ4	High Ambient Lighting	Areas of human activity where the vision of human residents and users is adapted to high light levels. Lighting is generally considered necessary for safety, security and/or convenience and it is mostly uniform and/or continuous. After curfew, lighting may be extinguished or reduced in some areas as activity levels decline.
LZ3	Moderately High Ambient Lighting	Areas of human activity where the vision of human residents and users is adapted to moderately high light levels. Lighting is generally desired for safety, security and/or convenience and it is often uniform and/or continuous. After curfew, lighting may be extinguished or reduced in most areas as activity levels decline.
LZ2	Moderate Ambient Lighting	Areas of human activity where the vision of human residents and users is adapted to moderate light levels. Lighting may typically be used for safety and convenience but it is not necessarily uniform or continuous. After curfew, lighting may be extinguished or reduced as activity levels decline.
LZ1	Low Ambient Lighting	Areas where lighting might adversely affect flora and fauna or disturb the character of the area. The vision of human residents and users is adapted to low light levels. Lighting may be used for safety and convenience but it is not necessarily uniform or continuous. After curfew, most lighting should be extinguished or reduced as activity levels decline.
LZ0	No Ambient Lighting	Areas where the natural environment will be seriously and adversely affected by lighting. Impacts include disturbing the biological cycles of flora and fauna and/or detracting from human enjoyment and appreciation of the natural environment. Human activity is subordinate in importance to nature. The vision of human residents and users is adapted to the darkness, and they expect to see little or no lighting. When not needed, lighting should be extinguished.

26.2.3 Facades

Facade lighting can address a number of goals from functional to decorative or both. Opportunity exists to use facade lighting as a contributor to functional outdoor tasks such as walking, dining, or socializing in some situations, as illustrated in Figure 26.2.

The need or desire for facade lighting should be established during programming. However, the design opportunities for facade lighting may not be known until architectural design schemes have been sufficiently developed. There are three general approaches to facade lighting, where such is deemed essential:

- Lighting facade features or details
- Lighting facade fields
- Some combination

Any of these techniques can be quite effective. However, overlighting, both in intensity and area of coverage, as a result of improper lamp wattage, luminaire optic, or poor layout geometry is inappropriate. Where facades are glass or specular or semi-specular metal, lighting is discouraged. Most techniques on these facade types contribute greatly to light pollution since most of the light reflects up and into the night sky when uplighting is used. Little, if any, worthwhile lighting effect results.

Lighting facade features can be highly effective, energy savvy, and most respectful of the night sky. Overlighting must be avoided. If the intensity is too great, then the detail appears to levitate from the building or is visually washed out. If the area of coverage is too big, the detail blends with the surrounds and loses appeal. There are no uniformity criteria associated with lighting of facade details. Figures 26.2 and 26.3 illustrate lighting of facade details.

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Table 26.5 | Recommended Light Trespass Illuminance Limits

Lighting Zone	Limit in lux[a] Pre-curfew	Post-curfew
LZ4	15	6
LZ3	8	3
LZ2	3	1
LZ1	1	0
LZ0	0.1	0

a. Maximum initial illuminance on a plane perpendicular to the line of sight to the luminaire(s). Plane located at observer position where light trespass is under review. [7]



Figure 26.2 | Facade Detail
Each column in the colonnade is illuminated with two uplights lamped with 100W/CMH/PAR38 lamps exhibiting 3000 K and 82 CRI. Uplights are positioned to each side of the columns on a line parallel with the front face of the columns. This introduces visual depth to the facade and accentuates the stone detailing of the columns and capitals.
» Image ©Glen Calvin Moon

Where facades are of a material that is opaque and matte in finish or of a design that consists of decorative screening comprised of opaque and matte materials, lighting facade fields can be appropriate. These fields might consist of large repetitive areas related to architectural modules or scale or might consist of the entire facade. The challenge is selecting luminaires and establishing a layout that minimize strong gradients or streaks and limit spill beyond the areas of intended coverage.

Combining the facade fields approach with the facade details approach can provide visual interest and depth and establish an overall nighttime building context not achieved with just one or the other approaches. Figures 11.3 and 26.4 illustrate combination approaches to facade lighting. In any event, lamps exhibiting CRIs ≥80 are appropriate for most facade types and finishes unless a specific color effect is desired. CCTs can be used to accentuate dimensionality (such as 3000 K lamping on foreground surfaces and 5000 K lamping on background surfaces) or for dramatic effect (such as 6500 K) or for traditional effect (such as 2700 K).

Where buildings have glass exterior walls in proximity to interior spaces that themselves exhibit highlighted walls or ceilings, the facade will have a presence during occupied hours as shown in Figure 26.1. Light spill to the outdoors can be limited by using optically controlled luminaires or shielding luminaires, orienting them away from windows, and using sensible lighting criteria for the interior spaces. Automated shades can be used to block interior light from escaping after some predetermined and reasonable curfew if none is mandated.

Facade lighting in the traditional sense is not necessary or appropriate in many situations. The context of viewing and use of the areas in close proximity to the building and activity levels should affect the decision to light or not light the facade and, if to be lighted, should affect the design approach for lighting. Some buildings have a landmark or cultural status and a community reverence. Some buildings are on key vehicular or pedestrian routes and can help define the route or the place, serve as destination markers, and contribute to perceptions of safety or security.

Techniques to lighting facades include downlighting, uplighting, and backlighting or the interior lighting discussed above. Downlighting can limit light pollution providing appropriate wattages and optical selections are made. However, light spill to adjacent properties, direct glare, the visual aesthetic of the equipment mounted to the facade, and more difficult maintenance procedures must be assessed.

Uplighting must be optically controlled and carefully adjusted and locked in place in order to limit light pollution. Walk-over, heat, water-management, and ease of maintenance and adjustment must be assessed.

26.2.4 Fountains

Fountain accenting can serve the accenting function identified previously in section 26.2.1. However, establishing illuminance criteria for water effects is elusive. The dispersion and attenuation of light in water is affected by the depth of the water over the light source. The aeration of the water through nozzles, if such is the design of the fountain, affects the quality of light refracted and reflected. Where waterfalls or cascades are the fountain effects, the spill height and aeration affect the quality of the lighting effects. Generally, luminaires must be positioned within a few inches of the waterline to be effective. For classic fountains consisting of long and medium throw streams, center beam candlepower is more important than wattage. Tighter beams are generally best for longer water sprays with one luminaire per spray nozzle positioned as close to the base of the stream as possible. At waterfalls or cascades, luminaires should be centered at the target position of the falling water. Consult with fountain designers and luminaire vendors to determine lighting equipment appropriate for the planned water effects. Equipment must

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Figure 26.3 | Facade Detail
Here "details" of this 1931 Moderne structure are themselves quite simple and large. Lighting these repetitive elements does not highlight any inherent decorative detailing, but helps establish a nighttime building presence without floodlighting the entire facade. The backlighting creates a more dimensional effect than floodlighting. Here, straw filters are added to metal halide uplights backlighting the facade apertures to give an appearance of a filament lamp glow from within the building.
» Photography ©Brad Feinknopf 2004

be certified to UL/CSA/NOM standards for underwater application. The designer must assess needs for wet/dry equipment and IP68 ratings. See Figures 26.1 and 26.5.

Although seemingly convenient, lighting fountains and other water features from outside of the water element is typically unsuccessful. Unless very close in proximity to the water feature, literally within feet if not inches, or extraordinarily powerful, the aerated sprays, waterfalls, or cascades will appear flat and very dim. Reflecting pools or still-water features will simply reflect the focal light off into the direction opposite that of the incoming light. This is glary, obscures any detail or visual interest, and is only visible from one very specific observation point.

Consistent with design practice for all lighting applications, the design team must research and determine and address codes and standards specific to water-feature lighting. Factors affected may include luminaire rating, labeling, and listing requirements, lamp types, operating voltages, cutoff requirements, among others.

26.2.5 Parking Decks

The lighting of parking decks and undergrounds is most effective when the following details are addressed:

- Assess daylighting opportunities
- Define activities and tasks
- Define surface reflectances
- Define accenting
- Establish horizontal illuminance criteria, including uniformities
- Establish vertical illuminance criteria, including uniformities
- Establish accenting criteria

Above-ground structures, parking decks, are a cross between indoor and outdoor space. Daylighting opportunities should be explored early in the project. The "design" of many

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Figure 26.4 | Facade Field and Features
The field of the lower facade is illuminated and serves to provide sufficient horizontal and vertical illuminance at the terrace for circulation or a catered event. The lantern pendants are decorative and lamped with a filament lamp.

Features are accented on the second floor facade. Window frames are uplighted as is the gable detail. Automated controls allow for convenient setbacks through switching and dimming.

» Images www.jmaconochie.com

parking structures is sufficiently formulaic that most daylighting can only be fractional. That is, for above-ground structures, the structure itself is not oriented or designed to take advantage of daylighting, thereby leaving only the piecemeal option of switching off some lights near daylight apertures if and when daylight should meet the illuminance target. See 11.3.2.4 Design Strategies. Undergrounds, intentionally constructed under buildings, typically have no daylighting opportunity.

Defining the activities and tasks within the deck helps in the development of a comprehensive lighting design addressing users' needs. Overlighting and energy use are more likely to be minimized and a more visually engaging environment may result. For example, by understanding and addressing the tasks at key functional areas such as vehicular and pedestrian entrances and exits, elevator lobbies, pay stations, and passenger or valet drop-offs, lighting is better tuned to function. Review the list in Table 26.2 and visit several parking decks to understand uses. This information is used to establish illuminance criteria.

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Surface reflectances significantly affect electric light and daylight efficiencies. Recommending light reflectance values (LRVs) of 50% on most columns and walls and at least 65% on ceiling surfaces are appropriate. Where color accents for coding floors and guiding users are used, LRVs should be at least 30%. As Figure 26.6 illustrates, high LRVs and appropriate luminaire light distributions greatly improve luminances and overall perceptions. High LRVs have the following advantages:

1. Assist with vertical illuminances at face heights and at columns and walls, allowing for lower wattage luminaires.
2. Assist with better uniformities on horizontal and vertical illuminances, reducing wattages and equipment quantities.
3. Reduce glare by increasing background luminance against which luminaires are seen.
4. Improve users' perceptions.

In addition to surface reflectances contributing to overall lighting system efficiency, controls contribute greatly to overall energy use and tune illuminances to activity levels and curfews. Automated astronomical time clock, photocell, and motion-sensor operation will help maintain a consistent and efficient operation. Instant-on and readily dimmed light sources can be used with these control techniques to ramp-up illuminances based on occupant sensing as needed during low-activity periods or after curfew.



Figure 26.5 | Fountain Accenting
Fountains might be centerpieces in parks, plazas, or public lawns. Although lighting will contribute little illuminance to the surrounding area, the luminance qualifies these as dramatic or feature focal points. This luminance can be made more dramatic with low illuminance, if any, in the vicinity of the fountain.

Underwater luminaires are lamped with filament or LED lamps and are typically dimmed. LEDs offer the advantage of saturated color or color effects synchronized to dynamic fountain effects with much greater efficiency than filament counterparts.

Where water features function as reflecting pools, no underwater lighting effects are introduced.

» Image ©Dan Bannister/JAI/Corbis

26.2.5.1 Parking Deck Illuminance Criteria

Check the bookstore at www.ies.org for updates on lighting for parking facilities dated 2011 or later. If no updates are available, then document the following procedure to establish recommended illuminance criteria to review with the team and owner for the project at hand.

1. Review Section 4.12 An Illuminance Determination System.
2. Establish an illuminance category for each activity and task appropriate to the level of activity and the nighttime outdoor lighting zone.
3. Assess observers' ages and determine appropriate horizontal and vertical illuminance targets.
4. Determine design gauge (average, minimum, maximum) and uniformities.
5. Determine if mesopic multipliers are appropriate.
6. Finalize recommended nighttime and daytime illuminance criteria for the project.

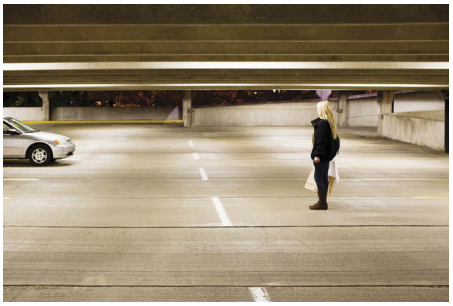
An Illuminance Determination System

Section 4.12 outlines the latest IES system for determining illuminance criteria. Illuminance categories are identified in Table 4.1 | Recommended Illuminance Targets. Parking decks are a cross between interior and exterior space. Precedent suggests categories A through K make an appropriate pool from which to determine nighttime illuminance criteria for many activities and tasks in parking decks. However, the designer must assess these criteria in the context of activity level and lighting zone.

Activities and Tasks

Outline the various activities and tasks to be addressed in the parking deck. This may be a lifting, extension, or modification of those cited in Table 26.2 or a completely different assessment by the designer based on a task survey (see Table 12.3 | Sample Visual Task Survey). Some activities and tasks addressed in other chapters, such as stairs or elevator lobbies (see Table 22.2 | Common Applications Illuminance Recommendations), may be deemed appropriate. In any event, most, if not all, activities and tasks will have a need for horizontal and vertical illuminance criteria. The designer must define and track these planar requirements. For parking deck situations, nearly all horizontal illuminance criteria are at finished grade or floor. Vertical illuminance criteria are related to standing or walking face height, typically identified at 5 feet above finished grade. The designer must

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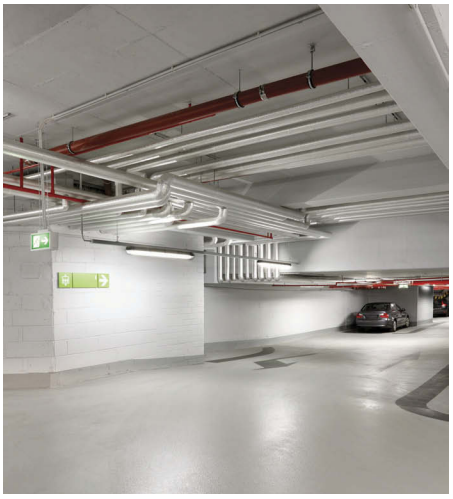


Figure 26.6 | Parking Decks
Uniformity of illuminance, both horizontal and vertical at face height, is important to visibility at all times and in all directions, to states of adaptation, and to perceptions. The middle and bottom images illustrate the effectiveness of painting ceiling, wall, and column surfaces. This significantly improves light distribution and efficiency and minimizes glare.

Luminaires and lamps exhibiting general-diffuse optical qualities, like the fluorescent varieties shown here, result in significantly less glare. Lamps with CRIs ≥82 offer improved color discrimination.

Strategically positioning luminaires to highlight perimeter vertical surfaces helps define architectural boundaries, destinations such as elevators and stairs, and signage.

» Top Image ©Image Source/Corbis
» Middle Image ©Jack Lacey/Corbis
» Bottom Image ©Gregor Schuster/Photographer's Choice/Getty

establish which viewing directions are most important with a minimum of two directions of travel and sometimes up to four.

Preliminary Illuminance Categories
For each of the activities and tasks and planes of interest, identify a preliminary illuminance category based on experience, IES precedent, or study of the categories' typical application and task characteristics and the visual performance description in Table 4.1. Developing a table outlining criteria for all three methods would allow the designer to use averaging or at least understand the extent of the variances. The goal is to establish the lowest illuminance criteria appropriate to the need. Overlighting as a convenience is inappropriate.

Activity Level
Activity levels influence illuminance criteria. High activity levels demand greatest illuminances to address the volumes of vehicular and pedestrian traffic. Reaction times are typically shortest as the likelihood of vehicle and pedestrian interaction is greatest. From Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions, identify the anticipated activity level. For those activities and tasks where vehicles and pedestrians interact, use the outdoor activity level category. For those activities and tasks where only people are involved, use the indoor activity level category. If the activity level is expected to change according to time of day, identify the various activity levels and their durations. Generally, a "high activity" level gives merit to the highest illuminance under consideration. A "medium activity" level gives merit to the moderate illuminance under consideration. A "low activity" level gives merit to the lowest illuminance under consideration.

Nighttime Outdoor Lighting Zone
Lighting zones influence illuminance criteria. Lighting zones in more urban areas require greater illuminances given densities of nighttime activity and a need to maintain states of adaptation consistent with surroundings. If not codified as part of an ordinance, code, or sustainable initiative, then from Table 26.4 | Nighttime Outdoor Lighting Zone Definitions determine the most appropriate lighting zone descriptor for the environmental setting within which the project is located. Generally, Z4 and Z3 give merit to the highest illuminance under consideration. For each step reduction in lighting zone, a concomitant step reduction in illuminance category is merited.

Assess Observers' Ages
The illuminance categories outlined in Table 4.1 each consist of a range of three illuminance targets with: a low value associated with situations where the visual ages of at least half the observers are less than 25 years old; a middle value associated with situations where the visual ages of at least half the observers are between 25 and 65 years old; and a high value associated with situations where the visual ages of at least half the observers are greater than 65 years old. Where observers' visual ages are equally split among the three age groups, the designer must establish recommendations based on other techniques, such as combining two groups to establish a majority and using the older group's illuminance criteria or using the 25-65 age group's illuminance criteria, and reviewing the outcome with the team and client. Deliberation might include the hours of operation and the user demographics at various times of day and night. There may be situations where more than half the clientele have visual ages greater than 65 years old, but the clientele are outnumbered by staff, such as might occur at a hospital where staff and visitors and patients share the same parking deck. Designing for the clientele is a reasonable conclusion. Once visual ages are established, the designer can identify recommended illuminance targets for the various activities and tasks.

Design Gauges and Uniformities
Illuminance targets must be calculated and measured against a gauge of average, minimum, or maximum. Using average as a gauge along with uniformities of average-to-min-

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imum and of maximum-to-minimum defines the upper and lower limits on illuminance. This assures some minimal illuminance for detection and adaptation purposes while also minimizing the detrimental effects of overlighting if no maximum were set. For parking decks maximum-to-minimum ratios should not exceed 10-to-1 (10:1). The tighter the maximum-to-minimum uniformity ratio, the more consistent the illuminance, resulting in less glare and adaptation effects for people traveling through the deck and yielding fewer shadowed areas thereby improving senses of safety and security.

Mesopic Multipliers

As identified in 4.12.3 Spectral Effects, an additional modifier for low luminance situations accounts for users' adaptation states. Adaptation state is important in developing recommended illuminance criteria for low-light activities and tasks. In order to have some understanding of adaptation state, a tentative lighting approach must be identified. In a very rough sense, direct lighting (downlight only) in a parking deck will result in a lower adaptation state than will all indirect lighting or some combination of direct and indirect.

Generally, as eyes adapt to the lower luminances experienced in low-illuminance settings, mesopic adaptation occurs, typically at or below 3 cd/m^2. See Table 2.1 | Vision Adaptation States. These are luminances that might be experienced in low-light situations with moderate-to-low surface reflectances or in very-low-light situations with moderate-to-high reflectances. Such as might occur in some parking deck, parking lot, and pedestrian walkway situations. Under mesopic adaptation, lamps with spectra exhibiting shorter wavelengths (cooler-toned color quality) are more efficacious than longer wavelength (warmer-toned counterparts). It is quite possible, especially where illuminances are less than 10 lx, to find a specific design situation where an assessment of background luminance shows, for example, that a lighting system using standard 2000 K HPS lamps is 13 percent less efficacious than one using 3000 K CMH lamps or 19 percent less efficacious than one using 4000 K CMH lamps. Table 26.6 | Parking Deck Mesopic Multiplier Example Worksheet outlines steps involved in determining if observers are likely to be in the mesopic adaptation state and, if so, the affect of various lamping options on illuminance criteria for this example.

Using the method outlined in 4.12.3 and Figure 4.27, mesopic multipliers adjust the illuminance criteria to account for the anticipated photopic background luminance and the spectra of the lamps under consideration. In the example in Table 26.6, in the design phase, this means illuminance criteria would need to be increased if HPS lamps are under consideration for the specific design situation discussed here or decreased if CMH lamps are under consideration. This can affect lamp wattages, luminaire selections, and luminaire layouts or both and may greatly affect connected loads or control schemes for night operation and curfew situations. If LED lamps are under consideration, then S/P data and photometry are required.

Finalize Recommended Illuminance Criteria

Itemize nighttime and daytime horizontal and vertical illuminance and uniformity criteria. Generally, nighttime illuminances are consistent throughout the vehicular access areas, including drive aisles and parking bays, ramps and corners, and entries and exits. This is considered a baseline illuminance condition. Daytime illuminances respond to the nature of the tasks and states of adaptation with respect to the outdoor daylight. Daytime illuminances at drive aisles and parking bays are consistent with the nighttime baseline illuminances. However, ramps and corners might be illuminated to 2 times baseline during daylight hours of operation while entries and exits are illuminated to 10 times baseline during daylight hours of operations. See Figure 26.7. Additionally, surface finishes of walls and ceilings, particularly in the vicinity of ramps and corners and entries and exits, should exhibit high LRVs. During daylight hours of operations, employ strategies using any combination of daylighting and electric lighting to achieve target values. Daylighting may require unconventional architectural approaches.

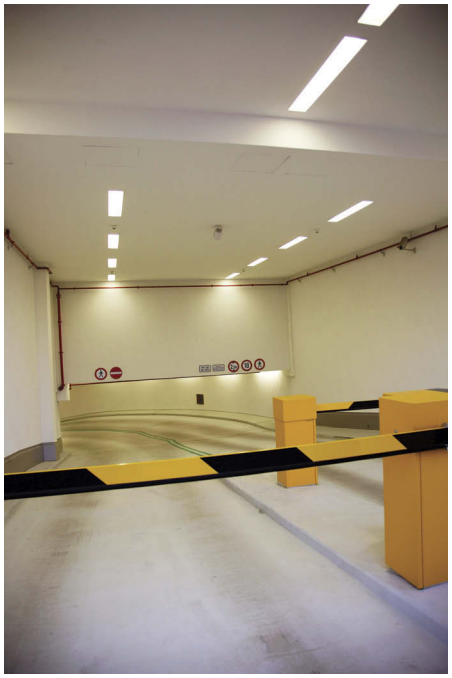


Figure 26.7 | Parking Deck Entries

Luminances at the entries to and exits from parking decks, both above ground and underground varieties are critical to drivers' adaptation states as they enter or exit the relatively dark parking structure during daylight hours.

Relatively high surface LRVs are important to achieving transitional luminances from exterior to interior and vice versa during daytime hours of operation. Architectural designs transitioning from 2- or 3-story exterior openings down to 1-story interior circulation drives great assist with daylighting of these areas.

During nighttime hours of operation, illuminances at entries and exits are reduced through selective switching or dimming to trim illuminances to match those of baseline conditions at drive aisles and parking bays within the parking structure.

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Table 26.6 | Parking Deck Mesopic Multiplier Example Worksheet

Step	Process	For This Example
1	**Tentative Design Approach**	
	To best judge the photopic luminance ($L_{photopic}$) in a low-light interior or interior/exterior situation such as might be found in a low-activity parking deck in a Z1 nighttime outdoor lighting zone, determine tentative lighting approach: direct; direct/indirect; indirect.	Say direct/indirect with 85% direct light and 15% indirect light as might be achieved with some fluorescent or HID systems.
2	**Establish Recommended Photopic Illuminance Criteria**	
	Illuminance affects photopic luminance. Identify photopic horizontal (E_h) and vertical (E_v) illuminance criteria from Table 4.1.	• $E_{hphotopic}$ = 6 lx average, maintained
		• $E_{vphotopic}$ = 2 lx average, maintained
3	**Propose Surface Reflectances**	
	Reflectances also affect photopic luminance. Propose preliminary reflectances.	
	Ceiling reflectance ($\rho_{ceiling}$)	65 percent (0.65)
	Floor reflectance (ρ_{floor})	40 percent (0.40)
	Wall reflectance (ρ_{walls})	40 percent (0.40)
4	**Determine Photopic Luminance**	
	For the average $L_{photopic}$ in observer's field of view, sum and average relevant luminances.	
	a. $L_{photopic}$ of floor = $(E_h \times \rho_{floor}) \div \pi$	0.76 cd/m^2
	b. $L_{photopic}$ of walls = $(E_v \times \rho_{walls}) \div \pi$	0.25 cd/m^2
	c. $L_{photopic}$ of ceiling from 85% direct light $= 0.85 \times ((E_h \times \rho_{floor} \times \mathbf{0.8}) + (E_v \times \rho_{walls} \times (1-\mathbf{0.8}))) \times \rho_{ceiling} \div \pi$	0.36 cd/m^2
	d. $L_{photopic}$ of ceiling from 15% indirect light $= 0.15 \times ((E_h \div \mathbf{0.8}) \div \pi)$	0.36 cd/m^2
	e. $L_{photopic}$ total of ceiling = $L_{photopic}$ direct light+$L_{photopic}$ indirect light	0.72 cd/m^2
	f. $L_{photopic}$ of environment = Average contribution of $L_{photopic}$ identified in a, b, and e above.	
	$L_{photopic}$ of environment = $((2 \times L_{photopic}$ of floor$) + (2 \times L_{photopic}$ of ceiling$) + (1 \times L_{photopic}$ of walls$)) \div 5$	0.64 cd/m^2
5	**State of Adaptation**	
	Confirm luminance of environment puts observer in mesopic state of adaptation (≤3 cd/m2).	
6	**Mesopic Multipliers**	
	Determine multipliers to adjust recommended photopic illuminance target values for mesopic adaptation.	
	• 2000 K HPS illuminance criteria multiplier	1.07
	• 3000 K CMH illuminance criteria multiplier	0.95 (13% better than 2000 K HPS)
	• 4000 K CMH illuminance criteria multiplier	0.9 (19% better than 2000 K HPS)
7	**Recommended Mesopic Illuminance Criteria**	
	Adjusted recommended illuminance target based on lamp selection.	
	2000 K HPS (multiply photopic illuminance targets by 1.07)	• $E_{hmesopic}$ = 6.4 lx average, maintained • $E_{vmesopic}$ = 2.1 lx average, maintained
	3000 K CMH (multiply photopic illuminance targets by 0.95)	• $E_{hmesopic}$ = 5.7 lx average, maintained • $E_{vmesopic}$ = 1.9 lx average, maintained
	4000 K CMH (multiply photopic illuminance targets by 0.9)	• $E_{hmesopic}$ = 5.4 lx average, maintained • $E_{vmesopic}$ = 1.8 lx average, maintained

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Reference and Rationale
See photometric report to determine percent direct lumens and indirect lumens for a potential luminaire.This is a "what-if" scenario to test a luminaire for consideration and determine if observers will be in a mesopic state of adaptation and, if so, the extent of light source spectral effects on final recommended illuminance criteria. Mesopic adaptation is typical in situations where illuminance is likely to be 10 lx or less, average, maintained.
Designer's discretion for recommendation to team and client based on Table 4.1 Category D, average maintained illuminance, visual ages of at least half the observers are 25 to 65 years old, low activity level, Z1 nighttime outdoor lighting zone.
Designer's discretion and typically ⅓ to ½E_h
Painting ceilings improves efficiency and uniformity. Periodic cleaning and repainting required.
Painting floors or using high-reflectance concrete improves efficiency. Periodic cleaning and repainting required.
Painting walls improves efficiency. Assuming here some walls are white and some are colored. Periodic cleaning and repainting required.
The **0.8** value is an assumed form factor, representing the amount of flux emitted by the respective surfaces (floor and walls in this case) that is likely to reach the ceiling. In relatively low-ceiling, wide spaces, form factors between floor and ceiling approach 1. See 10.4.2.1 Radiative Transfer for more information.
The **0.8** value is an assumed form factor. See 10.4.2.1 Radiative Transfer for more information.
Observer's binocular field of view can be defined for some relatively central location in a parking deck with the floor and ceiling subtending about 2 steradians of solid angle each and the walls subtending 1 steradian of solid angle for a total of 5 steradians.
Averaging photopic luminances by solid angles (in steradians) yields the photopic luminance value to be used in Figure 4.27.
See Table 2.1 | Vision Adaptation States.
Use the "$L_{photopic}$ of environment value" of 0.64 cd/m2 from Step 4 to determine multipliers from Figure 4.27.
Multiplier to adjust recommended photopic illuminance target value for mesopic adaptation for 2000 K HPS lamps with S/P of 0.60 for this specific example.
Multiplier to adjust recommended photopic illuminance target value for mesopic adaptation for 3000 K CMH lamps with S/P of 1.38 for this specific example.
Multiplier to adjust recommended photopic illuminance target value for mesopic adaptation for 4000 K CMH lamps with S/P of 1.81 for this specific example.
Recommended mesopic illuminance criteria if 2000 K HPS lamps with S/P of 0.60 are proposed for this specific example.
Recommended mesopic illuminance criteria if 3000 K CMH lamps with S/P of 1.38 are proposed for this specific example.
Recommended mesopic illuminance criteria if 4000 K CMH lamps with S/P of 1.81 are proposed for this specific example.

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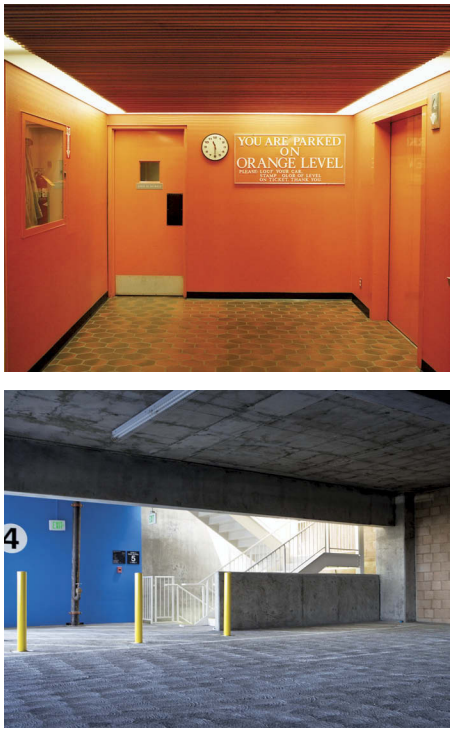


Figure 26.8 | Circulation Lobbies
Many times color is used for wayfinding. In the top image, walls are electrically lighted for accenting. If the elevator is open to the parking deck, the lighted and colorful walls would be visible for some distance.

Daylight is used in the bottom image to highlight the pedestrian exit area. Where daylight is also sufficient to meet illuminance in parking bay and drive aisles, electric lights are extinguished.

» Top Image ©David Zaitz/Photonic/Getty

» Bottom Image ©CGIBackgrounds.com/Collection Mix:Subjects/Getty

26.2.5.2 Parking Deck Accenting Criteria

Accenting is used to visually lead users to important activity areas and will help with users' overall brightness perceptions. Some areas typically worthy of accenting include color coded markers at elevators or stairs, signage, and public art. The significance of the accent focal areas or points must be determined. Generally, annotate a plan with accenting opportunities or requirements and indicate visual hierarchies or priorities. Elevator and stair locations are usually of keen interest to users. These might be directly visible from the parking deck drive aisles and parking bays. Examples of vertical surface accenting of elevator and stair lobbies are shown in Figure 26.8. Lighting perimeter walls helps define the architectural boundaries, provides walking- and driving-distance references and can be used as wayfinding. See middle and bottom images in Figure 26.6 and see Figure 26.9. As noted in Table 26.2, accenting criteria can be derived from Table 15.2 | Accent Illuminance Ratios.

26.2.6 Parking Lots

A strategy similar to that for parking decks is appropriate to the lighting of parking lots:

- Define activities and tasks
- Define surface reflectances
- Define accenting
- Establish horizontal illuminance criteria, including uniformities
- Establish vertical illuminance criteria, including uniformities
- Establish accenting criteria

Defining the activities and tasks within the parking lot is necessary to develop a comprehensive lighting design addressing users' needs.

Controls contribute greatly to overall energy use and tune illuminances to activity levels and curfews. Automated astronomical time clock, photocell, and motion-sensor operation will help maintain a consistent and efficient operation. Instant-on and readily dimmed light sources can be used with these control techniques to ramp-up illuminances as needed during low-activity periods or after curfew.

The six step process outlined in 26.2.5.1 also applies to parking lots. Mesopic multipliers apply to parking lot situations, however, unlike parking decks, no ceiling luminance exists. "Wall" luminances might consist of the effects of actual walls, adjacent building surfaces, and landscaping.

Ordinances, codes, or sustainable guides may dictate luminaire backlight, uplight, and glare (BUG) ratings. This criteria must be addressed during selection of luminaires. See 8.2.1.5 IES Luminaire Classification System for Outdoor Luminaires and 8.2.1.6 Outdoor Environmental Classification. BUG ratings identify the extent of uplight, if any, allowed for lighting equipment used in specific nighttime outdoor lighting zones. Figures 26.10 and 26.11 illustrate the use of optically well-controlled luminaires.

Where parking lots and pedestrian ways abut, the parking lot lighting and the pedestrian way lighting may be achieved by a single system or multiple systems. In the top image of Figure 26.11 pedestrian post lights contribute to the lighting of the pedestrian way and the parking area in the near vicinity while shoebox luminaires (out of the photographic frame) also contribute to the lighting of the pedestrian way and the parking area in the vicinity of the pedestrian way. In situations where nighttime pedestrian activity is anticipated or encouraged on dedicated walkways throughout early evening, smaller-scale pedestrian postlights offer a human-scale approach unachievable with the ubiquitous and institutional shoebox-on-a-pole-everywhere. See Pedestrian Ways and Bike Ways below.

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26.2.7 Pedestrian Malls

Lighting criteria for pedestrian malls are outlined under CENTERS, OUTDOOR in Table 34.2 | Retail Illuminance Recommendations. BUG ratings may be mandated and must be addressed during development of design techniques and selection of luminaires.

26.2.8 Pedestrian Stairs

Lighting criteria for pedestrian stairs are outlined under CENTERS, OUTDOOR in Table 34.2 | Retail Illuminance Recommendations. BUG ratings may be mandated and must be addressed during development of design techniques and selection of luminaires.

Accenting of walls or grade features, sculpture, or landscaping might be appropriate where stairs are part of a ceremonial area such as a plaza or civic, cultural, or corporate pedestrian way of significance and where nighttime activity is anticipated.

26.2.9 Pedestrian Ways and Bike Ways

Pedestrian and bike ways are considered outdoor applications. For covered or partially- or fully-enclosed pedestrian ways, the designer must determine if lighting for the area is better-designed for an outdoor condition or an indoor condition. Outdoor situations are addressed here. Indoor situations are considered circulation corridors.

Where lighting is deemed necessary for pedestrian or bike ways, the lighting depends on proximity to vehicular traffic, on activity level, and on nighttime outdoor lighting zone. A strategy similar to that for parking decks is appropriate to the lighting of parking lots:

- Define activities and tasks
- Define surface reflectances
- Define accenting, if deemed necessary
- Establish horizontal illuminance criteria, including uniformities
- Establish vertical illuminance criteria, including uniformities
- Establish accenting criteria, if accenting deemed necessary

Adjacency to vehicular traffic generally warrants greater horizontal and vertical illuminances on pedestrian and bike ways. Higher activity levels generally warrant greater horizontal and vertical illuminances. LZ3 and LZ4 lighting zones generally warrant greater horizontal and vertical illuminances. Accenting of walls or grade features, sculpture, or landscaping might be appropriate where a path is part of a ceremonial area such as a civic, cultural, or corporate campus of significance and where nighttime activity is anticipated. See tree accenting in Figure 26.1. A criteria example is shown in Table 12.7 | Pedestrian Way Mesopic Multiplier Example Worksheet.

Figures 26.12, 13, 14, and 15 illustrate several approaches to pedestrian way and bike way lighting. Where pedestrian activity is anticipated and encouraged and a more sociable setting is desired, attention to factors other than optical control and efficiency is also important. Luminaire scale, light intensity and distribution from the luminaires, color of light, styling and finishes of luminaires, and the lighting effects on and from adjacent buildings or landscaping must be considered, if not orchestrated, by the designer.

BUG ratings may be mandated and must be addressed during development of design techniques and selection of luminaires.

26.2.10 Plazas

Lighting criteria for pedestrian plazas are outlined under CENTERS, OUTDOOR/Plazas and Town Squares in Table 34.2 | Retail Illuminance Recommendations. BUG ratings may be mandated and must be addressed during development of design techniques and selection of luminaires.



Figure 26.9 | Perimeter Wall Lighting
Perimeter walls when made distinctly visible can help the user judge distance and identify location or position within the parking structure. These walls can also help guide users to pedestrian circulation paths. Here, the color of the lighted perimeter wall adds interest and further assists in defining location.
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Figure 26.10 | Parking Lots
For many parking lot, top-of-parking-deck, and roadway situations where there is a need for large areas of contiguous lighting, shoebox (so named for their shallow rectilinear) or stylized shoebox luminaires on poles typically ranging from 15′ to 40′ in height are common. The best of these use well-controlled optics to direct the light downward and limit uplight and glare.

Optics and house-side shields can be used to limit spill light beyond the parking pavement. Optics and pole heights and spacings are responsible for meeting illuminance criteria, including horizontal and vertical uniformities.

Well-controlled optics should always be employed for best efficiencies and limited light trespass. Where BUG ratings are mandated, even more precise optical control and use of shields are employed. Strategic layout of luminaires is even more important to limit light spill at property lines. These techniques intentionally result in darker-appearing settings.

Lighting not warranted after curfew should be extinguished or placed on motion-sensor to be available as needed.

» Top image ©Rod Morata/Stone/Getty
» Bottom image ©Tony Gale/Photographer's Choice/Getty

26.2.11 Pools, Outdoor

Lighting for outdoor pools is discussed in 28 | LIGHTING FOR HOSPITALITY AND ENTERTAINMENT. BUG ratings may be mandated and must be addressed during development of design techniques and selection of luminaires.

26.2.12 Residential Exteriors

Lighting for residential exteriors is discussed in 33 | LIGHTING FOR RESIDENCES. Luminaire shielding requirements and lumen limits may be mandated and must be addressed during development of design techniques and selection of luminaires.

26.2.13 Retailing, Outdoor

Lighting for outdoor retail is discussed in 34 | LIGHTING FOR RETAIL. BUG ratings may be mandated and must be addressed during development of design techniques and selection of luminaires.

26.2.14 Roadways

Establish the rationale for a need for roadway lighting. Where lighting is deemed necessary for roadways, check the bookstore at www.ies.org for updates on roadway lighting dated 2011 or later. If no updates are available, then document criteria based on IES RP-8-00 | Roadway Lighting. Alternatively, establish criteria based on Table 4.1 | Recommended Illuminance Targets using the process identified in Section 26.2.5 Parking Decks. At the designer's discretion, adjustments may be deemed appropriate to account for activity levels, nighttime outdoor lighting zones, and mesopic adaptation. Adjustments for mesopic adaptation should not be made to illuminances or luminances for roadways where the speed limit is greater than 25 mph. Age determination should be well-deliberated and based on anticipated use. All adjustments should be documented and the recommended criteria reviewed with the team and client. BUG ratings may be mandated and must be addressed during development of design techniques and selection of luminaires.

26.2.15 Roundabouts

Establish the rationale for a need for roundabout lighting. Where lighting is deemed necessary for roundabouts, check the bookstore at www.ies.org for updates on roadway lighting dated 2011 or later. If no updates are available, then document criteria based on IES DG-19 | Design Guide for Roundabout Lighting. Alternatively, establish criteria based on Table 4.1 | Recommended Illuminance Targets using the process identified in Section 26.2.5 Parking Decks. At the designer's discretion, adjustments may be deemed appropriate to account for activity levels, nighttime outdoor lighting zones, and mesopic adaptation. Adjustments for mesopic adaptation should not be made to illuminances or luminances for roadways where the speed limit is greater than 25 mph. Age determination should be well-deliberated and based on anticipated use. All adjustments should be documented and the recommended criteria reviewed with the team and client. BUG ratings may be mandated and must be addressed during development of design techniques and selection of luminaires.

26.2.16 Tunnels

Check the bookstore at www.ies.org for updates on roadway lighting dated 2011 or later. If no updates are available, then document criteria based on IES RP-22 | IESNA Recommended Practice for Tunnel Lighting. Alternatively, establish criteria based on Table 4.1 | Recommended Illuminance Targets using the process identified in Section 26.2.5 Parking Decks. At the designer's discretion, adjustments may be deemed appropriate to account for activity levels, nighttime outdoor lighting zones, and mesopic adaptation. Adjustments for mesopic adaptation should not be made to illuminances or luminances for tunnels where the speed limit is greater than 25 mph. Age determination should be

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well-deliberated and based on anticipated use. All adjustments should be documented and the recommended criteria reviewed with the team and client. Although BUG ratings may be mandated for the locale, tunnel applications will be inherently well-controlled when low-glare equipment is employed and illuminances and luminances appropriately adjusted for the activity level and nighttime outdoor lighting zone.

26.3 Illuminance Criteria

Illuminance criteria, when fully deployed, are a robust set of quantitative values that influence visibility, visual performance, and visual comfort and attention. Short-circuiting the criteria selection or designing to a single criterion value, such as horizontal illuminance, to address worst-case tasks will surely result in dissatisfaction. Even if clients accept the visual results, not getting the most from the energy expended or, worse, energy waste is a likely result. Following are notes related to various aspects outlined in Table 26.2.

26.3.1 Applications and Tasks

Applications and tasks encountered on any given project may be different from those identified in Table 26.2 and may warrant different illuminance criteria. Cross-referencing closely-associated applications or tasks is appropriate. Sometimes naming trends or conventions for space types or functions change to conform to current practice, client programming, or architectural, landscape, or civil engineering conventions, but the actual activities and tasks remain the same and this cross-referencing works. Failing this technique, reviewing the list in Table 26.2 may be in order to determine if any applications or tasks exhibit a similar visual-component to the unique applications or tasks. Otherwise, reviewing 4.12 An Illuminance Determination System and Table 4.1 is necessary to establish a task category based on the task characteristics or visual performance descriptions most closely associated with the unique applications or tasks. These exercises as well as any deviations from recommendations the designer intends to make should be carefully documented for the record.

26.3.2 Notes

Notes may refer to other application and task headings in the table or to other handbook chapters as appropriate. Where some degree of clarification is warranted, notes are made.

26.3.3 Recommended Maintained Illuminance Targets

Values cited are maintained on the area of coverage for the task under consideration. Illuminance is additive. Where practical and without negatively affecting the intended application of light, target values are achieved with any combination of daylighting and/or electric lighting in whatever mix of functional and accent lighting techniques is deemed appropriate to meet these and the other lighting goals established during design. See 12 | COMPONENTS OF LIGHTING DESIGN and see 10.7.1 Light Loss Factors.

With respect to light loss factors, account for anticipated losses through the point in time at which group relamping and cleaning should occur. Group relamping and cleaning should be standard practice, though these need not occur at the same frequency. Periodic cleaning and group relamping essentially maintain the illuminance at criteria and make the most efficient use of the installed equipment. For purposes of sustainability, cleaning and group relamping can no longer be presumed to be infrequent or unlikely. Maintenance procedures must be part of the design discussions with the client. See the IES document IESNA/NALMCO RP-36 Recommended Practice for Planned Indoor Lighting Maintenance for additional information. Where maintenance is deferred or practiced poorly or not at all, the actual illuminance values will fall below criteria targets. This is inefficient, unsustainable, and may be unsafe while adversely affecting users' quality of life or work. Ratcheting initial illuminances higher is poor practice, will result in excess energy use and in many exterior



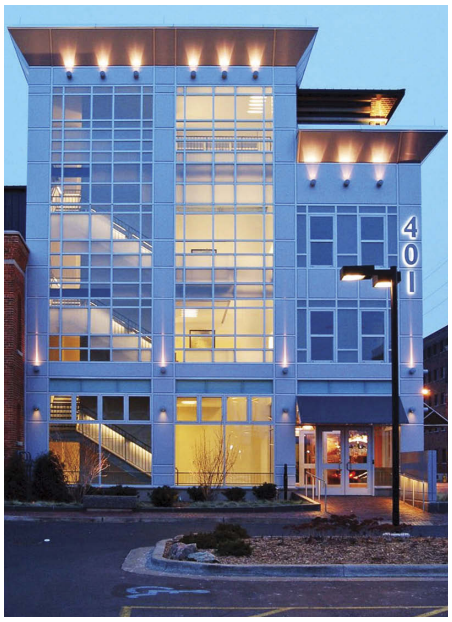




Figure 26.11 Parking Lots
The parking lots in top images are illuminated partly or entirely with 3000 K, 82 CRI 100W/CMH/ED17 shoebox luminaires shown in the bottom image. Luminaires near parking lot perimeters use house side shields. Coated lamps are used to soften harsh striations, shadows, and glare. Compliance with any BUG mandates must then be shown with coated-lamp photometry. E_h for the medium activity lot in the middle image is 20 lx average, maintained with 3:1 avg-to-min and 14:1 max-to-min ratios.
» Top image www.jmaconochie.com
» Middle image ©Nelson Breech Nave, AIA, Architect
» Bottom image ©GarySteffyLightingDesign Inc.

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Figure 26.12 | Outdoor Direct Lighting for Pedestrian Ways
Where lighting is deemed necessary into the late night, if not all night, well-controlled luminaire optics directing light only downward may be most appropriate or mandated. If no other lighting is used or is permitted as part of the scene, then the effect is stark and dark appearing. In these situations, the desire to increase illuminances to overcome this effect is self-defeating as higher pavement illuminances and, therefore, luminances exacerbate the contrast with the dark surrounds and contribute to greater light pollution. Lighter-toned building surfaces and pavement can be helpful to a limit, but these, too, exacerbate contrast unless the designer adjusts illuminance criteria to lower values to account for these higher surface reflectances.
» Image ©Michael Mohr/PhotoAlto/Corbis



Figure 26.13 | Outdoor Indirect Lighting for Pedestrian Ways
Where pedestrian activity is encouraged through curfew at which point lighting can be extinguished or reduced and where more social interaction is expected, an indirect technique may be appropriate. The luminaire styling and lighting effect can contribute to the pedestrian experience and help define place. Even during the day, when extinguished, these modern decorative luminaires contribute to the architectural scene. Versions of these luminaires are available with dimensionally articulated reflective discs combined with well-controlled uplight optics to trap upward light from escaping beyond the reflective disc. See also Figure 15.10.
» Image ©Christian Kober/Robert Harding World Imagery/Corbis



Figure 26.14 | Outdoor Architectural Lighting for Pedestrian Ways
Here, uplighting an architectural canopy on the left and downlighting the architectural colonnade on the right illuminate the pedestrian way. The combined techniques must collectively address all criteria, including horizontal and vertical illuminances and uniformities and light trespass and light pollution. One scenario at curfew might extinguish the uplighting on the left, but retain the downlighting on the right. This would address designer-recommended and client-accepted post-curfew criteria where vertical illuminance is very low or non-existent. Alternatively, the width of the path itself is redefined to be a zone within 6' of the building facade on the right. The infrequent pedestrians could then choose to walk the lighted path.
» Image ©Jon Hicks/Corbis



Figure 26.15 | Outdoor Decorative and Architectural Lighting for Pedestrian Ways
Traditional decorative lanterns on postlights can exhibit optical control which, when combined with relatively low-wattage lamps, offer mostly downlight with some amount of general outward and upward glow intended to illuminate building and tree canopies in close proximity as may be desired in shopping districts with narrow streets or pedestrian malls. Depending on the luminaire style, optical control might involve use of internal refractors or louvered reflectors covering the lamps, lantern lenses with refractive designs, top reflectors, or some combination of these. Some varieties exhibit such well-controlled light patterns that the resulting lighting effects may appear inappropriate to the civic, cultural, or shopping pedestrian applications. Mockups, even if just of an operable lantern, or visits to sites of similar installations are appropriate.
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situations, will result in more significant glare, light pollution, and light trespass. Ratcheting illuminances is not recommended. Maintenance procedures may be especially problematic with LEDs where promises of extraordinarily long life may be offered, but usually with the caveat that lamp lumen depreciation (LLD) at that rated life is 70% or perhaps even as low as 50% of initial rating. If replacement cycles are presumed to be rated life, then LLD alone must be 0.7 or 0.5 or whatever lumen rating is certified by the LED vendor. See 13.3 Life and Lumen Maintenance.

Targets are consensus and recommended for respective functional activity. For some applications, IES recommendations are within 10% of code requirements. This apparently is an artifact of metrication. Footcandle conversions of any values cited in Table 26.2 should be made at 1 fc to 10 lx. This soft conversion avoids a redundant diminishing of illuminance values after multiple citations and conversions over time. This also eliminates a false sense of accuracy advanced by an ever-increasing number of decimal places and a false sense of urgency advanced by eccentric fractional values introduced by hard conversions. Nevertheless, a lighting design must meet code and the mechanics of which must be coordinated amongst the design team. The IES recommendations should not, do not, and cannot reflect all of the various code requirements in force in all jurisdictions at any given time.

Targets are intended to apply to the dominant plane of the task, typically, but not always, horizontal or vertical. In some situations, illuminance criteria are cited for one plane, such as the vertical plane for facades, while the other plane is blank. The blank signifies that illuminance on that plane is unimportant and may be a consequence of the illuminance of other applications or tasks within the vicinity or by whatever illuminance results from meeting the target illuminance for the prescribed plane of interest.

In some situations, no light is anticipated on one or both planes of a task. A dash indicates no light or zero light is recommended for the task or application, such as facades after curfew in LZ1 settings.

26.3.3.1 Target Planes

Many, though certainly not all, tasks are performed with the task in roughly a horizontal orientation or vertical orientation. A dominant orientation must be assigned and the illuminance target determined accordingly. There may be situations where the IES recommended target relating to the typical planar mode of a task must be applied to a different plane.

Nearly all tasks are expected to have both a horizontal illuminance component (E_h) and a vertical illuminance component (E_v). This allows some degree of task flexibility for off-plane viewing and accommodates various aspects of the task. In many exterior pedestrian applications, horizontal- and vertical-plane illuminances address the common situation where simultaneously walkway pavement visibility is related to horizontal illuminance while facial recognition is related to vertical illuminance.

Some illuminance targets, such as the pedestrian walkway pavement visibility and facial recognition are intended at differing planar elevations and must be deliberated and established by the designer. For criteria purposes, standing face height is defined by an imaginary vertical plane oriented perpendicular to the primary direction of travel and centered at 5’ above finished grade (AFG). Illuminance criteria are applied to both sides of this plane at consistent spacing increments along the length of the walkway. Establishing and tracking task orientations and addressing both horizontal and vertical illuminance is necessary. In pedestrian walkway situations, at least two vertical planes are of interest, both perpendicular to the direction of main travel on the path, one opposing the other. This is an important distinction for luminaire optical selection and orientation capabilities and for layout, calculations, and field measurements.

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26.3.3.2 Visual Ages of Observers

Illuminance criteria are based on the visual ages of more than half the intended observers. The designer must coordinate with the design team and client to establish the age group of the intended observers. During deliberations, the designer and client should review precedents as well as implications of tentative criteria proposals on infrastructure, cost, and user performance. The aspects of observers' ages and illuminance targets should be resolved during programming with the client. See 12.5.5 Illuminance and 4.12 An Illuminance Determination System for additional information and guidance.

26.3.3.3 Illuminance Categories

Illuminance categories are designated by letters A through Y. These are shown in Table 26.2 for more convenient reference to Table 4.1 | Recommended Illuminance Targets should the designer wish to explore other criteria targets or if applications or tasks on a specific project are not readily correlated to the table citations.

26.3.3.4 Gauge

The common gauge for determining illuminance target compliance is cited for each application. All gauges presume that point-by-point techniques are used for predictive calculations and presume that uniformity criteria are closely monitored. Where an average illuminance value over the area of coverage can satisfy target compliance, "Avg" is cited. In applications or tasks where a minimum or maximum target is necessary, the gauge for compliance is "Min" or "Max" respectively.

The designer may elect to use other methods to evaluate target compliance, such as criterion rating (CR) or coefficient of variation (C_v). See 4.12.4.5 Tasks at Uncertain Locations Over a Large Area.

In any event, once illuminance targets and uniformities are established, then any calculated deviation from them should be limited. Standard engineering allowance of ±10% might be acceptable for targets gauged as average unless contractual or code obligations demand otherwise. Minima and maxima must be achieved as intended.

Designs should be adjusted until predictions are within allowance for averages and meet minima and maxima. For additional information, see 4.12.4.1 Recommended Illuminances at Design Time, 4.12.5 Illuminance Ratios, 9.15.1.1 Average Illuminance, and 10.8 Assessing Computed Results.

26.3.4 Uniformity Targets

Illuminance uniformity targets work in conjunction with luminance uniformities and surface reflectances all of which must be addressed as part of the design to avoid visual discomfort, glare, and strain. Uniformity ratios are targets that define the widest recommended ranges. In many situations, uniformity ratio criteria are those between average values of an array of points and the minimum value in the same array of points. Uniformity targets apply to both horizontal and vertical illuminances over the area of coverage. Where horizontal uniformity criterion is different from vertical uniformity criterion, two ratios are reported with the first value for horizontal illuminance (E_h). In some situations, notably those with regard to exterior illuminances, two uniformity values are cited. The first value addresses the primary cited application or task. The parenthetical value references the parenthetical application or task, such as a curfew situation associated with nighttime outdoor lighting.

Generally the more important speed and accuracy and the more demanding the visual task, the tighter the ratio.

26.3.4.1 Maximum-to-average

This is the recommended ratio of maximum illuminance to the average illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations sensitive to even a relatively small degree of overlighting.

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26.3.4.2 Average-to-minimum

This is the recommended ratio of average illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where illuminance too far below average conditions is noticeable and detrimental to task performance or inconsistent with normal expectations.

26.3.4.3 Maximum-to-minimum

This is the recommended ratio of maximum illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where too much variation in illuminance is considered undesirable and untenable from a performance or safety perspective.

26.3.5 Daylighting Advancement

Generally, design strategies should embrace any combination of daylighting and electric lighting to achieve target values during daylight hours. The preference is for daylighting to provide all or most of the recommended illuminance presuming that all aspects of daylighting are properly addressed. A sunburst icon depicts those applications and tasks where daylighting is considered a strategic candidate. Use photocells and stepped-switching, stepped-dimming, or continuous dimming to reduce or eliminate electric lighting when not needed during daylight hours. See 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Even for those applications where daylighting is not traditionally a strategic candidate, it may be determined that very careful and coordinated design will offer great sustainability opportunities along with positive influences associated with daylight and views.

26.3.6 Veiling Reflections

Tasks with specular components, which in exterior settings include glossy metal, stone, or glass surfaces as might be found on facades, walls, or artworks and wet pavement, are prone to specular reflections. Where such reflections veil important task information, then these are known as veiling reflections. Diffuse-optic, low-wattage, and multiple luminaires can minimize the effects of veiling reflections, but not eliminate them. Diffuse-finish materials for walls, pavements, facades, and the like are helpful.

26.3.7 Defining Areas of Coverage

In addition to establishing planes of task orientation, the areas of coverage to which targets apply must be determined. Typical areas of task illuminance coverage are identified here, but these may not be appropriate to specific project situations. One area of coverage is "task proper or task area." Here, the illuminance criteria are applied to the task itself or to a relatively small area to which the task is confined. In some situations, such as accenting, the "task" area may consist of the entire wall when "feature wall" or "perimeter" accenting is desired.

Another area of coverage is "room or designated area." In this situation, illuminance criteria are applied to the room or an area of fairly substantive size representing the zone in which the applications and tasks are expected to occur. The designated area is typically established by the functional layout, such as that for a parking deck, but should be scrutinized by the design team. An assessment and determination must be made on which area of coverage best satisfies the lighting goals on a particular project.

26.4 Designing

Information provided here is specific to exteriors and should be used as part of the design and documentation processes outlined in Chapters 12, 15, and 20. For outdoor applications, lamps and ballasts, transformers, and drivers must be selected for ambient tem-

IESH/10e Economics Resources

> 15.3.3 Budgets
- for more on budgets and value engineering

> 18 | ECONOMICS
- for more on estimating costs
- for more on life cycle costs
- for more on paybacks and rates of return

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IESH/10e Energy Efficiency Resources

> 17.2 New Construction
- for more on designing for daylighting
- for more on electric lighting equipment
- for more on lighting controls

> 17.4 Lighting Codes, Regulations and Standards
- for more on application standards
- for more on equipment regulations

IESH/10eLightingExteriorsResources

> 12.5.5.6 Nighttime Outdoor Illuminances
- for more on lamp efficacies under mesopic adaptation

> 26 | LIGHTING FOR EXTERIORS
- for more on criteria

IESH/10e Sustainability Resources

> 13.11 Sustainability
- for more on lamps

> 19 | SUSTAINABILITY
- for more on controls
- for more on earth resources
- for more on energy
- for more on life cycle analyses
- for more on lighting design
- for more on recycling

perature conditions, some of which are extremely hot and others extremely cold. See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY for additional information on those respective aspects. Addressing all code requirements is a must. Energy efficient and sustainable practices are an integral part of all IES recommendations. Key design tenets include, but are not limited to:

- designing for the satisfaction of the observers intended to use the project
- using highest-efficacy lamps that meet color, optical and electrical control, and output criteria
- using highest-efficiency luminaires that meet aesthetic and luminance criteria
- using accenting to provide luminance balancing or improve brightness perceptions where necessary
- using controls liberally, preferably automated varieties such as presets, occupancy and vacancy sensors, astronomical time clocks, and photocells
- establishing IES-recommended illuminance criteria to meet programmed tasks
- establishing layouts that just meet IES-recommended illuminance criteria
- addressing outdoor environmental needs
- using calculations, photometrically-realistic renderings, and operational samples and mockups to prove concepts
- documenting all code-, energy-, sustainability-, and IES-criteria compliance
- documenting criteria and design deviations and rationale and subsequent disposition by team, client, or AHJ
- documenting clearly the layouts, controls, and luminaire and lamp selections

Designing for the satisfaction of the observers is the paramount design tenet and must be kept in perspective during all aspects of design. If the observers' expectations are not fulfilled, then how much energy could be saved is moot, as is how many fewer earth resources were spared, as is how much the whole affair cost or how much value engineering saved or the photogenic qualities of the project. See sidebar references for additional guidance on the key tenets. The design effort must be undertaken with coordinated and realistic expectations by all involved on initial and life cycle costs. Budgeting should include designer input and dialogue with the team and client at project commencement and design milestones. In other words, and paraphrasing Thomas Edison, genius is, indeed, just 1% inspiration and 99% perspiration.

26.5 References

[1] Mark S. Rea, ed. 2000. The IESNA lighting handbook: Reference and application. 9th edition. New York: IESNA. Ch 21, 22.

[2] Mark S. Rea, ed. 1993. The IESNA lighting handbook: Reference and application. 8th edition. New York: IESNA. Chapter 24.

[3] [IESNA] Illuminating Engineering Society. 1999. RP-33-99 Lighting for Exterior Environments. New York. 47 p.

[4] DiLaura DL and others. 2011. A procedure for determining target illuminances. Leukos 7(3):145-158.

[5] Boyce PR. 2003. Human factors in lighting. 2ns Edition. London: Taylor & Francis. pp 425-427.

[6] Boyce P. 2003. Human factors in lighting. 2ns Edition. London: Taylor & Francis. pp 413.

[7] [IESNA] Illuminating Engineering Society. 2000. Light Trespass: Research, Results and Recommendations TM-11-00. New York. 9 p.

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27 | LIGHTING FOR HEALTH CARE

Vision is not enough, it must be combined with venture. It is not enough to stare up the steps, we must step up the stairs.

Vaclav Havel , Czech Author, Dissident, Playwright, and Politician

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27.1 Project Type and Status. . . 27.2
27.2 Application Types 27.2
27.3 Illuminance Criteria 27.44
27.4 Designing. 27.49
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As with many applications, lighting for health care facilities is about balancing the aesthetic aspects with the analytic aspects. Undoubtedly, life itself or even treatment of pain is worth glare and overlighting from the conscious patient's perspective as long as the caregivers can see to perform their magic accurately and quickly and repeat as needed. Application of light is sometimes less about patient comfort and more about caregiver performance. During recuperation or for diagnostics and treatments, lighting collaborates with interior planning and architecture to establish a comfortable backdrop to the angst and unpleasantries of consultations, procedures, waiting, and convalescing. This chapter outlines lighting criteria for health care facilities. Electric lighting accounts for about 42% of the electricity used in health care facilities (see Figure 27.1) [1]. Efficient lighting and its careful application are critically important. What follows is a discussion of the key aspects affecting lighting: project status; space types; activities; application-specific design goals, and illuminance criteria in health care facilities.

For complete design efforts, rely on and reference material in 12 | COMPONENTS OF LIGHTING DESIGN, 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS, 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. The designer should have a thorough understanding of the design tenets outlined in those chapters, must identify those deemed appropriate and develop lighting goals and strategies accordingly. This chapter primarily addresses illuminance specifics related to health care facilities which should influence luminaire optical selections, lampings, and final layouts based on previously developed thought-starters (see 15.2 A Lighting Scheme). Use of the material in this chapter to the exclusion of material in Chapters 12, 13, 14, and 15 will likely lead to unsatisfactory results. Previous and current IES related documents serve as archival and reference sources [2] [3].

Deliberate thought must be applied to the lighting problem and solution. Many times rote solutions are based on expedience of application, procurement, installation, or cost with little regard for the purpose at hand: create a healing environment for the patient. Venturing beyond these rote solutions can yield remarkable returns on the very minimal investment that lighting requires relative to the overall health care facility costs. For example, for the lighting of an exam table in an examination room, illuminance criteria are based on the need for caregivers' assessments of the patients' conditions. Architectural lighting for this examination task might be accomplished with one or two over-scaled 2'×4' ceiling recessed luminaires. Although this banal approach may well meet cleaning, cost, and ceiling integration expectations, it does not excuse an all-on/all-off switching arrangement or the cheapest, but most glary optical selection. The design should address patient needs of pre- and post-examination with reduced illuminances and of less harshness during full-on when viewed from the supine position on the exam table. Venturing from the conventional can contribute, in part, to more satisfied patients and caregivers, less aversion, however minutely, to examinations by patients, and ultimately more revenue. Specific details like these are not enumerated for applications and tasks and may only be obvious after careful thought of the medical procedure. This might help avoid misapplication of basic prismatic luminaires where outlines of glary lamps are visible from below or of so-called low-glare-

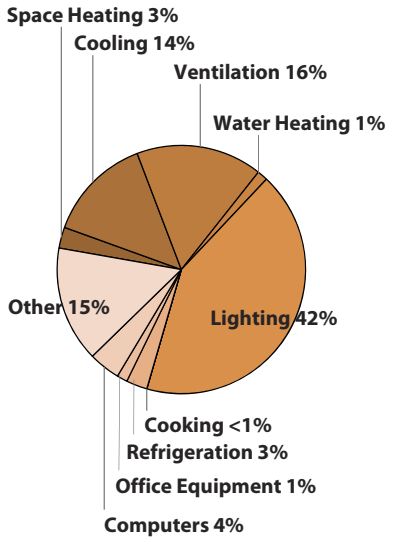


Figure 27.1 | Electricity Use of Health Care Buildings
Based on 2003 data from the US DOE's Energy Information Administration, lighting accounts for 42% of electricity use in health care buildings (electricity use for cooking rounds to 0%). These buildings themselves account for 7% of electricity use by all commercial and institutional buildings.

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Table 27.1 | Health Care Lighting Checklist

Topics
✔ **Criteria and Design Resources**
Accenting
15.1.1.3 Accent Lighting
Table 12.2 | Subjective Impressions
Table 15.2 | Accent Illuminance Ratios
Table 22.2 | Common Applications Illuminance Recommendations
Appearance
12.2 Spatial Factors
Color
12.5.6 Color Considerations
Controls
16 | LIGHTING CONTROLS
Daylighting
14 | DESIGNING DAYLIGHTING
Electric Lighting
15 | DESIGNING ELECTRIC LIGHTING
Flicker
4.6 Flicker and Temporal Contrast Sensitivity
Glare
4.10.1 Discomfort Glare
4.10.2 Disability Glare
Illuminance
This Chapter: Table 27.2
12.5.5.1 Applications and Tasks
Table 12.6 | Default Illuminance Ratio Recommendations
Figure 12.22 | Task Coverage Example
Light Distribution
12.3.2 Subjective Impressions
Luminances
12.5.2 Luminance
Table 12.5 | Default Luminance Ratio Recommendations
Maintenance
15.4.4 Installation and Maintenance
Nighttime Outdoor Environment
Table 15.6 | Nighttime Operational Strategies for Improved Outdoor Environmental Regard
Systems Integration
12.6 Systems Factors
Veiling Reflections
This Chapter: Section 27.3.6
12.5.4 Veiling Reflections
Visual Tasks
This Chapter: Section 27.2
This Chapter: Table 27.2
Table 11.2 | Programming: Inventory Scope and Specific Examples
12.5.1 Visual Tasks
Table 12.3 | Sample Visual Task Survey

louvered luminaires where harsh bare lamps are visible from directly below. Table 27.1 offers a checklist of IES lighting topics and criteria. The design team is responsible for determining and addressing indoor and outdoor lighting and energy criteria set forth by authorities having jurisdiction (AHJ) which may be different from and supersede IES criteria. See also 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

27.1 Project Type and Status

An understanding of the project type and scope is necessary before commencing design work. This will establish the extent to which daylighting can address the lighting goals. New, renovation, and restoration projects each offer varying opportunities. See 11.2 Planning, 11.3.1 Pre-design, and 11.3.2 Schematic Design. At every opportunity the lighting designer should give every consideration to daylighting as a light source. For some applications and tasks, daylighting can be the primary light source. Critically, this means addressing the host of lighting design factors identified in 12 | COMPONENTS OF LIGHTING DESIGN. Daylight demands attention to moderate or eliminate glare and balance visible and thermal energy.

27.2 Application Types

To develop lighting solutions that meet quality, quantity, and operational criteria, an inventory is made of the health care space types under consideration and the anticipated occupants, functions, and tasks (see Table 11.2 | Programming: Inventory Scope and Specific Examples and Table 12.3 | Sample Visual Task Survey). Otherwise, lighting cannot be best targeted to the users, their expectations, functions and tasks.

Space type definitions are required early in the project design in order to track design efforts that include inventorying the project knowns, anticipated functions, and tasks and calculating lighting, power, and energy compliance. Room names, from which functions can be deduced, and numbers for tracking should be clearly marked on architectural backgrounds. The applications and tasks cited in Table 27.2 | Health Care Facilities Illuminance Recommendations should be reviewed against the project knowns and correlated with the named space types and functions to establish recommended illuminance criteria. Seek clarification with the client where discrepancies occur between programming information, the list of room names, and the available application and task citations in Table 27.2.

Unlike most other applications, highly specialized procedures, tasks, and applications are prevalent in health care facilities. These facilities may be community clinics, physicians' offices, infirmaries, for-profit imaging centers, and Level 1 Trauma Centers, to name a few. Each of these have unique power, lighting and control requirements. Beyond the aspects discussed in 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY, lighting must be coordinated with the electrical engineer's efforts to address normal, critical care, and life safety classifications.

Medical procedures, and consequently tasks and applications, change frequently and, in some instances, even become obsolete. Many procedures supported by analog devices and visual tasks have recently or are now converting to digital devices and visual tasks. Lighting requirements can be dramatically different. The designer must review the program for the specific facility in question and closely coordinate the design with the programmed tasks and review frequently and completely with the team and owner.

Health care projects are complex and costly. Lighting is one convenient target when budget shortfalls arise. So-called value engineering efforts which are typically cost-driven substitutions with lighting equipment that does not meet all of the project criteria will usually yield

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insipid institutional settings of glary lighting, unaddressed accenting, one-level-control, and poor-quality hardware. Vigilance by the design team and owner is warranted.

Several general guidelines should be at the forefront throughout design. These are: color quality of light; germ and dust management; lighting controls; systems coordination; hazardous materials; medications; and medical equipment interference.

Color quality of light has direct affect on skin tones which, in turn, affects caregivers' assessments of patients' conditions and affects patients' self-esteem. All lamps should exhibit CRIs ≥82. In acute-care situations, lamps with CCT of 5000 K are also appropriate.

Germ and dust management is an ongoing effort in any health care facility. Luminaire finishes, lenses, and dust covers can assist. Antimicrobial finishes are available on many painted components. Most luminaires, even if made to be unlensed, are available with dust covers. Programming should identify these and other special requirements, such as wash-down after procedures, which influence luminaire UL and IP ratings.

With the exception of storage rooms and closets, most spaces in health care facilities are well-served by multi-level controls. In some instances, this helps convey an interest in the patient's well-being as caregivers toggle or dim lighting based on functional need or visual comfort. At the least, multi-level switching should be employed in patient clinical spaces. Access to lighting controls and where these should be located should be established during programming. Controls for patient courtesy lighting are readily available to the patient. Otherwise, controls are most convenient to staff. In some situations, such as mental health and secure patient areas, controls are purposely limited to staff access.

The demands made of all building systems in health care facilities are extremely high. Unlike many other applications where lighting layouts may well influence ductwork or even structural layouts, health care design is much less tolerant of such influence. Further, systems not found in other building types may affect lighting layouts and equipment selections. For example, in patient rooms where lift systems are employed to assist caregivers in transferring patients to and from beds, lighting is subservient to the lift track and mechanism. Advance programming and coordination is a necessity.

Hazardous and flammable materials are found in various methods of health care diagnoses and treatments. Where this material is stored, handled, and queued for disposal, lighting must accommodate the function and, if necessary, address stricter hardware safety requirements. The design team must research and establish which areas involve such hazards and address relevant codes and standards.

Medications are a key component of treatments. Wherever medications are stored, processed, and dispensed, lighting must address the reading, coding, and dosage tasks.

Review programming for any special electrical or mechanical requirements of the lighting equipment to avoid undesirable or even catastrophic interferences with medical equipment. In operating rooms lighting equipment must meet rigid electromagnetic interference (EMI) requirements. EMI potentially disrupts diagnostic and procedural equipment electronics. Determine which treatments and procedures are EMI-sensitive during programming. At this writing, specifying luminaires certified to MIL-STD-461F are one method of limiting the effects of EMI [4].

In some diagnostic and treatment spaces where radiation is involved, lighting equipment must be made of non-ferrous materials and operate on shielded direct current. The advent of LEDs and remote 12V and 24V drivers has improved longevity, efficiency, and optical selections. Special wiring requirements must also be followed. Medical technologies advance rapidly and requisite lighting effects and equipment parameters continually change. The designer must maintain familiarity with the most current project program and consult with the design team and medical equipment consultants and lighting equipment vendors to determine if and where lighting equipment with non-ferrous materials is required.

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Table 27.2 | Health Care Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b,c,d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
ACCENTING	Accenting influences observers' overall brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. See 15.1.1.3 Accent Lighting. These are criteria for consideration in any application.											
• Art	On artwork plane (typically vertical). See 21 | LIGHTING FOR ART for preservation-worthy materials.								see Table 15.2			
• Feature Wall	On wall plane								see Table 15.2			
• Important Focal Point	On focal point plane			see Table 15.2					see Table 15.2			
• Perimeter	On wall plane								see Table 15.2			
ACTIVITY AREAS												
• Arts, Crafts and Collecting	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	P	150	300	600	Avg
• Circulation/General	E_h @floor; E_v @5' AFF		Avg ≥0.2 times task E_h of activity or as cameras require, but with min ≥10 lx					Avg ≥0.2 times task E_v of activity or as cameras require				
• Cleanup	E_h and E_v @2' 6" AFF		100	100	100	Min	I	15	30	60	Avg
• Dining	See 22 | LIGHTING FOR COMMON APPLICATIONS/FOOD SERVICE/Dining Areas											
• Games	Intended for informal or spontaneous activity among unacquainted. For sanctioned refereed sports activites see 35 | LIGHTING FOR SPORTS AND RECREATION.											
• Analog Games												
• Billiards	E_h @2' 6" AFF; E_v @5' AFF	P	150	300	600	Avg	L	37.5	75	150	Avg
• Board and card games	E_h @2' 6" AFF; E_v @4' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
• Competitive table games	E_h @2' 6" AFF; E_v @4' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
• Pinball	E_h @3' AFF; E_v @5' AFF	L	37.5	75	150	Avg	I	15	30	60	Avg
• Shuffleboard	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Digital Games	E_h @floor; E_v @4' AFF	J	20	40	80	Avg	G	7.5	15	30	Avg
• Sports	Intended for informal or spontaneous activity among unacquainted in **INDOOR** facilities. For sanctioned refereed sports activites see 35 | LIGHTING FOR SPORTS AND RECREATION.											
• Individual Practice	E_h @3' AFF; E_v @5' AFF	N	75	150	300	Avg	L	37.5	75	150	Avg
• Group Play	E_h @3' AFF; E_v @5' AFF	P	150	300	600	Avg	N	75	150	300	Avg
ADMINISTRATION	See 22 | LIGHTING FOR COMMON APPLICATIONS											
AMBULATORY CARE												
• Ambulatory Surgery	See SURGICAL SUITES/Operating Rooms											
• Consultation	See CONSULTATION											
• Emergency Entrance	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.											
• Lobby												
• Day	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Night	E_h @2' 6" AFF; E_v @4' AFF	N	75	150	300	Avg	L	37.5	75	150	Avg
• Porte Cochere	**OUTDOOR** application. Lighting should address the intended area of ambulance unloading to door. E_h @3' AFG; E_v @4' AFG.											
• LZ4[i]		O	100	200	400	Avg	L	37.5	75	150	Avg
• LZ3[i] (and LZ4 curfew)		N	75	150	300	Avg	K	25	50	100	Avg
• LZ2[i] (and LZ3 curfew)		M	50	100	200	Avg	J	20	40	80	Avg
• LZ1[i] (and LZ2 curfew)		L	37.5	75	150	Avg	I	15	30	60	Avg
• LZ0[i] (and LZ1 curfew)	Control with motion sensors[j]	K	25	50	100	Avg	H	10	20	40	Avg
• Vestibule											
• Day	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	K	25	50	100	Avg
• Night	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg

Table 27.2 | Health Care Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	see 15.1.1.3		☀	↓	■	
	see 15.1.1.3		☀		■	
	see 15.1.1.3		☀	↓	■	
	see 15.1.1.3		☀		■	
	3:1		☀		■	
	3:1		☀			■
	3:1		☀			■
	3:1		☀		■	
	3:1		☀	↓	■	
	3:1		☀		■	
	4:1		☀	↓		■
	3:1		☀	↓	■	
	4:1		☀	↓		■
	3:1		☀	↓	■	
	3:1		☀	↓	■	
	3:1		☀			■
	3:1					■
	3:1				■	
	3:1				■	
	3:1				■	
	3:1				■	
	3:1				■	
	3:1		☀			■
	3:1					■

Notes for Table 27.2

The table column headings are discussed in detail in 27.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 27.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 27.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 27.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ↓ signals high likelihood; gray and white ↓ signals moderate likelihood; pale gray and white ↓ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. See Section 27.2.4 Ambulatory Care for additional information.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. Illuminance targets cited are for target area so noted and achieved with a minimum of 3-level control, if not dimming control, of architectural lighting.

l. Use lamps with CRIs ≥85.

m. Use lamps with CCTs of 5000 K and CRIs ≥85.

n. Control architectural lighting with dimmers to accommodate varied needs.

o. Provisions should be made for secure lighting equipment and controls.

p. Independently control lighting for use as necessary during procedures.

q. Use nightlights producing spectra at between 600 to 620 nm. See 12.4 Physiological Factors.

r. Some scanning equipment affects ferrous metals with potentially catastrophic results. See Section 27.2.36 Radiology for more information.

s. Make electrical provisions for portable work lights.

t. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 27.2 | Health Care Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
AMBULATORY CARE	(continued)										
• Examination and Treatment											
• Charting Station	E_h @3' 6" AFF; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Exam Table[k, l]	E_h @3' AFF; E_v @4' AFF	T	500	1000	2000	Avg	P	150	300	600	Avg
• General[l]	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg
• Life Support Unit											
• General[m]	E_h @3' AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Over Bed[m, n]	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg
• Multipurpose Examination	See AMBULATORY CARE/Examination and Treatment										
• Observation and Treatment											
• General[l]	E_h @3' AFF; E_v @4' AFF	M	50	100	200	Avg	N	75	150	300	Avg
• Head of Bed (Patient Use)[k, l]	E_h @3' AFF; E_v @4' AFF	P	150	300	600	Avg	K	25	50	100	Avg
• Over Bed[k, m]	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg
• Screening											
• Proctoscopy	See AMBULATORY CARE/Examination and Treatment										
• Sigmoidoscopy	See AMBULATORY CARE/Examination and Treatment										
• Security Examination[m, o]	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	P	150	300	600	Avg
ANESTHESIA											
• Anesthesiology	Patient preparation and recovery										
• General	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Patient Beds[k, l]	E_h @3' AFF; E_v @4' AFF	T	500	1000	2000	Avg	P	150	300	600	Avg
• Storage	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Workroom	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
ATRIA and COURTYARDS	See 22 | LIGHTING FOR COMMON APPLICATIONS										
AUDIOMETRY	See EAR, NOSE, AND THROAT										
AUDITORIA	See 24 | LIGHTING FOR EDUCATION										
AUTOPSY	See MORGUE										
BUILDING ENTRIES	See AMBULATORY CARE/Emergency Entrance/Porte Cochere; also see 22 | LIGHTING FOR COMMON APPLICATIONS										
CHAPEL/MEDITATION	See 37 | LIGHTING FOR WORSHIP										
CIRCULATION	See TRANSITION SPACES/Circulation Corridors										
CLASSROOMS	See 24 | LIGHTING FOR EDUCATION										

Table 27.2 | Health Care Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage			[f]	[g]	Typical Area of Coverage[h]	
1st ratio E_h/2nd ratio E_v if different uniformities apply					Task Proper or Task Area	Room or Designated Area
Max:Avg	Avg:Min	Max:Min				
see Table 12.6			☀	↓	■	
see Table 12.6			☀		■	
3:1			☀			■
3:1			☀			■
see Table 12.6			☀		■	
3:1			☀			■
see Table 12.6			☀	↓	■	
see Table 12.6			☀		■	
3:1			☀			■
3:1			☀			■
2:1			☀		■	
3:1			☀			■
3:1			☀	↓		■

Notes for Table 27.2

The table column headings are discussed in detail in 27.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 27.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 27.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 27.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ↓ signals high likelihood; gray and white ↓ signals moderate likelihood; pale gray and white ↓ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. See Section 27.2.4 Ambulatory Care for additional information.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. Illuminance targets cited are for target area so noted and achieved with a minimum of 3-level control, if not dimming control, of architectural lighting.

l. Use lamps with CRIs ≥85.

m. Use lamps with CCTs of 5000 K and CRIs ≥85.

n. Control architectural lighting with dimmers to accommodate varied needs.

o. Provisions should be made for secure lighting equipment and controls.

p. Independently control lighting for use as necessary during procedures.

q. Use nightlights producing spectra at between 600 to 620 nm. See 12.4 Physiological Factors.

r. Some scanning equipment affects ferrous metals with potentially catastrophic results. See Section 27.2.36 Radiology for more information.

s. Make electrical provisions for portable work lights.

t. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 27.2 | Health Care Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
CONSULTATION											
• Conversational	E_h @floor; E_v @5' AFF	N	75	150	300	Avg	L	37.5	75	150	Avg
• Form-filling, Instructional Reading, Medication and Chart Review	E_h @floor; E_v @5' AFF	Q	200	400	800	Avg	N	75	150	300	Avg
• Observing/Teaching[n]	E_h @floor; E_v @5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
CONFERENCING	See 22 | LIGHTING FOR COMMON APPLICATIONS										
CORRIDORS	See TRANSITION SPACES/Circulation Corridors for illuminance criteria for typical back-of-house and public circulation corridors. As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• Dental Suite	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Laboratories	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Non-nursing	See TRANSITION SPACES/Circulation Corridors										
• Nursing											
• In-patient											
• General Circulation											
◦ Day	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
◦ Night	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Work Station	See NURSES' STATIONS/In-patient										
• Intensive Care											
• General Circulation											
◦ Day	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
◦ Night	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Work Station	See NURSES' STATIONS/Intensive Care										
• Surgery Pre- and Post-Op											
• General Circulation	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Work Station	See NURSES' STATIONS/Surgery Pre- and Post-op										
• Quarters	E_h @floor; E_v @5' AFF	J	20	40	80	Avg	H	10	20	40	Avg
DENTAL SUITE											
• Consultation/Interview	See CONSULTATION										
• Examination, Hygiene, and Treatment[m]	E_h and E_v @3' AFF	T	500	1000	2000	Avg	P	150	300	600	Avg
• Oral Surgery[k, m]											
• Chair	E_h @3' AFF; E_v @4' AFF	W	1500	3000	6000	Avg	T	500	1000	2000	Avg
• Cleanup/Setup	E_h @3' AFF; E_v @4' AFF	T	500	1000	2000	Avg	R	250	500	1000	Avg
• General	E_h @3' AFF; E_v @4' AFF	V	1000	2000	4000	Avg	S	375	750	1500	Avg
• Surgical or Operating Field	This is the area of and immediately surrounding the site of the surgery. Depending on the medical procedures and equipment involved, illuminance criteria at the site of the surgery may need to be well in excess of 25,000 lx for direct-view methods and and is typically provided by surgical-style articulated luminaires. For video-view methods, dimmed architectural general lighting or background wall lighting is used. Consult vendors of the medical equipment involved or medical equipment consultants; survey state-of-the-art oral surgery facilities.										
• Preparations, Sterilization	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	P	150	300	600	Avg
• Preventive Dentistry	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	P	150	300	600	Avg

Table 27.2 | Health Care Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	2:1		☀			■
	2:1/3:1		☀			■
	2:1/3:1					■
	2:1/3:1		☀			■
	2:1/3:1					■
	2:1/3:1		☀			■
	2:1		☀			■
	3:1		☀			■
	2:1		☀	■		
	4:1		☀			■
	4:1		☀			■
	3:1		☀			■
	3:1		☀			■

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f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◥ signals high likelihood; gray and white ◥ signals moderate likelihood; pale gray and white ◥ signals some likelihood; and all-white signals little-to-no likelihood.

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i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. See Section 27.2.4 Ambulatory Care for additional information.

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k. Illuminance targets cited are for target area so noted and achieved with a minimum of 3-level control, if not dimming control, of architectural lighting.

l. Use lamps with CRIs ≥85.

m. Use lamps with CCTs of 5000 K and CRIs ≥85.

n. Control architectural lighting with dimmers to accommodate varied needs.

o. Provisions should be made for secure lighting equipment and controls.

p. Independently control lighting for use as necessary during procedures.

q. Use nightlights producing spectra at between 600 to 620 nm. See 12.4 Physiological Factors.

r. Some scanning equipment affects ferrous metals with potentially catastrophic results. See Section 27.2.36 Radiology for more information.

s. Make electrical provisions for portable work lights.

t. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 27.2 | Health Care Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
DENTAL SUITE	(continued)										
• Prosthetics Laboratory[m]											
• Benches	E_h @3' AFF; E_v @4' AFF	U	750	1500	3000	Avg	R	250	500	1000	Avg
• General	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Impressions	E_h @3' AFF; E_v @4' AFF	V	1000	2000	4000	Avg	S	375	750	1500	Avg
• Recovery[m]											
• Observation	E_h @3' AFF; E_v @4' AFF, chair	S	375	750	1500	Avg	P	150	300	600	Avg
• Rest	E_h @3' AFF; E_v @4' AFF, room	M	50	100	200	Avg	I	15	30	60	Avg
• Research	See DENTAL SUITE/Prosthetics Laboratory										
• Soiled Sterile Processing and Distribution (SPD) Cart Holding	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Supply Room	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
DIAGNOSTIC PROCEDURES	Clinical Procedure Suites										
• Colonoscopy	See DIAGNOSTIC PROCEDURES/Endoscopy										
• Culdoscopy	See DIAGNOSTIC PROCEDURES/Endoscopy										
• Cystoscopy	See DIAGNOSTIC PROCEDURES/Endoscopy										
• Endoscopy											
• Procedure Room											
• General[m, n]	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg
• Procedure	This is the area of and immediately surrounding the site of the procedure. Illuminance criteria may need to be well in excess of 10,000 lx for direct-view methods and is typically provided by surgical-style articulated luminaires. For video-view methods, dimmed room general lighting or background wall lighting is used. Consult vendors of the medical equipment involved or medical equipment consultants; survey state-of-the-art procedure facilities.										
• Decontamination	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Workroom	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg
• Electrocardiography (ECG)	Also known as EKG										
• General (use indirect lighting)	E_h @2' 6" AFF; E_v @4' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• Machine	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Electroencephalography (EEG)											
• Examination	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg
• General	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Instrument and Workroom	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg
• Physician's Reading											
• Electronic Monitor	E_h @2' 6" AFF; E_v @3' 6" AFF	N	75	150	300	Avg	K	25	50	100	Avg
• Paper	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Electromyography (EMG)[m]	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Laparoscopy	See DIAGNOSTIC PROCEDURES/Endoscopy										
• Peritoneoscopy	See DIAGNOSTIC PROCEDURES/Endoscopy										
• Pulmonary Function Test											
• Examination	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg
• General	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg

Table 27.2 | Health Care Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1		☀			
	4:1		☀			
	2:1		☀			
	2:1		☀			
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	3

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		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
DIALYSIS CENTERS												
• Dialysate Preparation	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg
• Equipment Service Room												
• Clean and Soiled	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Storage	E_h @2' 6" AFF; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Final Water Treatment	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Treatment Room												
• Bed or Chair[p]	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg
• General	E_h @2' 6" AFF; E_v @4' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
• Needle Insertion[p]	E_h and E_v @patient's arm	T	500	1000	2000	Avg					
EAR, NOSE, AND THROAT	ENT Clinic											
• Audiometry Testing	Audiometry testing is typically performed in a prepackaged or turnkey set of rooms with integral lighting, the criteria and execution of which are implemented by the vendor. Otherwise, recommended criteria are cited below.											
• Control Booth or Room[n]	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Testing Booth or Room	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	P	150	300	600	Avg
• Consultation	See CONSULTATION											
• Examination and Treatment	See AMBULATORY CARE/Examination and Treatment											
• Lobby	See TRANSITION SPACES/Lobbies and Waiting Rooms											
• Speech Pathology Therapy	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	P	150	300	600	Avg
• Workroom												
• General	E_h @floor; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Preparations, Sterilization	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	P	150	300	600	Avg
ELECTRON MICROSCOPE												
• Cutting Room												
• Cutting	E_h @2' 6" AFF; E_v @4' AFF	V	1000	2000	4000	Avg	R	250	500	1000	Avg
• General	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Preparation[m]	E_h @2' 6" AFF; E_v @4' AFF	T	500	1000	2000	Avg	P	150	300	600	Avg
• Scope Room[n]	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
EMERGENCY DEPARTMENT	See AMBULATORY CARE											
EXAMINATION	See AMBULATORY CARE/Examination and Treatment											
EYE CLINIC												
• Examination and Treatment	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Refraction Testing	E_h @2' 6" AFF; E_v @4' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
• Surgery	See SURGICAL SUITES/Operating Rooms											
• Visual Field/Dark-adaptation Testing[n]	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg
FOOD SERVICE	See 22 | LIGHTING FOR COMMON APPLICATIONS											

Table 27.2 | Health Care Facilities Illuminance Recommendations continued next page

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1		☀			
	3:1		☀			
	3:1		☀			
	3:1		☀			
	3:1		☀			
	3:1		☀			
	2:1		☀			
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	3:1		☀			

Notes for Table 27.2

The table column headings are discussed in detail in 27.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 27.3 | SI Dimensional Conversions.

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b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 27.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◥ signals high likelihood; gray and white ◥ signals moderate likelihood; pale gray and white ◥ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. See Section 27.2.4 Ambulatory Care for additional information.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. Illuminance targets cited are for target area so noted and achieved with a minimum of 3-level control, if not dimming control, of architectural lighting.

l. Use lamps with CRIs ≥85.

m. Use lamps with CCTs of 5000 K and CRIs ≥85.

n. Control architectural lighting with dimmers to accommodate varied needs.

o. Provisions should be made for secure lighting equipment and controls.

p. Independently control lighting for use as necessary during procedures.

q. Use nightlights producing spectra at between 600 to 620 nm. See 12.4 Physiological Factors.

r. Some scanning equipment affects ferrous metals with potentially catastrophic results. See Section 27.2.36 Radiology for more information.

s. Make electrical provisions for portable work lights.

t. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 27.2 | Health Care Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
GIFT SHOP	See 34 | LIGHTING FOR RETAIL											
IT	See 22 | LIGHTING FOR COMMON APPLICATIONS											
INTENSIVE CARE												
• Nurse Control Center	See NURSES' STATIONS/Intensive Care											
• Patient Rooms	See PATIENT SERVICES/Patient Rooms											
• Life Support Unit	See AMBULATORY CARE/Life Support Unit											
LABORATORIES	The following are default criteria where no laboratories are identified as part of other health care applications.											
• Benches	E_h @3' AFF; E_v @4' AFF	T	500	1000	2000	Avg	P	150	300	600	Avg
• General	E_h @3' AFF; E_v @4' AFF	P	150	300	600	Avg	N	75	150	300	Avg
LAUNDRY												
• Cart Washer Area	E_h @3' AFF; E_v @3' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Central Liquid Supply	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Clean Linen Flow Rack and Assembly Area	E_h @3' AFF; E_v @3' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Clean Linen Processing	E_h @3' AFF; E_v @3' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Distribution Area (Cart Storage, Dispatch and Dock)	E_h @floor; E_v @4' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
• Linen Collection	E_h @floor; E_v @4' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
• Linen Pack Preparation	E_h @3' AFF; E_v @3' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Linen Repair	E_h and E_v @2' 6" AFF	T	500	1000	2000	Avg	P	150	300	600	Avg
• Linen Storage	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Production and Support	E_h @3' AFF; E_v @3' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Receiving	E_h @3' AFF; E_v @3' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Sorting and Washing	E_h @3' AFF; E_v @3' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Uniform Exchange (Automated)	E_h @3' AFF; E_v @3' AFF	M	50	100	200	Avg	K	25	50	100	Avg
LIBRARY	See 29 | LIGHTING FOR LIBRARIES											
LINEN												
• Closet	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Linen Room and Clean Sterile Processing and Distribution (SPD) Cart	E_h @3' AFF; E_v @3' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Linen Service	E_h @3' AFF; E_v @3' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Seamstress	See LAUNDRY/Linen Repair											
• Soiled Collection	E_h @3' AFF; E_v @3' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Soiled Collection and Central Sorting	E_h @3' AFF; E_v @3' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Soiled Linen Holding	E_h @3' AFF; E_v @3' AFF	M	50	100	200	Avg	I	15	30	60	Avg

Table 27.2 | Health Care Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1		☀		■	
	4:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	2:1		☀		■	
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
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d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◥ signals high likelihood; gray and white ◥ signals moderate likelihood; pale gray and white ◥ signals some likelihood; and all-white signals little-to-no likelihood.

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q. Use nightlights producing spectra at between 600 to 620 nm. See 12.4 Physiological Factors.

r. Some scanning equipment affects ferrous metals with potentially catastrophic results. See Section 27.2.36 Radiology for more information.

s. Make electrical provisions for portable work lights.

t. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 27.2 | Health Care Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
MEDICATION[l]												
• Medication Consultation	See CONSULTATION											
• Medication Preparation	See PHARMACY/Medication Preparation											
• Medication Stations	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Medication Storage	E_h @3' AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
MORGUE												
• Autopsy Rooms[k, m]	Clinical and forensic autopsy											
• Cleanup/Setup	E_h @3' AFF; E_v @4' AFF	T	500	1000	2000	Avg	R	250	500	1000	Avg
• General	E_h @3' AFF; E_v @4' AFF	V	1000	2000	4000	Avg	S	375	750	1500	Avg
• Inspection	Occurs as necessary to assess or extract tissue, organs, bone, or fluid. Inspection illuminance may need to be well in excess of 10,000 lx for direct-view methods and is typically provided by surgical-style articulated luminaires. For video-view methods, dimmed architectural general lighting or background wall lighting is used. Consult vendors of surgical luminaires or medical equipment consultants; survey state-of-the-art morgues.											
• Table	E_h @3' AFF; E_v @4' AFF	W	1500	3000	6000	Avg	T	500	1000	2000	Avg
• Isolation/Teaching Autopsy	See MORGUE/Autopsy Rooms											
• Mortuary Refrigerator	E_h @3' AFF; E_v @4' AFF	P	150	300	600	Avg	N	75	150	300	Avg
NUCLEAR MEDICINE												
• Conferencing and Common Viewing Room	E_h @3' AFF; E_v @3' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Equipment Calibration												
• Benches	E_h @3' AFF; E_v @4' AFF	T	500	1000	2000	Avg	R	250	500	1000	Avg
• General	E_h @3' AFF; E_v @4' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Isotope Storage and Preparation	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Radiopharmacy	E_h @3' AFF; E_v @4' AFF	S	375	750	1500	Avg	P	150	300	600	Avg
• Scanning Rooms												
• Preparation[k, l]	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Procedure[l, n]	E_h @3' AFF; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Walk-in Refrigerator	E_h @3' AFF; E_v @4' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
NURSES' STATIONS	These may also be known as communication centers, control centers, control stations, and work stations.											
• In-patient												
• General Circulation	See CORRIDORS/Nursing/In-patient											
• Work Station												
◦ General												
▪ Day	E_h @floor; E_v @5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
▪ Night	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	J	20	40	80	Avg
◦ Work Surface	E_h @floor; E_v @5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Intensive Care												
• General Circulation	See CORRIDORS/Nursing/Intensive Care											
• Work Station												
◦ Day	E_h @floor; E_v @5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
◦ Night	E_h @floor; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg

Table 27.2 | Health Care Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1		☀			
	3:1		☀			
	4:1		☀			
	4:1		☀			
	2:1		☀			
	4:1		☀			
	3:1		☀			
	2:1		☀			
	3:1		☀			
	3:1		☀			
	3:1		☀			
	3:1		☀			
	3:1		☀			
	3:1		☀			
	3:1		☀			
	3:1					
see Table 12.6			☀			
see Table 12.6			☀			
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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
NURSES' STATIONS	(continued)										
• Surgery Pre- and Post-Op											
• General Circulation	See CORRIDORS/Surgery Pre- and Post-Op										
• Work Station	E_h @floor; E_v @5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
OBSTETRICS											
• Birthing Rooms[l, p]											
• Art	On artwork plane (typically vertical)								see Table 15.2		
• Bathroom	See TOILETS/LOCKER ROOMS										
• Bed											
• Birthing Area	This is the area of and immediately surrounding the lower abdomen. Birthing illuminance criteria at the lower abdomen may need to be well in excess of 25,000 lx and in this more hospitality-like setting is typically provided by more discreet luminaires mounted in or on the ceiling or by portable luminaires. Consult medical equipment consultants; survey state-of-the-art birthing facilities.										
• Cleanup/Setup	E_h @3' AFF; E_v @4' AFF, full bed	P	150	300	600	Avg	N	75	150	300	Avg
• Reading	Small area at head of bed at reading position. E_h and E_v @3' AFF.	O	100	200	400	Avg	M	50	100	200	Avg
• Television Viewing	Small area at head of bed at sitting position. E_h @3' AFF.	K	25	50	100	Avg					
• Closet	E_h and E_v @4' AFF @shelf face	I	15	30	60	Avg	H	10	20	40	Avg
• Casual Chair	E_h and E_v @2' 6" at sitting areas	N	75	150	300	Avg	K	25	50	100	Avg
• General	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Nightlight[q]	On motion sensor. E_h @floor.	A	0.5	1	2	Avg					
• Night Observation	E_h @3' AFF; E_v @4' AFF, full bed	I	15	30	60	Avg	D	3	6	12	Avg
• Service Alcove											
• Storage	E_v over face of storage shelving						K	25	50	100	Avg
• Work Counter	E_h @3' AFF	P	150	300	600	Avg					
• Delivery Rooms[l]											
• Bed											
• Birthing Area	This is the area of and immediately surrounding the lower abdomen. Birthing illuminance criteria at the lower abdomen may need to be well in excess of 25,000 lx and is typically provided by surgical-style articulated luminaires. Consult medical equipment consultants; survey state-of-the-art delivery room facilities.										
• General	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Scrub Area	E_h @3' AFF; E_v @4' AFF	T	500	1000	2000	Avg	R	250	500	1000	Avg
• Labor Rooms											
• Bed	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• General	E_h @3' AFF; E_v @4' AFF	P	150	300	600	Avg	L	37.5	75	150	Avg
• Nurseries											
• General	E_h @3' AFF; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Observation	E_h @3' AFF; E_v @4' AFF	P	150	300	600	Avg	K	25	50	100	Avg
• Treatment	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	K	25	50	100	Avg
• Post-delivery Recovery											
• Observation	E_h @3' AFF; E_v @4' AFF, room	R	250	500	1000	Avg	O	100	200	400	Avg
• Rest	E_h @3' AFF; E_v @4' AFF, room	M	50	100	200	Avg	I	15	30	60	Avg

Table 27.2 | Health Care Facilities Illuminance Recommendations continued next page

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
see Table 12.6						
see 15.1.1.3						
	2:1					
	3:1					
	4:1					
	3:1					
	3:1					
	4:1					
	no ratio					
	4:1					
	3:1					
see Table 12.6						
	4:1					
	4:1					
	4:1					
	4:1					
	4:1					
	4:1					
	2:1					
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e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

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g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. See Section 27.2.4 Ambulatory Care for additional information.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. Illuminance targets cited are for target area so noted and achieved with a minimum of 3-level control, if not dimming control, of architectural lighting.

l. Use lamps with CRIs ≥85.

m. Use lamps with CCTs of 5000 K and CRIs ≥85.

n. Control architectural lighting with dimmers to accommodate varied needs.

o. Provisions should be made for secure lighting equipment and controls.

p. Independently control lighting for use as necessary during procedures.

q. Use nightlights producing spectra at between 600 to 620 nm. See 12.4 Physiological Factors.

r. Some scanning equipment affects ferrous metals with potentially catastrophic results. See Section 27.2.36 Radiology for more information.

s. Make electrical provisions for portable work lights.

t. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 27.2 | Health Care Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
ONCOLOGY											
• Chemotherapy											
• Agent Preparation	E_h @floor; E_v @4' AFF	T	500	1000	2000	Avg	P	150	300	600	Avg
• Treatment[l, p]											
• Preparation	E_h @3' AFF; E_v @4' AFF	T	500	1000	2000	Avg	P	150	300	600	Avg
• Procedure[n]	E_h @3' AFF; E_v @4' AFF	O	100	200	400	Avg	K	25	50	100	Avg
• Radiation	See RADIOLOGY										
OPERATING ROOMS	See SURGICAL SUITES										
PARKING	See 26 | LIGHTING FOR EXTERIORS										
PATIENT SERVICES[l]											
• Agent Cashier (Discharge)											
• General	E_h @floor; E_v @5' AFF	N	75	150	300	Avg	L	37.5	75	150	Avg
• Transaction Area	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• ATMs and Service Kiosks	E_h @3' AFF; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Consultation	See CONSULTATION										
• Interviews	E_h @2' 6" AFF; E_v @4' AFF										
• Conversational		N	75	150	300	Avg	L	37.5	75	150	Avg
• Formal	Form-filling and reading	Q	200	400	800	Avg	N	75	150	300	Avg
• Day Rooms	See TRANSITION SPACES/Lounges										
• Patient Rooms											
• Art	On artwork plane (typically vertical)								see Table 15.2		
• Bathroom	See TOILETS/LOCKER ROOMS										
• Bed[p]											
• Examination[m, n]	E_h @3' AFF; E_v @4' AFF, full bed	R	250	500	1000	Avg	O	100	200	400	Avg
• Reading	Small area at head of bed at reading position. E_h and E_v @3' AFF.	O	100	200	400	Avg	M	50	100	200	Avg
• Television Viewing	Small area at head of bed at sitting position. E_h @3' AFF.	K	25	50	100	Avg					
• Closet	E_h and E_v @4' AFF @shelf face	I	15	30	60	Avg	H	10	20	40	Avg
• Casual Chair	E_h and E_v @2' 6" at sitting areas	N	75	150	300	Avg	K	25	50	100	Avg
• Desk	E_h @desk; E_v @4' AFF	O	100	200	400	Avg	I	15	30	60	Avg
• General	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Isolation Anteroom	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Nightlight[q]	On motion sensor. E_h @floor.	A	0.5	1	2	Avg					
• Night Observation	E_h @3' AFF; E_v @4' AFF, full bed	I	15	30	60	Avg	D	3	6	12	Avg
• Security/Seclusion Observation	E_h @3' AFF; E_v @4' AFF, full bed	M	50	100	200	Avg	K	25	50	100	Avg
• Service Alcove											
• Storage	E_v over face of storage shelving						L	37.5	75	150	Avg
• Work Counter	E_h @3' AFF	P	150	300	600	Avg					
• Service Kiosks	See PATIENT SERVICES/ATMs and Service Kiosks										
• Solariums	See TRANSITION SPACES/Lounges										

Table 27.2 | Health Care Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1		☀			
	3:1		☀			
	3:1		☀			
	3:1		☀			
see Table 12.6			☀	◪		
	3:1		☀	◪		
	3:1		☀			
	3:1		☀			
see 15.1.1.3			☀	◪		
see Table 12.6			☀			
	3:1		☀	◪		
	4:1		☀	◪		
	3:1		☀			
	3:1		☀	◪		
see Table 12.6			☀	◪		
	4:1		☀			
	4:1		☀			
	no ratio					
	4:1					
	4:1		☀			
	3:1		☀			
see Table 12.6			☀			

Notes for Table 27.2

The table column headings are discussed in detail in 27.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 27.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 27.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 27.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◪ signals high likelihood; gray and white ◪ signals moderate likelihood; pale gray and white ◪ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. See Section 27.2.4 Ambulatory Care for additional information.

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l. Use lamps with CRIs ≥85.

m. Use lamps with CCTs of 5000 K and CRIs ≥85.

n. Control architectural lighting with dimmers to accommodate varied needs.

o. Provisions should be made for secure lighting equipment and controls.

p. Independently control lighting for use as necessary during procedures.

q. Use nightlights producing spectra at between 600 to 620 nm. See 12.4 Physiological Factors.

r. Some scanning equipment affects ferrous metals with potentially catastrophic results. See Section 27.2.36 Radiology for more information.

s. Make electrical provisions for portable work lights.

t. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 27.2 | Health Care Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
PEDESTRIAN WAYS	See 26 | LIGHTING FOR EXTERIORS											
PHARMACIES[l]												
• Controlled Substances Vault	E_h @3' AFF; E_v @4' AFF	S	375	750	1500	Avg	P	150	300	600	Avg	
• Drug Receiving, Record Control, and Storage	E_h @floor; E_v @4' AFF	S	375	750	1500	Avg	P	150	300	600	Avg	
• Drug Utilization Review	E_h @3' AFF; E_v @4' AFF	S	375	750	1500	Avg	P	150	300	600	Avg	
• Drug Vault	E_h @3' AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Extemporaneous Compounding	E_h @3' AFF; E_v @4' AFF	T	500	1000	2000	Avg	P	150	300	600	Avg	
• Extemporaneous Repackaging	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
• Filling and Assembly	E_h @3' AFF; E_v @4' AFF	T	500	1000	2000	Avg	P	150	300	600	Avg	
• General	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
• Hemodialysis Storage	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Intravenous Admixtures and Aseptic Transfers	E_h @floor; E_v @4' AFF	T	500	1000	2000	Avg	P	150	300	600	Avg	
• Medication Assignment	E_h @3' AFF; E_v @4' AFF	S	375	750	1500	Avg	P	150	300	600	Avg	
• Medication Preparation	E_h @3' AFF; E_v @4' AFF	S	375	750	1500	Avg	P	150	300	600	Avg	
• Poison Control Storage	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Prepackaging	E_h @3' AFF; E_v @4' AFF	T	500	1000	2000	Avg	P	150	300	600	Avg	
• Prescription Receiving	E_h @3' AFF; E_v @4' AFF	S	375	750	1500	Avg	P	150	300	600	Avg	
• Prosthetics and Medical Supplies	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Receiving	See PHARMACIES/Drug Receiving, Record Control, and Storage											
• Stat (Immediate Service)	E_h @3' AFF; E_v @4' AFF	T	500	1000	2000	Avg	P	150	300	600	Avg	
• Sterile Fluids and Admixture Sets Storage	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Unit Dose Dispensing	E_h @3' AFF; E_v @4' AFF	T	500	1000	2000	Avg	P	150	300	600	Avg	
• Vault	See PHARMACIES/Drug Vault											
PROCEDURES	See DIAGNOSTIC PROCEDURES											
RADIOLOGY												
• Anesthesiology	See ANESTHESIOLOGY											
• Consultation and Viewing	See CONSULTATION											
• Control Alcove or Booth[n]	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg	
• Diagnostics												
• Barium Kitchen	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
• Film Sorting (Legacy Media)	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
• Image Viewing[n]	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Radiography/Fluoroscopy[r]	Criteria apply to various scanning methods, such as Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and Ultrasound.											
• Ceiling Art	Introduce backlighted photomurals or art panels on ceiling above recumbent patient's head position.											
• Preparation[l, n]	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg	
• Procedure[l, n]	E_h @3' AFF; E_v @4' AFF	K	25	50	100	Avg	H	10	20	40	Avg	

Table 27.2 | Health Care Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1		☀		■	
	3:1		☀			■
	3:1		☀		■	
	3:1		☀		■	
	3:1		☀		■	
	3:1		☀		■	
	3:1		☀			■
	3:1		☀			■
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	3:1		☀		■	
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	3:1		☀			■
	3:1		☀	■		■
	3:1		☀	◪		■
	3:1		☀			■
	4:1		☀			■

Notes for Table 27.2

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a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 27.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 27.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◪ signals high likelihood; gray and white ◪ signals moderate likelihood; pale gray and white ◪ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. See Section 27.2.4 Ambulatory Care for additional information.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

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l. Use lamps with CRIs ≥85.

m. Use lamps with CCTs of 5000 K and CRIs ≥85.

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o. Provisions should be made for secure lighting equipment and controls.

p. Independently control lighting for use as necessary during procedures.

q. Use nightlights producing spectra at between 600 to 620 nm. See 12.4 Physiological Factors.

r. Some scanning equipment affects ferrous metals with potentially catastrophic results. See Section 27.2.36 Radiology for more information.

s. Make electrical provisions for portable work lights.

t. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 27.2 | Health Care Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
RADIOLOGY	(continued)										
• Examination	See AMBULATORY CARE/Examination and Treatment										
• Scrub Area	E_h @3' AFF; E_v @4' AFF	T	500	1000	2000	Avg	R	250	500	1000	Avg
• Therapy											
• Isotope Kitchen											
• Benches	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• General	E_h @3' AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Radiotherapy[r]	Criteria apply to various therapy methods.										
• Ceiling Art	Introduce backlighted photomurals or art panels on ceiling above recumbent patient's head position.										
• Preparation, Observation[l, n]	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	M	50	100	200	Avg
• Treatment[l, n]	E_h @2' 6" AFF; E_v @4' AFF	K	25	50	100	Avg	I	15	30	60	Avg
RECOVERY	See SURGICAL SUITES										
RETAIL	See 34 | LIGHTING FOR RETAIL										
SHOPS											
• Benches	E_h @3' AFF; E_v @4' AFF. Also see 30 | LIGHTING FOR MANUFACTURING.										
• Assembly	Difficult process	T	500	1000	2000	Avg	R	250	500	1000	Avg
• Inspection	Difficult process	T	500	1000	2000	Avg	R	250	500	1000	Avg
• Machining	Medium benchwork	T	500	1000	2000	Avg	R	250	500	1000	Avg
• Maintenance	General repairs in shop	R	250	500	1000	Avg	P	150	300	600	Avg
• Woodworking	Fine process	T	500	1000	2000	Avg	R	250	500	1000	Avg
• General	E_h @3' AFF; E_v @4' AFF		Avg = 0.3 times task E_h					Avg = 0.3 times task E_v			
SPAS	See 28 | LIGHTING FOR HOSPITALITY										
STERILE PROCESSING AND DISTRIBUTION	SPD; also known as Supply Processing and Distribution										
• Automatic Cart Wash	E_h @2' 6" AFF; E_v @4' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
• Bulk Storage Area	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Clean Receiving and Breakout	E_h @2' 6"; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Clean Side	E_h @2' 6"; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Inspection and Preparation of Surgical Linen and Packs	E_h @2' 6"; E_v @3' AFF	R	250	500	1000	Avg	P	150	300	600	Avg
• Manual Equipment Wash	E_h @2' 6"; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Preparation, Assembly, and Sterilization	E_h @2' 6"; E_v @3' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Sterile and Non-sterile Storage	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg

Table 27.2 | Health Care Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	4:1		☀			
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	3:1		☀			
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	4:1		☀			
	see Table 12.6		☀	↓		
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e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ↓ signals high likelihood; gray and white ↓ signals moderate likelihood; pale gray and white ↓ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. See Section 27.2.4 Ambulatory Care for additional information.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. Illuminance targets cited are for target area so noted and achieved with a minimum of 3-level control, if not dimming control, of architectural lighting.

l. Use lamps with CRIs ≥85.

m. Use lamps with CCTs of 5000 K and CRIs ≥85.

n. Control architectural lighting with dimmers to accommodate varied needs.

o. Provisions should be made for secure lighting equipment and controls.

p. Independently control lighting for use as necessary during procedures.

q. Use nightlights producing spectra at between 600 to 620 nm. See 12.4 Physiological Factors.

r. Some scanning equipment affects ferrous metals with potentially catastrophic results. See Section 27.2.36 Radiology for more information.

s. Make electrical provisions for portable work lights.

t. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 27.2 | Health Care Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
SUPPORT SPACES												
• Barber Shop	See 28 | LIGHTING FOR HOSPITALITY/SPAS/Salon											
• Beauty Shop	See 28 | LIGHTING FOR HOSPITALITY/SPAS/Salon											
• Break Rooms/ Lunch Rooms	E_h @2' 6" AFF; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Coat Check or Coat Rooms	E_h @3' 0"; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Copy/Print Rooms											
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Machines	E_h and E_v @3' 6" AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Interstitial Space[s]	E_h @floor; E_v @4' AFF	I	15	30	60	Avg	G	7.5	15	30	Avg
• Janitor's Closet	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Receiving/Shipping											
• Dock	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Receiving/Staging	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Salon	See 28 | LIGHTING FOR HOSPITALITY/SPAS/Salon											
• Storage	E_h @floor; E_v @4' AFF											
• Apparatus and Equipment		O	100	200	400	Avg	K	25	50	100	Avg
• Bulky items		K	25	50	100	Avg	H	10	20	40	Avg
• Medium items		M	50	100	200	Avg	I	15	30	60	Avg
• Small items		O	100	200	400	Avg	K	25	50	100	Avg
• Oxygen		M	50	100	200	Avg	I	15	30	60	Avg
• Stretchers and Wheelchairs		K	25	50	100	Avg	H	10	20	40	Avg
• Staff Quarters											
• Bedrooms											
• Casual Chair	E_h and E_v @2' 6" at sitting areas	N	75	150	300	Avg	K	25	50	100	Avg
• Desk	E_h @desk; E_v @4' AFF	Q	200	400	800	Avg	N	75	150	300	Avg
• General	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Corridors	See CORRIDORS/Quarters											
• On-call Rooms	See SUPPORT SPACES/Staff Quarters/Bedrooms											
SURGICAL SUITES												
• Clean and Sterile Supplies	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Clean Core Support Area	E_h @floor; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Control Rooms[k]											
• Cystoscopic	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Radiographic	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Decontamination	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Dictation Cubicle	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Operating Rooms (ORs)[k, m]	Cardiac, Cystoscopic, General Purpose, Neurosurgery, and Orthopedic Surgeries											
• Cleanup/Setup	E_h @3' AFF; E_v @4' AFF	T	500	1000	2000	Avg	R	250	500	1000	Avg
• General	E_h @3' AFF; E_v @4' AFF	V	1000	2000	4000	Avg	S	375	750	1500	Avg
• Surgical or Operating Field	This is the area of and immediately surrounding the site of the surgery. Depending on the medical procedures and equipment involved, illuminance criteria at the site of the surgery may need to be well in excess of 25,000 lx for direct view methods and is typically provided by surgical-style articulated luminaires. For video-view methods, dimmed architectural general lighting or background wall lighting is used. Consult vendors of the medical equipment involved or medical equipment consultants; survey state-of-the-art OR facilities.											
• Table	E_h @3' AFF; E_v @4' AFF	W	1500	3000	6000	Avg	T	500	1000	2000	Avg

Table 27.2 | Health Care Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀		■	
	3:1		☀			■
	3:1		☀			■
	2:1		☀			■
	2:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀	◪	■	
	see Table 12.6		☀	◪	■	
	4:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀	◪		■
	3:1		☀	◪		■
	3:1		☀			■
	3:1		☀			■
	4:1		☀			■
	4:1		☀			■
	2:1		☀		■	

Notes for Table 27.2

The table column headings are discussed in detail in 27.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 27.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 27.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 27.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◪ signals high likelihood; gray and white ◪ signals moderate likelihood; pale gray and white ◪ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. See Section 27.2.4 Ambulatory Care for additional information.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

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l. Use lamps with CRIs ≥85.

m. Use lamps with CCTs of 5000 K and CRIs ≥85.

n. Control architectural lighting with dimmers to accommodate varied needs.

o. Provisions should be made for secure lighting equipment and controls.

p. Independently control lighting for use as necessary during procedures.

q. Use nightlights producing spectra at between 600 to 620 nm. See 12.4 Physiological Factors.

r. Some scanning equipment affects ferrous metals with potentially catastrophic results. See Section 27.2.36 Radiology for more information.

s. Make electrical provisions for portable work lights.

t. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 27.2 | Health Care Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b,c,d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
SURGICAL SUITES	(continued)										
• Patient Holding Area[n]	E_h @3' AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Pump Technician's Prep Room	E_h @2' 6" AFF; E_v @4' AFF	S	375	750	1500	Avg	P	150	300	600	Avg
• Recovery[m]											
• Examination[n]	E_h @3' AFF; E_v @4' AFF, full bed	T	500	1000	2000	Avg	P	150	300	600	Avg
• General											
• Observation	E_h @3' AFF; E_v @4' AFF, room	R	250	500	1000	Avg	O	100	200	400	Avg
• Rest	E_h @3' AFF; E_v @4' AFF, room	M	50	100	200	Avg	I	15	30	60	Avg
• Scrub-up Alcove	E_h @3' AFF; E_v @3' AFF	T	500	1000	2000	Avg	P	150	300	600	Avg
• Soiled Holding Area	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Special Equipment Recording Room	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Storage and Closets											
• Anesthesia and Equipment	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Apparatus and Equipment	E_h @floor; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Housekeeping	E_h @floor; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Trash Collection Room	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Workroom	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg
THERAPY											
• Chemotherapy	See ONCOLOGY										
• Corrective Clinic	E_h @2' 6"; E_v @4' AFF	R	250	500	1000	Avg	P	150	300	600	Avg
• Educational/Vocational	E_h @2' 6"; E_v @4' AFF	R	250	500	1000	Avg	P	150	300	600	Avg
• Group Therapy Room[n]											
• General	E_h @floor; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Table	E_h @floor; E_v @4' AFF	R	250	500	1000	Avg	M	50	100	200	Avg
• Inhalation	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Orthotic and Splinting Area											
• Bench	E_h @3' AFF; E_v @4' AFF, room	R	250	500	1000	Avg	O	100	200	400	Avg
• Fine Detail	E_h @3' AFF; E_v @4' AFF, room	T	500	1000	2000	Avg	P	150	300	600	Avg
• General	E_h @3' AFF; E_v @4' AFF, room	P	150	300	600	Avg	M	50	100	200	Avg
• Physical											
• Arm and Leg Whirlpools	E_h @2' AFF; E_v @4' AFF, room	P	150	300	600	Avg	M	50	100	200	Avg
• Clinics	E_h @3' AFF; E_v @4' AFF, room	R	250	500	1000	Avg	O	100	200	400	Avg
• General	E_h @floor; E_v @4' AFF, room	M	50	100	200	Avg	I	15	30	60	Avg
• Hubbard Tanks	E_h @2' AFF; E_v @4' AFF, room	P	150	300	600	Avg	M	50	100	200	Avg
• Hydrotherapy	E_h @2' AFF; E_v @4' AFF, room	P	150	300	600	Avg	M	50	100	200	Avg
• Special Treatment Areas	E_h @3' AFF; E_v @4' AFF, room	S	375	750	1500	Avg	P	150	300	600	Avg
• Tables and Individual Exercise	E_h @3' AFF; E_v @4' AFF, room	P	150	300	600	Avg	M	50	100	200	Avg
• Treatment Areas	E_h @3' AFF; E_v @4' AFF, room	R	250	500	1000	Avg	O	100	200	400	Avg
• Radiation	See RADIOLOGY										
• Recreation	See ACTIVITY AREAS										
• Respiratory	See THERAPY/Inhalation										

Table 27.2 | Health Care Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1		☀			■
	3:1		☀			■
	2:1		☀		■	
	3:1		☀			■
	3:1		☀			■
	2:1		☀		■	
	3:1		☀			■
	3:1		☀	◪		■
	3:1		☀			■
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	3:1		☀			■
	3:1		☀		■	

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d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◪ signals high likelihood; gray and white ◪ signals moderate likelihood; pale gray and white ◪ signals some likelihood; and all-white signals little-to-no likelihood.

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m. Use lamps with CCTs of 5000 K and CRIs ≥85.

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o. Provisions should be made for secure lighting equipment and controls.

p. Independently control lighting for use as necessary during procedures.

q. Use nightlights producing spectra at between 600 to 620 nm. See 12.4 Physiological Factors.

r. Some scanning equipment affects ferrous metals with potentially catastrophic results. See Section 27.2.36 Radiology for more information.

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Table 27.2 | Health Care Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b,c,d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
THERAPY	(continued)										
• Speech Pathology	See EAR, NOSE, AND THROAT/Speech Pathology Therapy										
• Spinal Cord Injury											
• Arm and Leg Whirlpools	E_h @2' AFF; E_v @4' AFF, room	P	150	300	600	Avg	M	50	100	200	Avg
• Clinics	E_h @3' AFF; E_v @4' AFF, room	R	250	500	1000	Avg	O	100	200	400	Avg
• Hubbard Tanks	E_h @2' AFF; E_v @4' AFF, room	P	150	300	600	Avg	M	50	100	200	Avg
• Therapeutic Pool											
• Deck (Apron)	E_h @2' AFF; E_v @4' AFF, room	P	150	300	600	Avg	M	50	100	200	Avg
• Pool	E_h @3' AFF; E_v @4' AFF, room	O	100	200	400	Avg	L	37.5	75	150	Avg
TOILETS/LOCKER ROOMS											
• Fixtures	E_h @top of plumbing fixture; E_v @3'-5' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• General	E_h @floor; E_v @3'-5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Lockers	E_h @floor; E_v @locker faces	K	25	50	100	Avg	K	25	50	100	Avg
• Showers	E_h @floor; E_v @3'-5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Vanities	E_h @3' AFF; E_v @3'-5' AFF	N	75	150	300	Avg	O	100	200	400	Avg
TRANSITION SPACES											
• Circulation Corridors	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• Back-of-house											
◦ Adjacency Passageways	E_h @floor; E_v @5' AFF	Avg ≥0.3 times task E_h of adjacent space or as cameras require, but with min ≥10 lx					Avg ≥0.3 times task E_v of adjacent space or as cameras require				
◦ Independent Passageways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Public											
◦ Adjacency Passageways	E_h @floor; E_v @5' AFF	Avg ≥0.2 times task E_h of adjacent space or as cameras require, but with min ≥10 lx					Avg ≥0.2 times task E_v of adjacent space or as cameras require				
◦ Independent Passageways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Elevators											
• Freight											
◦ Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Threshold											
▫ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
▫ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Passenger											
◦ Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Threshold											
▫ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
▫ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Patient											
◦ Cab interior	E_h @floor; E_v @3' AFF	O	100	200	400	Avg	M	50	100	200	Avg
◦ Threshold											
▫ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
▫ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg

Table 27.2 | Health Care Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1		☀			
	3:1		☀			
	3:1		☀			
	3:1		☀			
	3:1		☀			
	2:1		☀			
	2:1		☀			
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	2:1		☀			

Notes for Table 27.2

The table column headings are discussed in detail in 27.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 27.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 27.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 27.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◥ signals high likelihood; gray and white ◥ signals moderate likelihood; pale gray and white ◥ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. See Section 27.2.4 Ambulatory Care for additional information.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. Illuminance targets cited are for target area so noted and achieved with a minimum of 3-level control, if not dimming control, of architectural lighting.

l. Use lamps with CRIs ≥85.

m. Use lamps with CCTs of 5000 K and CRIs ≥85.

n. Control architectural lighting with dimmers to accommodate varied needs.

o. Provisions should be made for secure lighting equipment and controls.

p. Independently control lighting for use as necessary during procedures.

q. Use nightlights producing spectra at between 600 to 620 nm. See 12.4 Physiological Factors.

r. Some scanning equipment affects ferrous metals with potentially catastrophic results. See Section 27.2.36 Radiology for more information.

s. Make electrical provisions for portable work lights.

t. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 27.2 | Health Care Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
TRANSITION SPACES	(continued)										
• Entries	See BUILDING ENTRIES										
• Escalators/Moving Walkways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Lobbies and Waiting Rooms											
• Circulation, Elevator Lobbies	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• General											
• At building entries	Close proximity to exterior. Lighting should be designed to assist with adaptation when passing to/from exterior.										
◦ Day	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
◦ Night	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Distant from entries	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
• Security Screening											
• Private Rooms	E_h @3' AFF; E_v @5' AFF	Q	200	400	800	Avg	O	100	200	400	Avg
• Public Lobbies	E_h @3' AFF; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Reading/Waiting Areas	E_h and E_v @2' 6" at sitting areas	P	150	300	600	Avg	N	75	150	300	Avg
• Reception	Such as visitor registration or informational/directional concierge.										
• Desk	Age determination may be as or more relevant with respect to guest or patron than staff.										
• Desk top	E_h @3' 6" AFF; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Focal wall behind desk	On wall plane								see Table 15.2		
• Lounges											
• Patients and Visitors											
• General	E_h @floor; E_v @4' AFF	J	20	40	80	Avg	G	7.5	15	30	Avg
• Table games	See ACTIVITY AREAS/Games										
• Television	E_h @floor; E_v @4' AFF	J	20	40	80	Avg	G	7.5	15	30	Avg
• Reading/Work Areas	E_h and E_v @2' 6" at sitting areas	O	100	200	400	Avg	L	37.5	75	150	Avg
• Social/Waiting Areas	E_h @floor; E_v @4' AFF	J	20	40	80	Avg	G	7.5	15	30	Avg
• Stairs	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• High Activity[t]	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Live Surveillance	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Typical	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
TREATMENT	See AMBULATORY CARE/Examination and Treatment										

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Uniformity Targets[e] Over Area of Coverage			[f]	[g]	Typical Area of Coverage[h]	
1st ratio E_h/2nd ratio E_v if different uniformities apply					Task Proper or Task Area	Room or Designated Area
Max:Avg	Avg:Min	Max:Min				
	2:1					
	4:1					
	4:1					
	4:1					
	2:1					
	2:1					
	4:1					
see Table 12.6						
	4:1					
	4:1					
	3:1					
	2:1					
	2:1					
	2:1					
	2:1					

Notes for Table 27.2

The table column headings are discussed in detail in 27.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 27.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 27.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

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f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. See Section 27.2.4 Ambulatory Care for additional information.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. Illuminance targets cited are for target area so noted and achieved with a minimum of 3-level control, if not dimming control, of architectural lighting.

l. Use lamps with CRIs ≥85.

m. Use lamps with CCTs of 5000 K and CRIs ≥85.

n. Control architectural lighting with dimmers to accommodate varied needs.

o. Provisions should be made for secure lighting equipment and controls.

p. Independently control lighting for use as necessary during procedures.

q. Use nightlights producing spectra at between 600 to 620 nm. See 12.4 Physiological Factors.

r. Some scanning equipment affects ferrous metals with potentially catastrophic results. See Section 27.2.36 Radiology for more information.

s. Make electrical provisions for portable work lights.

t. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 27.3 | SI Dimensional Conversions

US Customary	SI
General	**Hard Conversion**
inches	mm [inches × 25.40]
feet	m [feet × 0.30]
Specific	**Convenient Conversions[a]**
2'	610 mm or 0.6 m
2' 6"	760 mm or 0.75 m
3'	915 mm or 0.9 m
3' 6"	1065 mm or 1.1 m
4'	1220 mm or 1.2 m
5'	1525 mm or 1.5 m

a. Hard conversions rounded for reporting convenience. Not to be confused with metric-sized luminaires or other building materials. Not for precision construction.

The following discussion is keyed to major application headings in Table 27.2. Couple this with topics in Table 27.1 for comprehensive qualitative and quantitative criteria.

Although many health care applications include dedicated waiting areas, all waiting areas are addressed in Table 27.2 at TRANSITION SPACES/Lobbies and Waiting Rooms.

27.2.1 Accenting

Accenting affects people's brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. In health care facilities, accenting affects both the patient and caregiver experiences. Accenting contributes to a less intimidating and less institutional setting. Default accent lighting criteria are discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. Also see 15.1.1.3 Accent Lighting.

Where situations arise that cost or power budgets preclude complete implementation of accenting, color contrast can be an effective alternative to luminance contrast. Here, where lighting power densities drive neutral and light-toned finishes, colorful finish accents to small areas of ceilings or walls are helpful. However, color contrast as accenting should be limited to small and bold applications in areas where vertical illuminances or ceiling lighting effects are moderate to high. Otherwise, the effect is lost.

Health care facilities may be heavily signed. Signage can be internally illuminated, frontal accented, or lighted by the general light in a space or area. The amount of signage, the hierarchies and priorities of if and how signage is illuminated, and placement, size, and inherent contrast must be part of the programming. Coordination with other team members, including signage or graphics consultants is necessary.

27.2.2 Activity Areas

Activity areas are common spaces where patients, and sometimes visitors, can partake in arts and crafts and games. The design team should take advantage of what might be the only areas of respite from the more institutional nature of diagnoses, treatments, and even convalescing. Programming of the activities is important to tune lighting by space or area to the tasks. Although age plays a role in determining illuminances, it is important to note that these sorts of tasks or activities are not pressured by high degrees of accuracy or speed.

27.2.3 Administration

Lighting for administrative areas is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. The architectural scheme and task specifics vary based on the associated health care facility or campus and patient base. These details should affect the lighting design, from the kinds of lighting effects to lighting equipment styling to luminances and illuminances.

Administrative areas are typically consolidated into a single area, wing, or building. Several aspects may affect the degree to which the lighting design is sympathetic to or different from that of the other applications and tasks at the health care facility in question:

- Owner wishes and architectural desires
- Degree to which clientele or business prospects visit administrative operations
- View between administrative areas and health care areas
- Management style and immersion in health care functions

27.2.4 Ambulatory Care

Also called outpatient, ambulatory care is the department or building or buildings that accommodate patients generally not in need of admission to a hospital. Many outpatients are scheduled for diagnoses or treatments. An emergency department may be associated with ambulatory care. Nighttime illuminance targets for the porte cocheres are intended for application during dark hours of operation where lighting is deemed necessary or de-

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sirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits.

To provide less intimidating settings for patients and more flexible viewing conditions for caregivers, many ambulatory care facilities should be fitted with multi-level switching, if not dimming, systems. Exam rooms can then be set to a pre- and post-exam setting where lighting is somewhat subdued and can be more conducive to consultation and interviewing tasks. Depending on room sizes and geometry, an ambient lighting system on 3-level switching or dimming might meet most all lighting needs in an exam room except the charting task at the charting station. Here, task lighting is typically employed which, when used during the pre- or post-exam setting provide a more visually interesting, less institutional setting. This switching or dimming arrangement has the added benefit of reduced energy use compared to all lights full-on at all times.

Coordinate with the medical equipment consultant to determine if additional task-specific portable or permanent surgical, treatment, or exam lighting solely dedicated to respective tasks is necessary. This equipment, also known as procedure luminaires, is usually specified by the medical equipment consultant. Otherwise, research prescriptive lighting requirements as these vary greatly and are based on type of procedure, visual requirements, and medical equipment vendors' recommendations. For example, manual clinical techniques with direct view may have very different requirements than robotic techniques with video view and both may need to be accommodated.

27.2.5 Anesthesia

Administering anesthesia and observing patients under anesthesia is a critical task. Confirm that the anesthetics involved are nonflammable, otherwise lighting and switching equipment rated for hazardous locations is necessary where this material is handled and stored. Consult the AHJ and the design team.

27.2.6 Atria and Courtyards

Lighting for atria and courtyards is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. In large health care facilities and campuses, atria and courtyards play an important role as areas of respite. Lighting should be consistent with the functions of these areas while enhancing their roles of spatial and visual relief. Figure 27.1 illustrates a lighting approach for a large atrium.

27.2.7 Auditoria

Lighting for auditoria is discussed in 24 | LIGHTING FOR EDUCATION.

27.2.8 Building Entries

Lighting for building entries is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. The lighting of building entries for health care facilities contributes significantly to the nighttime arrival sequence where clarity of destination is important. At the entry, vertical and horizontal illuminance are important to assist in pedestrian/vehicular interaction. Lamps with CRI ≥82 enhance skin tones and clothing and vehicle color. Lamps with CCTs ≤3500 K offer a more inviting and less institutional appearance than higher color temperature counterparts.

One variable affecting criteria is activity level during the nighttime hours. Another variable is the nighttime outdoor lighting zone. Nighttime activity levels may vary by type of facility, such as a standalone specialty clinic, urgent care clinic, or full service hospital. The nighttime outdoor lighting zone within which the facility is located or to which the team and client elect to design affects the illuminance criteria for outdoor tasks. Nighttime outdoor lighting zone designations vary by local ordinance, sustainability

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guides, or the team's own definition of place. These are discussed in 26 | LIGHTING FOR EXTERIORS. Also see Table 15.6 | Nighttime Operational Strategies for Improved Outdoor Environmental Regard. The kind of facility, schedule of operation, activity-levels, and nighttime outdoor lighting zones must be established in programming. Figure 27.2 illustrates lighting of an entry to a heart care center.

27.2.9 Chapel/Meditation

Lighting for places of worship and meditation is discussed in 37 | LIGHTING FOR WORSHIP. In health care facilities, worship spaces are typically nondenominational. If these are programmed for use by a variety of religious orders, then preset scene controls may be convenient, if not a necessity. Figure 37.2 illustrates a hospital meditation chapel.

27.2.10 Classrooms

Many full service hospitals are associated with universities and may have need for classrooms. Regardless, most larger health care facilities have need for periodic, if not frequent, training. The lighting of classrooms is addressed in 24 | LIGHTING FOR EDUCATION.

27.2.11 Consultation

Consultation with patients may occur in spaces dedicated to the tasks of consulting and interviewing or may occur in clinical spaces, such as exam or treatment rooms. Controls should be used to address the needs for varying illuminances. This reduces energy consumption and helps contributes to a more patient-oriented experience.

27.2.12 Conferencing

The lighting of conferencing facilities is addressed in 22 | LIGHTING FOR COMMON APPLICATIONS.

27.2.13 Corridors

Corridor illuminances are related to adjacent space types in order to minimize extreme transitions from one space to another. Where intensive clinical procedures are part of the application and therefore task illuminances are great and where there is a likelihood of frequent patient or staff circulation in and out of these spaces, such as might occur in a dental suite, corridor illuminance is relatively greater than that of non-clinical situations.

In applications where patients are confined to bed, corridor illuminances typically correspond to day and night cycles. This necessitates controls and task-oriented lighting approaches at work areas to minimize nighttime annoyance of patients while accommodating nursing duties.

Codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and the requirements and design of which must be coordinated amongst the design team.

27.2.14 Dental Suite

Architectural lighting must provide appropriate background illuminance for dental procedures, treatments, and surgery. To accommodate the needs of the caregiver and the direct view techniques common in dentistry, architectural lighting should establish a minimum condition of 3-level control or, preferably, dimming which can then be used in conjunction with an exam or procedure luminaire or headlight on the primary caregiver.

Color temperature and color rendering must be appropriate to the procedure. In exam, treatment, and surgical spaces and where procedures involve color matching, such as prosthodontics, lamps should exhibit 5000 K CCTs and CRIs ≥85. Matching color of artificial

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versus natural teeth poses a great challenge, considering that the teeth will be seen under a variety of light sources. Daylighting is beneficial along with the 5000 K, 85+ CRI lamps.

27.2.15 Diagnostic Procedures

Some clinical situations involve minimally-invasive procedures or detailed surface or cavity examinations where highly-specialized articulated-arm exam or surgical luminaires (procedure luminaires) are used in addition to the architectural lighting. Most if not all of these procedure luminaires are specified by medical equipment consultants or supplied by the vendors providing the diagnostic and treatment equipment. Their type, such as ceiling-mount or portable, and the extent of their use depend on the procedure and the view techniques employed: direct view or video view. Procedure luminaire quantities and locations take priority. The architectural lighting must be planned accordingly and must provide appropriate background luminance and, consequently, illuminance. To accommodate the needs of the caregivers and the direct view and video view techniques, architectural lighting should be available incrementally through a minimum 3-level control or, for video view, preferably through dimming. Additional coordination and planning with medical procedure equipment providers and staff are recommended where video view techniques are involved so that the controls and illuminances available from architectural lighting are appropriately tailored.

Where procedure luminaires are used, appropriate luminance ratios between task and background are achieved with very high illuminances from procedure luminaires illuminating dark cavities or dark-toned areas exposed by incision versus relatively low to moderate illuminances from architectural lighting illuminating light-toned room surface finishes. These finishes are typically neutral to avoid any undesirable color shift in the available light.

Color temperature and color rendering must be appropriate to the procedure. In exam, treatment, and surgical spaces and where procedures involve color matching lamps should exhibit 5000 K CCTs and CRIs ≥85.

Where a neutral, nearly meditative environment is desired for diagnoses, such as that for electrocardiography, indirect lighting techniques are recommended for the general lighting.





Figure 27.1 | Atria
This daylighted atrium contains a lot of volume which can pose significant challenge to meeting illuminance criteria, lighting power densities, and overall spatial luminances. Three lighting approaches are used throughout the atrium: ambient, task, and accent.

Ambient lighting contributes much of the overall illuminance at floor level and is achieved primarily with indirect lighting techniques. Bulkheads are illuminated with 4″ diameter linear lensed tubular luminaires using lamps of 85 CRI and 3500 K CCT. Luminaires are cantilevered off the bulkhead about 8″ with optics oriented up and onto the bulkhead (see image above) ❶. Fluorescent cove lighting is used to light the ceilings at the circulation zones on each floor ❷. Fluorescent slot lights emphasize some art walls ❸.

Display cases and reception desk (not shown) exhibit internal task lighting.

39W/PAR20/CMH 30°-beam flood lamps fitted with 55° spread lenses and UV filters accent artwork ❸ and ❹.

» Images www.jmaconochie.com

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Figure 27.2 | Entry and Porte Cochere
The arrival and departure sequence at this health care facility are similar: patients and visitors experience a relatively bright porte cochere achieved with indirect lighting techniques. In-grade uplights wash large planar surfaces of column and service enclosures. Where these enclosures are perpendicular to the traffic flow, ceiling-recessed slots engage the enclosures and continue across the traffic lanes. A pattern of shorter recessed slots define the arrival/departure lane. The ceiling slots are dimensional troughs with lensed lighting equipment recessed into the vertical planes facing away from incoming traffic. This creates an impression of a softly glowing trough with no visible hardware. This also avoids the unseemly appearance of uncleaned lenses at the ceiling plane.

The indirect lighting techniques meet horizontal and vertical illuminances appropriate for areas where pedestrians and vehicles must interact.

All lamps exhibit CCTs of 3000 K with CRIs ≥82 for a warm and calming effect where skin tones and clothing and vehicle colors are accurately identifiable. The in-grade uplights use 70 W T6 CMH lamps. Decorative postlights are lamped with 150 W T6 CMH lamps. Recessed ceiling troughs use fluorescent luminaires lamped with 32 W T8 lamps. Note the contrast between "standard" 4100 K metal halide used in vehicular circulation in the left background of the top image versus the CMH and fluorescent 3000 K in the patient and visitor exterior zones.

» Images ©Tim Griffith

27.2.16 Dialysis Centers

The patient experience is greatly enhanced if lighting is planned and controlled to accommodate specific tasks, but only as needed. For example, during the initial steps of treatment, the patient is connected to a hemodialysis machine. Illuminance must be sufficient, but only for the time necessary to allow for cleaning of the insertion points and to make the machine-to-patient connection quickly and accurately. During treatment, the patient might read, watch TV, or sleep and the lighting and controls should accommodate these various tasks.

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27.2.17 Ear, Nose, and Throat (ENT)

Architectural lighting for ENT clinics must accommodate the various test procedures, many of which involve backlighting, projected images, and lighting integral with the testing equipment. An inventory of these procedures and their use of light can be used to establish which rooms or suites require dimmable architectural lighting.

27.2.18 Food Service

Food service lighting is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

27.2.19 Gift Shop

Retail lighting is discussed in 34 | LIGHTING FOR RETAIL.

27.2.20 IT

Lighting for IT facilities is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

27.2.21 Intensive Care

The physical status of patients is of prime importance and lighting must address such tasks as examination, emergency procedures, observation, and comfort. However, patient well-being can also be accommodated with attention to controls, glare, and adjacent-area lighting. Controls should be used to incrementally add or subtract light for the respective tasks. For example, lighting for observation might be accomplished comfortably with a wall-mounted luminaire at the head wall exhibiting an indirect component separately switched from a direct component. Observation from a distance is made with just the indirect component energized. Close-up observation is made with both the indirect and direct components energized (as illustrated in Figure 27.3). The direct component may also provide reading and visitation light for conscious patients.

27.2.22 Laboratories

Laboratories are typically found throughout a health care facility. Some labs are dedicated to research while most are dedicated to diagnostics and treatments. Default illuminance criteria are cited in Table 27.2 under LABORATORIES for those labs not specifically identified as part of other health care applications.

Where lab benches are fitted with overhead storage or shelving, it is common and typically most efficient to place task lighting under the overheads. The control of these task lights must be deliberated to balance energy use versus function. Occupancy sensors, group switching or dimming, individual switching or dimming or some combination are all options. Space and lab bench layouts and lab task setups should influence the design of the controls.

27.2.23 Laundry

The laundry is typically a standalone department or building and is the central collection, cleaning, pressing, packaging, and distribution of linens. For purposes of maintenance convenience and where these spaces adjoin occupied areas, lamp types and color qualities should match those used elsewhere in the facility under design.

27.2.24 Library

Lighting for libraries is discussed in 29 | LIGHTING FOR LIBRARIES.

27.2.25 Linen

Linens are handled in soiled and cleaned condition throughout a facility or campus. For purposes of maintenance convenience and where these spaces adjoin occupied areas, lamp types and color qualities should match those used elsewhere in the facility under design.

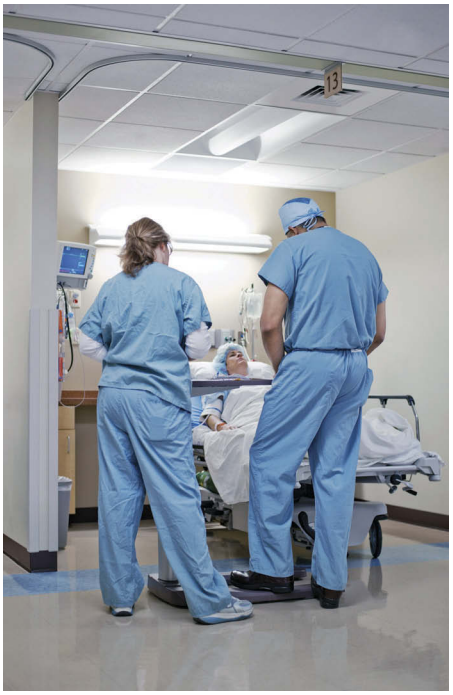


Figure 27.3 | Observation
Two luminaires with various switching or dimmer combinations provide sufficient illuminance and appropriate lighting effects for various tasks. Observation of the patient by caregivers can occur with the head wall luminaire in the direct, indirect, or combination mode. For conscious patients, the head wall luminaire offers indirect light for wakeful rest, direct light for reading, or combination for visitation, for example.

An overhead ceiling-recessed direct architecturally-dimensional luminaire is used here for examination. With variations on lamping, switching, or dimming, this arrangement can meet the needs for intensive care, patient rooms, and recovery. Depending on optical options and lamping, the direct architecturally-dimensional luminaire may be no less glary than conventional direct lensed luminaires when all lamps are energized. However, the architecturally-dimensional luminaires allow for multiple-lamp switching without obvious lamp streaking. Additionally, in the one- or two-lamp mode, the architecturally-dimensional versions are typically less glary than conventional lensed counterparts.

Antimicrobial finishes and dust covers are important for all luminaires used in these situations. This may limit choices on architecturally-dimensional luminaires.

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27.2.26 Medication

Lighting where medications are dispensed and stored should facilitate timely and accurate assessment. Since color discrimination is important, lamps exhibiting CRIs ≥85 are recommended.

27.2.27 Morgue

Lighting in autopsy rooms is similar to that found in operating rooms in surgical suites. Illuminances from procedure luminaires, however, may be somewhat lower as speed and precision are not as urgent.

27.2.28 Nuclear Medicine

Lighting in procedure spaces must accommodate two distinct uses: 1) preparation and clean up; and 2) patient procedures. Lighting for patient procedures should be dimmable and provide a calming, no-glare condition. Where patients will likely spend time on their backs, viewing backlighted art or photomural panels are typically introduced on the ceiling as a calming technique. This is an effective approach in any diagnostic or treatment space where low illuminances are appropriate during the procedure. See Figure 27.4.

Lighting equipment in proximity to the medical equipment that produces radiation in nuclear medicine typically must be made of nonferrous components and operated on shielded direct current. Consult the project design program, the design team, and scanning equipment specifications to determine or confirm these and any other limitations affecting luminaires and lighting controls. LED luminaires and remote drivers are available that meet these requirements.

Control booths or areas are used frequently during diagnostics and treatment radiation. Lighting in the control booths should be independently dimmed from the lighting in the patient treatment room.

27.2.29 Nurses' Stations

Tasks at nurses' stations involve written and printed paperwork, computer screens, and conversation on a 24-hour, 7-day basis. If programming identifies other tasks or tasks which are not considered typical paper- and computer-based, see READING AND



Figure 27.4 | Single Photon Emission Computed Tomography (SPECT)
As a diversion and a calming technique, photomurals backlighted by LEDs are placed above the scanning bed in locations where patients have lines of sight during the procedures. Where ceiling plenum depth permits, deep regressed wells at the backlighted panels can further allude to a skylight effect.

With the advent of useful lumen and optical packages from LEDs, under cabinet task lighting, overhead preparation and clean up lighting, and dimmable downlighting can more conveniently meet strict requirements for lighting equipment in vicinity of medical radiation equipment.

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WRITING in Table 22.2. At the actual task location, illuminance should be consistent day and night. This might best be achieved with task lighting integrated in the desk. Alternatively, a localized layout of ceiling-integrated equipment might meet the task lighting need, but the light distribution of such an approach should not create glare or annoying brightness at night that is disruptive to patients in nearby rooms. General circulation lighting in the vicinity of the station should cycle automatically from day (higher illuminance) to night (lower illuminance). This day-to-night transition is most dramatic in typical patient bed areas and less so in emergency and intensive care areas. In patient bed areas, patients are conscious and under periodic observation. The night cycle is an important aspect of normalcy. In emergency and intensive care areas, patients may be unconscious and are more likely to be under continual or frequent observation for life-changing if not life-threatening changes in condition. See Figure 27.5.

27.2.30 Obstetrics

Patients are likely to be in supine positions for long periods of time. Visual comfort is achieved with indirect or low-glare direct lighting with no visible lamping. Many facilities offer birthing suites where lighting is more home-like and typically achieved with wall sconces, coves, and wall slots or wallwashing techniques. Procedure lighting is disguised in ceiling recesses or even in lifts that deploy only when needed. Controls address the various situations. For example, localized lighting at a casual chair is switched independently for nighttime visitor use to limit patient disturbance. Labor rooms have evolved to less-harsh settings, but may retain the more obvious ceiling mounted articulated procedure luminaires.

27.2.31 Oncology

During preparation of the patient, lighting must accommodate intravenous therapy set up. However, during the treatment procedure, the patient should be made as comfortable as practical within the confines of the medical setting. Dimmable lighting is appropriate during treatment to accommodate a variety of patient tasks from reading to resting and sleeping as well as intermittent observation by the caregiver.

27.2.32 Parking

Lighting for parking facilities is discussed in 26 | LIGHTING FOR EXTERIOR. Parking facilities are patients' and visitors' first and last experiences. Unlike parking at work or retail applications where frequent use yields reduced anxiety, health care facilities are used infrequently by many patients and visitors. Lighting should provide a relatively bright and uniformly lighted appearance with low glare to assist in comfortable navigation of the parking facilities. Painted ceilings and walls of LRVs of ≥65% greatly improve appearances and lighting system efficiencies.

27.2.33 Patient Services

Although a host of tasks are cited, the patient room is of great interest. The patient experience is enhanced if lighting is planned and controlled to accommodate various tasks in an efficient and comfortable manner. While strategically placed 2x4 luminaires alone over the bed could be lamped and switched to meet the various illuminance criteria in a patient room, such an approach is quite harsh, institutional, and simply dehumanizing.

Lighting for periodic examination and observation can be effectively delivered from overhead ceiling-recessed luminaires. For example, 2x2 or circular luminaires with deep regressed opal or microprismatic lenses exhibit a less intimidating scale and resemble the appearance of shallow skylights. At a minimum, these lights should exhibit 3-level switched control, but preferably are dimmed. This addresses varying degrees of examination and observation as caregivers determine necessary for the patient's condition. Ceiling-recessed luminaires may need to be arranged around a patient lift system which has an unforgiving location.

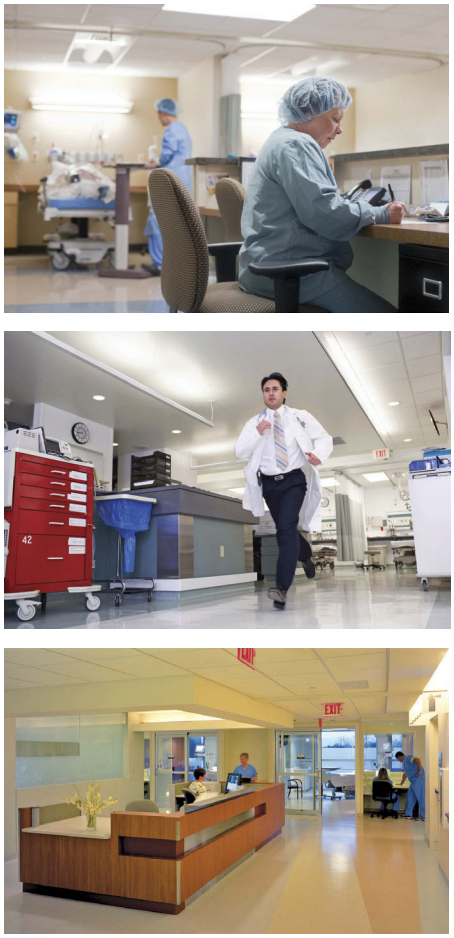


Figure 27.5 | Nurses' Stations
Lighting at and in the vicinity of the nurses' station depends on the care setting. The top two images illustrate situations where patients are under frequent observation and examination given the temporary severity of their conditions. General direct lighting illuminates the station in the top photo with no integral task lighting. In these situations, overhead lighting cannot be dimmed much, if at all, during nighttime operation without compromising illuminance criteria on the writing surface.

In the middle image, a linear indirect pendant luminaire provides some light to the nurses' station. The indirect lighting is less harsh than direct lighting. At night, this can be dimmed if task lighting is integrated into the nurses' station for charting.

In a nurses' station in a typical patient room corridor, bottom image, a cove at the nurses' station confines brightness to the station and can be dimmed at night if task lighting is integrated into the station.

» Top image ©Helen King/Corbis
» Middle image ©ERproductions Ltd/Blend Images/Corbis
» Bottom image ©Tim Griffith

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Lighting for reading at beds may take a number of forms, though wall- and ceiling-mounted options are preferred from a cleaning and germ-control perspective. Wall-mounted luminaires can offer multiple levels of illumination for patient use. A downlight only setting provides light for reading. Uplight-only provides light for computer, personal digital assistant, smart phone, or electronic reader use, television viewing or music listening. The combination of downlight and uplight might be used during visitation or for more intensive reading and writing tasks. See Figure 27.3.

Care should be taken by the design team to make efforts to accommodate a sleep cycle with no light between caregiver status checks and medication cycles. Nightlights are appropriate to assist with circulation to the toilet during the night or to assist caregiver circulation. A strategically placed architecturally-integrated steplight or several can serve this function. To limit sleep disturbance these should be tied to occupancy sensors on timers or photocells. To best limit the disturbance to the circadian rhythm during the sleep cycle, long wavelength sources such as LEDs that produce spectra between 600 and 620 nm are appropriate. However, there should be no direct view of the source or optical media and illuminances should be very low.

Caregiver stations near the room entrance can be problematic as these are usually in the patient's line of sight. Overlighting or use of glary equipment will disturb the patient.

Controls must be well planned to avoid disturbing on-off-dimming sequences and to minimize overwhelming patient or caregiver. Patient access to various lighting scenes is typically achieved through the patient control pad used for bed adjustment and nurse calls. Door- or bed-side control stations are typically used for control of exam lighting, observation lighting, caregiver station lighting, and visitor lighting, though the options and number of control points should be limited to barest minimum.

27.2.34 Pedestrian Ways

Lighting for pedestrian ways is discussed in 26 | LIGHTING FOR EXTERIOR.

27.2.35 Pharmacies

Lighting where medications are dispensed and stored should facilitate timely and accurate assessment. Since color discrimination is important, lamps exhibiting CRIs ≥85 are recommended.

27.2.36 Radiology

Lighting equipment in proximity to medical equipment that produces radiation must be made of nonferrous components. Consult the project design program, the design team, and scanning equipment specifications to determine or confirm these and any other limitations affecting luminaires and lighting controls.

Control booths or areas are used frequently during diagnostics and treatment radiation. Lighting in the control booths should be independently dimmed from the lighting in the patient treatment room.

Where patients will likely spend time on their backs or seated, backlighted art or photomural panels are typically introduced on the ceiling or walls as a calming technique.

27.2.37 Retail

Retail lighting is discussed in 34 | LIGHTING FOR RETAIL.

27.2.38 Shops

Industrial workshops are common in large health care facilities. These are lighted to address a myriad of electrical, mechanical, and woodworking repair, maintenance, and small construction projects.

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27.2.39 Spas

Lighting for spas is discussed in 28 | LIGHTING FOR HOSPITALITY AND ENTERTAINMENT.

27.2.40 Sterile Processing and Distribution (SPD)

Health care facilities maintain strict sterilization procedures involving the collection, sterilization, and distribution of instruments and devices used in medical procedures. Illuminance criteria are cited for the various tasks involved

27.2.41 Support Spaces

Many of these spaces are back-of-house and are self-explanatory. For purposes of maintenance convenience and where these spaces adjoin occupied areas, lamp types and color qualities should match those used elsewhere in the facility under design.

27.2.42 Surgical Suites

Lighting must accommodate efficient and precise work and is primarily about operating room (OR) staff visual needs rather than patient comfort. To accommodate varying viewing conditions in ORs for surgical staff, multi-level switching, if not dimming, is recommended. Dimming is best where surgeries are based on video view techniques. Color quality is critical in ORs and lamps with 5000 K CCT and CRI ≥85 are recommended for the all or the majority of the lamps. For minimally-invasive procedures, monitors are arranged for direct video-view of the procedure by surgeons. The video-view tasks are best accommodated by low-level general room lighting or background wall lighting. Some surgeons prefer this lower level background lighting to be generated with green (~550 nm) lamps. This can be accommodated if some lamps in multi-lamp luminaires are green and placed on independent control zones. The need for green lamps should be determined during the programming phase. Since many ORs must be flexible to accommodate a variety of surgical teams and the video-view procedures as well as the traditional direct-view procedures, dimming for the architectural lighting is appropriate. Coordinating the number of control zones for the architectural lighting to achieve flexible switching and dimming control and address normal power, emergency power, and battery backup circuiting must be done with the electrical engineer where the designer of the lighting is not the electrical engineer is necessary to properly specify the luminaires. See Figure 27.6.

OR ceilings are filled with equipment such as sensors, air diffusers, utility connections, fire-suppression devices, and surgical luminaires. Architectural lighting luminaires must be laid out in conjunction with this equipment and are typically 1x4 or 2x4 lensed varieties for efficiency of general light distribution and layout integration.

In addition to architecturally-integrated lighting, multiple surgical lights each typically capable of producing in excess of 25,000 lx are on booms and positioned on the ceiling to accommodate most any aiming situation and limit shadowing by the surgeons. LED surgical lights offer optional CCT selections to better accommodate surgeons' preferences. See Figure 27.6 middle image. Some include optional integral cameras. LEDs can reduce shadowing compared to halogen counterparts, and exhibit reduced radiant energy and beam temperature. Selection of surgical lights and their specification should be coordinated with, if not made by, the medical equipment consultant.

In recovery rooms or areas, lighting should provide for localized examination, observation, and patient rest. Independent controls or dimming are necessary to achieve the various illuminance criteria. Some attention to glare and optical control for the equipment is in order for patient comfort.

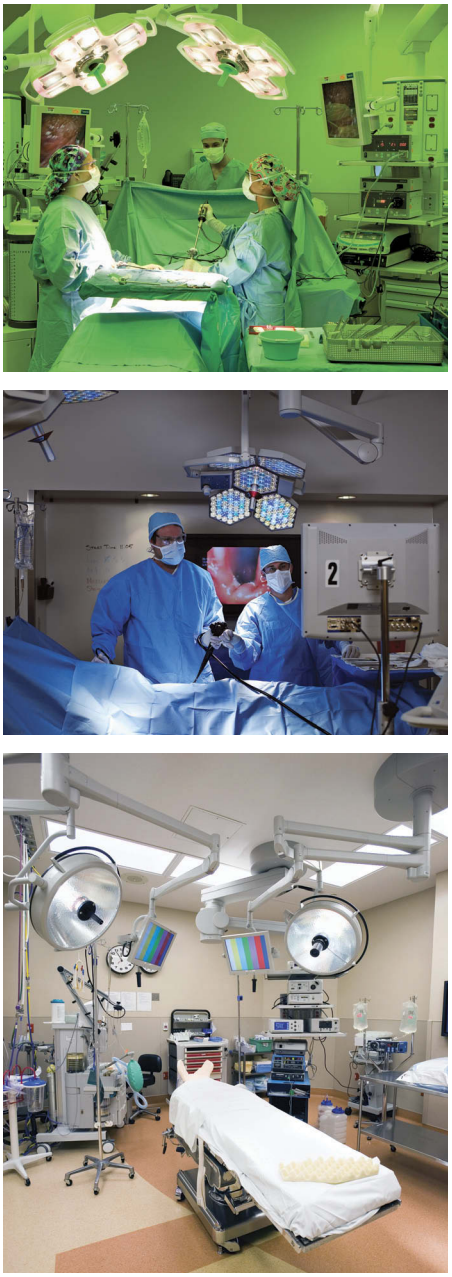


Figure 27.6 | Operating Rooms
Video-view is common for minimally-invasive surgery. Top image illustrates low-level green (~550 nm) background lighting. For direct-view surgery, all lamps, the majority of which are white-light, are energized in the architectural lighting equipment (not in view).

In the middle image, video-view is accommodated with low-level background white light. Here the surgical luminaires are LED.

In the bottom image, all lighting is energized for traditional direct-view surgery.

» Top image ©Robb Kendrick/Aurora/Getty Images
» Middle image ©Thomas M. Barwick INC/The Image Bank/Getty Images
» Bottom image ©Fabio Cardoso/Flame/Corbis

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Figure 27.7 | Lounges
Ambient lighting techniques of downlighting and cove lighting are used to provide general background illuminances. The luminances introduced from the cove help make the area feel bright.

Accenting artwork (far left background) and drinking fountain and phone niches (to the left) provide light at those functions and introduce peripheral luminances that contribute to senses of preference and relaxation (see Table 12.2 | Subjective Impressions).

» Image www.jmaconochie.com

27.2.43 Therapy

Lighting for therapy tasks must allow caregivers to assess patients' conditions and progress. Vertical illuminances at face height are important and take priority over patient visual comfort. Although not a requirement, lamp CRIs ≥85 will enhance patient self-esteem.

27.2.44 Toilets/Locker Rooms

Lighting for toilets and locker rooms needs to meet the functional requirements of illuminance criteria outlined in Table 27.2. Addressing the plumbing fixture will provide sufficient light where needed without overlighting the entire toilet room. Vanities are most problematic when little or no vertical illuminance is designed to light an imaginary facial plane (roughly a zone of sufficient size to encompass faces) in front of the mirror.

Vertical illuminance over the faces of lockers will assist with locker use.

27.2.45 Transition Spaces

Most of these spaces are self-explanatory, but several deserve discussion. Freight and visitor/staff passenger elevators are illuminated for basic utility. Patient elevators involving the transfer of patients from horizontal circulation to vertical circulation mode with IVs, monitors, and possible other tethered equipment are illuminated for basic observation by caregivers during the transfer-transportation process. Since patients are likely face-up on gurneys, attention to visual comfort is warranted.

Lobbies and waiting rooms should be lighted to general background levels for circulation and conversational seating. Where reading or reception or security screening are programmed, these should be illuminated accordingly.

Lounges should be lighted to levels and effects evoking living room or family room settings and conducive to conversation, television viewing, analog or digital games, and reading as programming requires. See Figure 27.7.

Stairs are lighted based on anticipated activity levels.

Codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and the requirements and design of which must be coordinated amongst the design team.

27.3 Illuminance Criteria

Illuminance criteria, when fully deployed, are a robust set of quantitative values that influence visibility, visual performance, and visual comfort and attention. Short-circuiting the criteria selection or designing to a single criterion value, such as horizontal illuminance, to address worst-case tasks will surely result in dissatisfaction. Even if clients accept the visual results, not getting the most from the energy expended or, worse, energy waste is a likely result. Following are notes related to various topics outlined in Table 27.2.

27.3.1 Applications and Tasks

Applications and tasks encountered on any given project may be different from those identified in Table 27.2 and may warrant different illuminance criteria. This is especially likely in health care situations where technologies, diagnoses, and treatments are constantly updated, if not reinvented. Cross-referencing closely-associated applications or tasks is appropriate. Sometimes naming trends or conventions for space types or functions change to conform to current practice, client programming, or architectural conventions, but the

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actual activities and tasks remain the same and this cross-referencing works. Failing this technique, reviewing the list in Table 27.2 may be in order to determine if any applications or tasks exhibit a similar visual-component to the unique applications or tasks. Otherwise, reviewing 4.12 An Illuminance Determination System and Table 4.1 is necessary to establish a task category based on the task characteristics or visual performance descriptions most closely associated with the unique applications or tasks. An additional resource in health care situations are the vendors of the medical equipment who typically have experience with their product in various settings and may be familiar, if not specific, with lighting criteria. These exercises as well as any deviations from recommendations the designer intends to make should be carefully documented for the record.

27.3.2 Notes

The notes in Table 27.2 may refer to other task headings in the table or to other handbook chapters as appropriate. Where some degree of clarification is warranted, notes are made.

27.3.3 Recommended Maintained Illuminance Targets

Values cited are maintained on the area of coverage for the task under consideration. Illuminance is additive. Where practical and without negatively affecting the intended application of light, target values are achieved with any combination of daylighting and/or electric lighting in whatever mix of ambient, task, and accent lighting is deemed appropriate to meet these and the other lighting goals established during design. See 12 | COMPONENTS OF LIGHTING DESIGN and see 10.7.1 Light Loss Factors.

With respect to light loss factors, account for anticipated losses through the point in time at which group relamping and cleaning should occur. Group relamping and cleaning should be standard practice, though these need not occur at the same frequency. Periodic cleaning and group relamping essentially maintain the illuminance at criteria and make the most efficient use of the installed equipment. For purposes of sustainability, cleaning and group relamping can no longer be presumed to be infrequent or unlikely. Maintenance procedures must be part of the design discussions with the client. See the IES document IESNA/NALMCO RP-36 Recommended Practice for Planned Indoor Lighting Maintenance for additional information. Where maintenance is deferred or practiced poorly or not at all, the actual illuminance values will fall below criteria targets. This is inefficient, unsustainable, and may be unsafe while adversely affecting users' quality of life or work. Ratcheting initial illuminances higher is poor practice and not recommended. Maintenance procedures may be especially problematic with LEDs where promises of extraordinarily long life may be offered, but usually with the caveat that lamp lumen depreciation (LLD) at that rated life is 70% or perhaps even as low as 50% of initial rating. If replacement cycles are presumed to be rated life, then LLD alone must be 0.7 or 0.5 or whatever lumen rating is certified by the LED vendor. See 13.3 Life and Lumen Maintenance.

Targets cited are consensus and recommended for respective functional activity. For some applications, IES recommendations are within 10% of code requirements. This apparently is an artifact of metrication. Footcandle conversions of any values cited in Table 27.2 should be made at 1 fc to 10 lx. This soft conversion avoids a redundant diminishing of illuminance values after multiple citations and conversions over time. This also eliminates a false sense of accuracy advanced by an ever-increasing number of decimal places and a false sense of urgency advanced by eccentric fractional values introduced by hard conversions. Nevertheless, a lighting design must meet code and the mechanics of which must be coordinated amongst the design team. The IES recommendations should not, do not, and cannot reflect all of the various code requirements in force in all jurisdictions at any given time.

Targets are intended to apply to the dominant plane of the task, typically, but not always, horizontal or vertical. In some situations, illuminance criteria are cited for one plane, such as the horizontal plane for needle insertion during dialysis treatment, while the other plane is blank. The blank signifies that illuminance on that plane is unimportant and may

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be a consequence of the illuminance of other tasks within the vicinity or by whatever illuminance results from meeting the target illuminance for the prescribed plane of interest.

27.3.3.1 Target Planes

Many, though certainly not all, tasks are performed with the task in roughly a horizontal orientation or vertical orientation. A dominant orientation must be assigned and the illuminance target determined accordingly. There may be situations where the IES recommended target relating to the typical planar mode of a task must be applied to a different plane.

Nearly all tasks are expected to have both a horizontal illuminance component (E_h) and a vertical illuminance component (E_v). This allows some degree of task flexibility for off-plane viewing and accommodates various aspects of the task. In some applications, like oral surgery chair situations, horizontal- and vertical-plane illuminances address a variety of patient chair positions and caregiver viewing positions with architectural lighting to set the background against which the articulated surgery luminaire illuminates the oral cavity.

Where illuminance targets are intended at differing planar elevations, this is indicated under "Notes." For example, for DIAGNOSTIC PROCEDURES/Electroencephalography/Physician's Reading/Electronic Monitor, horizontal illuminances apply to the work surface plane at 2' 6" AFF while vertical illuminances apply to the screen monitor plane at 3' 6" AFF. This accommodates some degree of notetaking and reading while also analyzing the digital image. Although the nature of architectural lighting in many of these situations is such that the target illuminance will coincidentally be met on work surface elevations of 3' or 3' 6" for tall sit-down benches or stand-up benches respectively and on computer screens at 4' AFF or 4' 6" respectively, the designer may elect to set the criteria elevation for a specific condition as design plans might outline. Establishing and tracking task orientations and elevations and addressing both horizontal and vertical illuminance is necessary. If orientations in the project under consideration are programmed to be flipped from what might be considered normal-viewing, then criteria must be adjusted accordingly. If a task is scheduled to be oriented on some plane off axis from horizontal or vertical by more than 10°, say, then the illuminance criteria must be applied to that off-axis orientation. This is an important distinction for luminaire optical selection and aiming capabilities and for layout, calculations, and field measurements.

For planes related to vertical illuminance targets, some guidance is indicated under "Notes." However, the designer may elect to use alternate or multiple vertical planes. In some situations the vertical planes could be oriented in a number of directions and the designer must determine which are most appropriate for the situation. For example, in a lounge at a game table (ACTIVITY AREAS/Games/Analog Games/Competitive table games) the number and orientation of vertical planar points assessed depends on the size of the table involved or the area of multiple tables, and likely number of players. For most such situations, a universal layout is appropriate and, therefore, at least four vertical planes are of interest. One in each of the four cardinal directions of the plan over the intended area of game tables.

27.3.3.2 Visual Ages of Observers

Illuminance criteria are based on the visual ages of more than half the intended observers. This aspect should be resolved during programming with the client. It may be determined that illuminance criteria for an age group other than that representing the majority of the intended observers is appropriate. However, this may result in overlighting, underlighting, harsh lighting, visual displeasure, or visual discomfort for many of the observers. See 12.5.5 Illuminance and 4.12 An Illuminance Determination System for additional information and guidance. In health care situations, it is important to carefully assign tasks to observers and then establish visual ages. For example, in a patient room, examination

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lighting is for the visual benefit of the caregivers. As such, the visual ages of more than half the caregivers likely to use the examination lighting must be established. However, the reading and television viewing lighting is for the visual benefit of the patient. As such, the visual ages of more than half the patients likely to use the reading and television lighting must be established. For some projects, it may be straightforward to determine patients' ages. On other projects, this may be impractical or impossible. The designer must then consider the implications of selecting the wrong age group.

27.3.3.3 Illuminance Categories

Illuminance categories are designated by letters A through Y. These are shown in Table 27.2 for more convenient reference to Table 4.1 | Recommended Illuminance Targets should the designer wish to explore other criteria targets or if applications or tasks on a specific project are not readily correlated to the table citations.

27.3.3.4 Gauge

The common gauge for determining illuminance target compliance is cited for each application. All gauges presume that point-by-point techniques are used for predictive calculations and presume that uniformity criteria are closely monitored. Where an average illuminance value over the area of coverage can satisfy target compliance, "Avg" is cited. In applications or tasks where a minimum or maximum target is necessary, the gauge for compliance is "Min" or "Max" respectively.

The designer may elect to use other methods to evaluate target compliance, such as criterion rating (CR) or coefficient of variation (C_v). See 4.12.4.5 Tasks at Uncertain Locations Over a Large Area.

In any event, once illuminance targets and uniformities are established, then any calculated deviation from them should be limited. Standard engineering allowance of ±10% might be acceptable for targets gauged as average unless contractual or code obligations demand otherwise. Minima and maxima must be achieved as intended.

Designs should be adjusted until predictions are within allowance for averages and meet minima and maxima. For additional information, see 4.12.4.1 Recommended Illuminances at Design Time, 4.12.5 Illuminance Ratios, 9.15.1.1 Average Illuminance, and 10.8 Assessing Computed Results.

27.3.4 Uniformity Targets

Illuminance uniformity targets work in conjunction with luminance uniformities and surface reflectances all of which must be addressed as part of the design to avoid visual discomfort, glare, and strain. Uniformity ratios are targets that define the widest recommended ranges. In many situations, uniformity ratio criteria are those between average values of an array of points and the minimum value in the same array of points. Uniformity targets apply to both horizontal and vertical illuminances over the area of coverage. Where horizontal uniformity criterion is different from vertical uniformity criterion, two ratios are reported with the first value for horizontal illuminance (E_h). In some situations, notably those with regard to exterior illuminances, two uniformity values are cited. The first value addresses the primary cited application or task. The parenthetical value references the parenthetical application or task, such as a curfew situation associated with nighttime outdoor lighting.

Generally the more important speed and accuracy and the more demanding the visual task, the tighter the ratio.

27.3.4.1 Maximum-to-average

This is the recommended ratio of maximum illuminance to the average illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations sensitive to even a relatively small degree of overlighting.

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27.3.4.2 Average-to-minimum

This is the recommended ratio of average illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where illuminance too far below average conditions is noticeable and detrimental to task performance or inconsistent with normal expectations.

27.3.4.3 Maximum-to-minimum

This is the recommended ratio of maximum illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where too much variation in illuminance is considered undesirable and untenable from a performance or safety perspective.

27.3.5 Daylighting Advancement

Generally, design strategies should embrace any combination of daylighting and electric lighting to achieve target values during daylight hours. The preference is for daylighting to provide all or most of the recommended illuminance presuming that all aspects of daylighting are properly addressed. A sunburst icon depicts those applications and tasks where daylighting is considered a strategic candidate. Use photocells and stepped-dimming or continuous dimming to reduce or eliminate electric lighting during daylight hours. See 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Even for those applications where daylighting is not traditionally a strategic candidate, it may be determined that very careful and coordinated design will offer great sustainability opportunities along with positive influences associated with daylight and views.

27.3.6 Veiling Reflections

Tasks with specular components, such as some video game consoles and display monitors, which may be in different planes, are prone to veiling reflections. The likelihood of particular applications/tasks predisposed to veiling reflections is indicated by a "reflected light" icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood. Veiling reflections are minimized by controlling the overall amount and direction of daylight with respect to the task locations and orientations. Alternatively, tasks sensitive to veiling reflections can be screened or isolated. Employing indirect soft, diffuse electric lighting or direct electric lighting with multiple low-output luminaires, or positioning tasks and luminaires and luminance patterns to avoid harsh reflections from tasks can be effective.

27.3.7 Defining Areas of Coverage

In addition to establishing planes of task orientation, the areas of coverage to which targets apply must be determined. Typical areas of task illuminance coverage are identified here, but these may not be appropriate to specific project situations. One area of coverage is "task proper or task area." Here, the illuminance criteria are applied to the task itself or to a relatively small area to which the task is confined. See 12.5.5.1 Tasks and Applications and Figure 12.22 | Task Coverage Example. In some situations, such as accenting, the "task" area may consist of the entire wall when "feature wall" or "perimeter" accenting is desired. It is important to remember that illuminance is additive, that is, task illuminance can be achieved with some combination of ambient lighting, task lighting, and/or accent lighting, providing that the total illuminance on the task proper or task area meets the illuminance criteria outlined in Table 27.2.

Another area of coverage is "room or designated area." In this situation, illuminance criteria are applied to the room or an area of fairly substantive size representing the zone in which the applications/tasks are expected to occur. The designated area is typically established by the furniture layout, for example, or might be established by the design team or client. The area-of-coverage citations in Table 27.2 are based on traditional notions. So, for example, it may be determined that a "task proper or task area" coverage would result

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in some amount of LPD reduction when compared to "room or designated area" coverage. If the task can be confined to one area rather then multiple areas, if the room or area in which the task is located is itself relatively small, such as a single-occupant office, and if the other design goals and criteria outlined in 12 | COMPONENTS OF LIGHTING DESIGN are addressed, then this strategy of redefining area of coverage has merit.

An assessment and determination must be made on which area of coverage best satisfies the lighting goals on a particular project.

27.4 Designing

Information provided here is specific to health care facilities and should be used as part of the design and documentation processes outlined in Chapters 12, 15, and 20. For outdoor applications, lamps and ballasts, transformers, and drivers must be selected for ambient temperature conditions, some of which are extremely hot and others extremely cold. See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY for additional information on respective aspects. Addressing all code requirements is a must. Energy efficient and sustainable practices are an integral part of all IES recommendations. Key design tenets include, but are not limited to:

- designing for the satisfaction of the observers intended to use the project
- using baseline reflectances of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively) in interior production, circulation, and work-oriented spaces
- using daylighting that meets luminance and illuminance criteria
- using highest-efficacy lamps that meet color, optical and electrical control, and output criteria
- using highest-efficiency luminaires that meet aesthetic and luminance criteria
- using accenting to provide luminance balancing or improve brightness perceptions where necessary
- using controls liberally, preferably automated varieties such as presets, occupancy and vacancy sensors, astronomical time clocks, and photocells
- establishing IES-recommended illuminance criteria to meet programmed tasks
- establishing layouts that just meet IES-recommended illuminance criteria
- addressing outdoor environmental needs
- using calculations, photometrically-realistic renderings, and operational samples and mockups to prove concepts
- identifying and designing to code-specific requirements, if any, for ambient, task, and accent lighting
- documenting all code-, energy-, sustainability-, and IES-criteria compliance
- documenting criteria and design deviations and rationale and subsequent disposition by team, client, or AHJ
- documenting clearly the layouts, controls, and luminaire and lamp selections

Designing for the satisfaction of the observers is the paramount design tenet and must be kept in perspective during all aspects of design. If the observers' expectations are not fulfilled, then how much energy could be saved is moot, as is how many fewer earth resources were spared, as is how much the whole affair cost or how much value engineering saved or the photogenic qualities of the project. See sidebar references for additional guidance on the key tenets. The design effort must be undertaken with coordinated and realistic expectations by all involved on initial and life cycle costs. Budgeting should include designer input and dialogue with the team and client at project commencement and design milestones. In other words, and paraphrasing Thomas Edison, genius is, indeed, just 1% inspiration and 99% perspiration.

IESH/10e Economics Resources

> 15.3.3 Budgets
  - for more on budgets and value engineering

> 18 | ECONOMICS
  - for more on estimating costs
  - for more on life cycle costs
  - for more on paybacks and rates of return

IESH/10e Energy Efficiency Resources

> 17.2 New Construction
  - for more on designing for daylighting
  - for more on electric lighting equipment
  - for more on lighting controls

> 17.4 Lighting Codes, Regulations and Standards
  - for more on application standards
  - for more on equipment regulations

IESH/10e Lighting Exteriors Resources

> 12.5.5.6 Nighttime Outdoor Illuminances
  - for more on lamp efficacies under mesopic adaptation

> 26 | LIGHTING FOR EXTERIORS
  - for more on criteria

IESH/10e Sustainability Resources

> 13.11 Sustainability
  - for more on lamps

> 19 | SUSTAINABILITY
  - for more on controls
  - for more on earth resources
  - for more on energy
  - for more on life cycle analyses
  - for more on lighting design
  - for more on recycling

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27.5 References

[1] [DOE] US Department of Energy, Energy Information Administration. 2008. Table E5A. In: Electricity Consumption (kWh) by End Use for All Buildings, 2003 [Internet]. DOE. [cited December 2008]. Available from: http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html#enduse03.

[2] Mark S. Rea, ed. 2000. The IESNA lighting handbook: Reference and application. 9th edition. New York: IESNA. Ch 16.

[3] [IESNA] Illuminating Engineering Society. 2006. Recommended Practice for Lighting for Hospitals and Health Care Facilities. IESNA RP-29-06. New York: IESNA.

[4] [DOD] US Department of Defense. 2007. Department of Defense interface standard: Requirements for the control of electromagnetic interference characteristics of subsystems and equipment, MIL-STD-461F [Internet]. DOD. [cited April 4, 2011]. Available from: http://www.assistdocs.com/search/document_details.cfm?ident_number=35789&StartRow=1&PaginatorPageNumber=1&doc%5Fid=461F&title=ELECTROMAGNETIC%20INTERFERENCE&status%5Fall=ON&search%5Fmethod=BASIC

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28 | LIGHTING FOR HOSPITALITY AND ENTERTAINMENT

A room is like a stage. If you see it without lighting, it can be the coldest place in the world.
Paul Lynde, 20th Century American Actor

Contents

28.1 Project Type and Status. . . . 28.2
28.2 Application Types 28.2
28.3 Illuminance Criteria 28.28
28.4 Designing. 28.32
28.5 References 28.33

Lighting in most any application is as much about the aesthetic as it is about the analytic. In hospitality and entertainment facilities, the aesthetic is the priority. Although consequences of analytic failure are great, the aesthetics of lighting equipment and lighting effects should remain at the forefront. This chapter outlines lighting criteria for casinos, exhibition halls, fitness centers, hotels, restaurants, spas, and theaters. Electric lighting accounts for about 36% of the electricity used in the food service and lodging industries (see Figure 28.1) [1]. Efficient lighting and its careful application are, therefore, critically important. What follows is a discussion of the key aspects affecting lighting: project status; space types; activities; application-specific design goals, and illuminance criteria in hospitality and entertainment facilities.

For complete design efforts, there must be significant reliance on and reference to material in 12 | COMPONENTS OF LIGHTING DESIGN, 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS, 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. The designer should have a thorough understanding of the design tenets outlined in those chapters, must identify those deemed appropriate and develop lighting goals and strategies accordingly. This chapter primarily addresses illuminance specifics related to hospitality and entertainment facilities which should influence luminaire optical selections, lampings, and final layouts based on previously developed thought-starters (see 15.2 A Lighting Scheme). Use of the material in this chapter to the exclusion of material in Chapters 12, 13, 14, and 15 will likely lead to unsatisfactory results. Previous and current IES related documents serve as archival and reference sources [2] [3].

Deliberate thought must be applied to the lighting problem and solution. For example, for the informal meeting area in a hotel business center, illuminance criteria are based on common social activity and viewing of large or high-contrast tasks. Average-to-minimum (avg:min) uniformity is 2-to-1 (2:1) and the illuminance is intended to be average over the designated informal meeting room or area. Although the vertical illuminance criteria, intended for application at seated face height, might be accomplished with two over-scaled 2'×4' ceiling recessed luminaires, that solution would make for an awkward and sterile institutional setting, let alone a viable hospitality setting. Here, a series of narrow, discrete, linear ceiling recessed luminaires and an art accent for a modern design or a decorative, yet efficient and functional pendant luminaire plus some art accents or sconces or wallwashing of one or two walls for a traditional design are worthy. Such aesthetic integration with the space type and functions can contribute, in part, to increased use, repeat business, and ultimately more revenue. Specific details like these are not enumerated for applications and tasks. Table 28.1 offers a checklist of IES lighting topics and criteria. The design team is responsible for determining and addressing indoor and outdoor lighting and energy criteria set forth by authorities having jurisdiction (AHJ) which may be different from and supersede IES criteria. See also 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

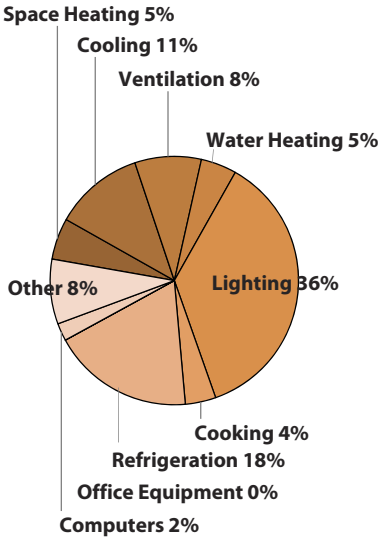


Figure 28.1 | Electricity Use of Food Service and Lodging Buildings
Based on 2003 data from the US DOE's Energy Information Administration, lighting accounts for 36% of electricity use in food service and lodging buildings (electricity use for Office Equipment rounds to 0%). These buildings themselves account for 13% of electricity use by all commercial and institutional buildings.

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Table 28.1 | Hospitality and Entertainment Lighting Checklist

Topics
✔ **Criteria and Design Resources**
Accenting
15.1.1.3 Accent Lighting
Table 12.2 | Subjective Impressions
Table 15.2 | Accent Illuminance Ratios
Table 22.2 | Common Applications Illuminance Recommendations
Appearance
12.2 Spatial Factors
Color
12.5.6 Color Considerations
Controls
16 | LIGHTING CONTROLS
Daylighting
14 | DESIGNING DAYLIGHTING
Electric Lighting
15 | DESIGNING ELECTRIC LIGHTING
Flicker
4.6 Flicker and Temporal Contrast Sensitivity
Glare
4.10.1 Discomfort Glare
4.10.2 Disability Glare
Illuminance
This Chapter: Table 28.2
12.5.5.1 Applications and Tasks
Table 12.6 | Default Illuminance Ratio Recommendations
Figure 12.22 | Task Coverage Example
Light Distribution
12.3.2 Subjective Impressions
Luminances
12.5.2 Luminance
Table 12.5 | Default Luminance Ratio Recommendations
Maintenance
15.4.4 Installation and Maintenance
Nighttime Outdoor Environment
Table 15.6 | Nighttime Operational Strategies for Improved Outdoor Environmental Regard
Systems Integration
12.6 Systems Factors
Veiling Reflections
This Chapter: Section 28.3.6
12.5.4 Veiling Reflections
Visual Tasks
This Chapter: Section 28.2
This Chapter: Table 28.2
Table 11.2 | Programming: Inventory Scope and Specific Examples
12.5.1 Visual Tasks
Table 12.3 | Sample Visual Task Survey

28.1 Project Type and Status

An understanding of the project type and scope is necessary before commencing design work. This will establish the extent to which daylighting can address the lighting goals. New, renovation, and restoration projects each offer varying opportunities. See 11.2 Planning, 11.3.1 Pre-design, and 11.3.2 Schematic Design. At every opportunity the lighting designer should give every consideration to daylighting as a light source. For some applications and tasks, daylighting can be the primary light source. Critically, this means addressing the host of lighting design factors identified in 12 | COMPONENTS OF LIGHTING DESIGN. Daylight demands attention to moderate or eliminate glare and balance visible and thermal energy.

28.2 Application Types

To develop lighting solutions that meet quality, quantity, and operational criteria, an inventory is made of the hospitality and entertainment space types under consideration and the anticipated occupants, functions, and tasks (see Table 11.2 | Programming: Inventory Scope and Specific Examples and Table 12.3 | Sample Visual Task Survey). Otherwise, lighting cannot be best targeted to the users, their expectations, functions and tasks.

Space type definitions are required early in the project design in order to track design efforts that include inventorying the project knowns, anticipated functions, and tasks and calculating lighting, power, and energy compliance. Room names, from which functions can be deduced, and numbers for tracking should be clearly marked on architectural backgrounds. The applications and tasks cited in Table 28.2 | Hospitality and Entertainment Facilities Illuminance Recommendations should be reviewed against the project knowns and correlated with the named space types and functions to establish recommended illuminance criteria. Seek clarification with the client where discrepancies occur between programming information, the list of room names, and the available application and task citations in Table 28.2.

The following discussion is keyed to major application headings in Table 28.2. Couple this with topics in Table 28.1 for comprehensive qualitative and quantitative criteria.

28.2.1 Accenting

Accenting affects people's brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. Default accent lighting criteria are discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. Also see 15.1.1.3 Accent Lighting.

Unlike many other applications, hospitality and entertainment facilities may be heavily signed. Signage can be internally illuminated, accented, or lighted by the general light in a space or area. The amount of signage, the hiearchies and priorities of if and how signage is illuminated, and placement, size, and inherent contrast must be part of the programming. Coordination with signage or graphics consultants and other team members is necessary.

28.2.2 Administration

Lighting for administrative areas is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. The architectural scheme and even task specifics will vary based on the associated hospitality or entertainment facility and clientele. These details should affect the lighting design, from the kinds of lighting effects to lighting equipment styling to luminances and illuminances.

The administrative areas are typically consolidated in a hospitality or entertainment facility or campus into a single area, wing, or building. Several aspects may affect the degree to which the lighting design in the administrative area is sympathetic to or different from that of the other applications and tasks at the hospitality or entertainment facility in question:

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- Client wishes and architectural desires
- Degree to which clientele or business prospects visit administrative operations
- View between administrative areas and hospitality or entertainment areas
- Management style and immersion in hospitality or entertainment functions

28.2.3 Ballrooms

Ballrooms are typified by their size and flexibility in use. Ballrooms are typically configurable from one very large space to multiple smaller spaces. Lighting and controls must be laid out to address the various sizes and configurations. Functions are quite varied even within designations dining, exhibition, demonstration, and presentations. This usually requires design of a controls system that may demand operators instructed in the use of the system. Additionally, in smaller meeting room setups it may be necessary to have simplified controls accessible to participants to accommodate AV presentations and overhead projection without the need for professional staffing.

Challenges include lighting system efficiency given high ceilings and large space volumes. Light-finish ceiling and wall surfaces are important. Provisions for entertainment lighting are usually required. Some ballroom designs include sound and light locks where lighting should be designed to manage the luminance change from a darkened ballroom to the adjacent prefunction space. See Figure 24.2 | Sound and Light Lock. If no sound and light locks are employed, then the adjacent prefunction and circulation areas should be designed to limit brightness distractions. This may involve linking the lighting in the prefunction and circulation areas with ballroom lighting controls so that lighting tracks ballroom presets.

Figure 28.2 illustrates a typical ballroom setup and identifies the architectural lighting to support that and other setups.



Figure 28.2 | Ballrooms
This ballroom can be reconfigured into as many as five smaller ballrooms or meeting rooms. Lighting layouts and control zoning and the controls are arranged to accommodate the variations. A combination of cove lighting (not energized here), chandeliers, and recessed downlights (not energized here) are employed. The coves use dimmable long compact fluorescent lamps, the chandeliers use nondim CFLs, and the downlights and accents use halogenIR_{120V}. The chandeliers use two zones of control for 2-level lighting. Lamp CCT is 3000 K and CRI is ≥82 and the chandelier lenses are color-tuned to achieve the look of a filament-lamp glow. Stage lighting rigging and instruments are in place for entertainment lighting at this dinner banquet.
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28.2.4 Building Entries

Lighting for building entries is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. The lighting of building entries for hospitality and entertainment facilities contributes significantly to the nighttime arrival sequence. Hospitality and entertainment destinations are often intended as social occasions (breaks, getaways, or celebrations) or as business occasions (retreats or advances, learning, and fraternizing). All of this involves a sense of anticipation and desire. The entry architecture and lighting can further these sentiments and popularize places as highly desirable or even necessary destinations. See Figure 28.3.

One variable is activity level during the nighttime hours. Another variable demanding attention prior to establishing illuminance criteria is the nighttime outdoor lighting zone. Nighttime activity levels may vary by type of facility, such as hotel, restaurant, or theater. The hotel is likely to have low-to-medium steady activity over some period of time, but if ballroom and meeting facilities are involved, then short bursts of high activity are likely. Activity at theaters is typified by the number of screens in film theaters and the timing of performances in stage theaters. Multi-screen film theaters may exhibit medium to high activity over multiple half-hour periods. Stage theaters typically exhibit medium to high activity over single half-hour period pre-show and again post-show. All of this may demand a control system capable of addressing various settings on various evenings through manual intervention, automated time clock, and photocell functions. These and other aspects of schedule, activity-levels, and nighttime outdoor lighting zones must be established in programming.

The nighttime outdoor lighting zone within which the facility is located or to which the team and client elect to design affects the illuminance criteria for outdoor tasks. Nighttime outdoor lighting zone designations vary by local ordinance, sustainability guides, or the team's own definition of place. These are discussed in 26 | LIGHTING FOR EXTERIORS. Also see Table 15.6 | Nighttime Operational Strategies for Improved Outdoor Environmental Regard.

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Table 28.2 | Hospitality and Entertainment Facilities Illuminance Recommendations

Applications/Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
ACCENTING	Accenting influences observers' overall brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. See 22 | LIGHTING FOR COMMON APPLICATIONS/ACCENTING for default accenting criteria for consideration in any application.											
ADMINISTRATION	See 22 | LIGHTING FOR COMMON APPLICATIONS											
BALLROOMS												
• Breakout/Prefunction												
• Accenting												
• Art	On artwork plane (typically vertical)							see Table 15.2				
• Feature Wall	On wall plane							see Table 15.2				
• Perimeter	On wall plane							see Table 15.2				
• Circulation	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	G	7.5	15	30	Avg	
• No Event/Off Hours	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	G	7.5	15	30	Avg	
• Registration Tables	E_h @2' 6"; E_v @4' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg	
• Social Function	E_h @2' 6"; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg	
• Cleanup	E_h and E_v @2' 6" AFF	N	75	150	300	Avg	J	20	40	80	Avg	
• Control Booths	See CONTROL BOOTHS											
• Dancing (Social)	E_h @dance floor; E_v @5' AFF	I	15	30	60	Avg	F	5	10	20	Avg	
• Dining												
• Casual	E_h @2' 6"; E_v @4' AFF	O	100	200	400	Avg	K	25	50	100	Avg	
• Formal												
• Business	E_h @2' 6"; E_v @4' AFF	N	75	150	300	Avg	J	20	40	80	Avg	
• Evening	E_h @2' 6"; E_v @4' AFF	L	37.5	75	150	Avg	H	10	20	40	Avg	
• Exhibition	E_h @3' AFF; E_v @5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
• Meeting	E_h @2' 6" AFF; E_v @4' AFF	Q	200	400	800	Avg	N	75	150	300	Avg	
• Set-up/Tear-down	E_h and E_v @2' 6" AFF	N	75	150	300	Avg	L	37.5	75	150	Avg	
• Presentation	High degree of flexibility											
• Audience	E_h @2' AFF; E_v @4' AFF											
• AV and notes	Notetaking is intended	K	25	50	100	Avg	G	7.5	15	30	Avg	
• AV and no notes	No notetaking is intended	F	5	10	20	Avg	D	3	6	12	Avg	
• Feature presentation		F	5	10	20	Avg	D	3	6	12	Avg	
• No AV		M	50	100	200	Avg	J	20	40	80	Avg	
• Demonstration		T	500	1000	2000	Avg	R	250	500	1000	Avg	
• Screen (front projection)	Cited values are intended for screen plane when screen is in use (limit light on screen for best viewing condition)											
• Feature AV presentation	Little live narration or oral presentation, if any							10	10	10	Max	
• Periodic screen reference	Live narration or oral presentation accompanied by some AV							50	50	50	Max	
• Speaker/Panel	Lighting at the speaker or panel of speakers											
• AV												
◦ Face(s)	E_v @4' AFF seated or @5' AFF standing							Avg ≤3 times audience E_h				
◦ Task surface	E_h @2' 6" AFF			Avg ≤3 times audience E_h								
• No AV	E_h @2' 6" AFF seated or 3' 6" standing; E_v @4' AFF seated or @5' AFF standing	S	375	750	1500	Avg	O	100	200	400	Avg	
BUILDING ENTRIES	See 22 | LIGHTING FOR COMMON APPLICATIONS											

Table 28.2 | Hospitality and Entertainment Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	see 15.1.1.3		☀	☁		
	see 15.1.1.3		☀			
	see 15.1.1.3		☀			
	3:1		☀			
	3:1		☀			
	4:1		☀			
	3:1		☀			
	3:1		☀			
	2:1		☀			
	3:1		☀			
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	2:1					
	2:1					
	3:1		☀			

Notes for Table 28.2

The table column headings are discussed in detail in 28.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 28.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 28.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 28.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ☁ signals high likelihood; gray and white ☁ signals moderate likelihood; pale gray and white ☁ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. "High Light Setting" typically employed where exhibit displays have little or no internal lighting and where no theatrical rigging is used. "Low Light Setting" typically employed where exhibit displays have significant internal lighting or where theatrical rigging and instruments are used. "Low Light Setting" used for set-up, tear-down, and cleanup.

j. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

k. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

l. Make half the illuminance available from lamps exhibiting CCTs of 5000 K or 6500 K and CRI ≥85 and half from lamps exhibiting CCTs of 2700 K or 3000 K and CRI ≥85. Provide three control settings: for one CCT; for the other CCT; and for both CCTs to be energized for maximum viewing flexibility.

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		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
BUSINESS CENTERS											
• Computer Stations	E_h and E_v @3' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• Copy/Print Stations	E_h and E_v @3' AFF	P	150	300	600	Avg	L	37.5	75	150	Avg
• Informal Meeting Area	E_h @2' AFF; E_v @4' AFF	L	37.5	75	150	Avg	J	20	40	80	Avg
CONFERENCING	See 22 | LIGHTING FOR COMMON APPLICATIONS										
CONTROL BOOTHS											
• Live Productions	Auditoria; Ballrooms; Theaters										
• Backlit Boards and Monitors	Boards and controls with backlighting										
• During production	E_h @boards and controls	-	0	0	0		-	0	0	0	
• Pre/Post-show, Intermission	E_h @boards and controls	O	100	200	400	Avg	M	50	100	200	Avg
• General											
• Cleanup	E_h @floor; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• During production	E_h @floor	B	1	2	4	Avg	-	0	0	0	
• Pre/Post-show, Intermission	E_h @floor; E_v @4' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Set-up/Tear down	E_h @floor; E_v @4' AFF	Q	200	400	800	Avg	O	100	200	400	Avg
• Worksurface/Unlit Boards	Boards and controls with no backlight and worksurfaces										
• During production	E_h @3' AFF	H	10	20	40	Avg	-	0	0	0	
• Pre/Post-show, Intermission	E_h @floor; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Studio Productions											
• General											
• Cleanup	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• During production	E_h @floor	M	50	100	200	Avg	K	25	50	100	Avg
• Set-up/Tear down	E_h @floor; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Worksurface/Boards	Boards and controls with no backlight and worksurfaces										
• During production	E_h @worksurface; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	
EXHIBIT HALLS											
• Circulation Concourses											
• Accenting											
• Art	On artwork plane (typically vertical)								see Table 15.2		
• Displays	On plane(s) of display			see Table 15.2					see Table 15.2		
• Feature Displays	On plane(s) of display			see Table 15.2					see Table 15.2		
• Feature Wall	On wall plane								see Table 15.2		
• Perimeter	On wall plane								see Table 15.2		
• Concessions	See 22 | LIGHTING FOR COMMON APPLICATIONS/FOOD SERVICE										
• Circulation	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• No Exhibition	Applies when auxiliary spaces are in use. E_h @floor; E_v @5' AFF	K	25	50	100	Avg	G	7.5	15	30	Avg
• Registration Stations	E_h @3' 6"; E_v @5' AFF	Q	200	400	800	Avg	N	75	150	300	Avg
• General Exhibition											
• High Light Setting[i]	E_h @floor; E_v @5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Low Light Setting[i]	E_h @floor; E_v @5' AFF	N	75	150	300	Avg	L	37.5	75	150	Avg

Table 28.2 | Hospitality and Entertainment Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1		☀			
	2:1		☀			
	4:1		☀			
	2:1			↑		
	2:1					
	2:1			↑		
	2:1			↑		
	2:1					
	2:1			↑		
	2:1			↑		
	2:1					
	2:1			↑		
	2:1					
	2:1			↑		
see 15.1.1.3			☀	↑		
see 15.1.1.3			☀	↑		
see 15.1.1.3			☀	↑		
see 15.1.1.3			☀			
see 15.1.1.3			☀			
	2:1		☀			
	2:1		☀			
	4:1		☀			
	2:1		☀			
	2:1		☀			

Notes for Table 28.2

The table column headings are discussed in detail in 28.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 28.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 28.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 28.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ↑ signals high likelihood; gray and white ↑ signals moderate likelihood; pale gray and white ↑ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. "High Light Setting" typically employed where exhibit displays have little or no internal lighting and where no theatrical rigging is used. "Low Light Setting" typically employed where exhibit displays have significant internal lighting or where theatrical rigging and instruments are used. "Low Light Setting" used for set-up, tear-down, and cleanup.

j. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

k. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

l. Make half the illuminance available from lamps exhibiting CCTs of 5000 K or 6500 K and CRI ≥85 and half from lamps exhibiting CCTs of 2700 K or 3000 K and CRI ≥85. Provide three control settings: for one CCT; for the other CCT; and for both CCTs to be energized for maximum viewing flexibility.

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Table 28.2 | Hospitality and Entertainment Facilities Illuminance Recommendations

Applications/Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
FITNESS CENTERS											
• Circulation	See TRANSITION SPACES										
• Cleanup	E_h @floor; E_v @2' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Exercise Areas											
• Aerobics	E_h @floor; E_v @3' - 5' AFF	N	75	150	300	Avg	J	20	40	80	Avg
• Group Exercise	E_h @floor; E_v @3' - 5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Personal Training	E_h @floor; E_v @3' - 5' AFF	Q	200	400	800	Avg	N	75	150	300	Avg
• Strength Training	E_h @floor; E_v @3' - 5' AFF	Q	200	400	800	Avg	N	75	150	300	Avg
• Lockers	See TOILETS/LOCKER ROOMS/Lockers										
• Pools	See 37 | LIGHTING FOR SPORTS AND RECREATION for illuminance criteria for competitive situations										
• Indoor	**INDOOR** applications and tasks cited here. See FITNESS CENTERS/Pools/Outdoor for respective outdoor applications.										
• In-hot-tub	This highly-specialized application is often best addressed with equipment and layouts recommended by hot tub or lighting vendors. Consult with respective vendors. Use more lower-wattage luminaires in favor of fewer higher-wattage luminaires.										
• In-pool	This highly-specialized application is often best addressed with equipment and layouts recommended by pool or lighting vendors. Consult with respective vendors. Do not center lights in swimming lanes of lap pools; Use more lower-wattage luminaires in favor of fewer higher-wattage luminaires.										
• Perimeter vertical surfaces	Accent opaque surfaces; See TRANSITION SPACES/Accenting										
• Pool and hot tub deck	Pool and hot tub presumed to be internally lighted. Lighting should address the pool and actual deck extension from the pool edge. E_v should be on planes perpendicular to the outline of the pool in two primary directions of travel around the pool.										
◦ High activity[j]	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
◦ Medium activity[j]	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
◦ Low activity[j]	E_h @floor; E_v @5' AFF	F	5	10	20	Avg	C	2	4	8	Avg
• Outdoor	**OUTDOOR** applications and tasks cited here. See FITNESS CENTERS/Pools/Indoor for respective indoor applications..										
• In-hot-tub	This highly-specialized application is often best addressed with equipment and layouts recommended by hot tub or lighting vendors. Consult with respective vendors. Use more lower-wattage luminaires in favor of fewer higher-wattage luminaires.										
• In-pool	This highly-specialized application is often best addressed with equipment and layouts recommended by pool or lighting vendors. Consult with respective vendors. Do not center lights in swimming lanes of lap pools; Use more lower-wattage luminaires in favor of fewer higher-wattage luminaires.										
• Pool and hot tub deck	Pool and hot tub presumed to be internally lighted. Lighting should address the pool and a "deck area" extending 10' beyond the pool edge or consisting of the actual deck extension, whichever is greater. E_v should be on planes perpendicular to the outline of the pool in two primary directions of travel around the pool.										
◦ High activity[j]	E_h @grade; E_v @5' AFG										
LZ4[k]		F	5	10	20	Avg	D	3	6	12	Avg
LZ3[k] (and LZ4 curfew)		E	4	8	16	Avg	C	2	4	8	Avg
LZ2[k] (and LZ3 curfew)		D	3	6	12	Avg	B	1	2	4	Avg
LZ1[k] (and LZ2 curfew)		C	2	4	8	Avg	A	0.5	1	2	Avg
LZ0[k] (and LZ1 curfew)		B	1	2	4	Avg	-	0	0	0	
◦ Medium activity[j]	E_h @floor; E_v @5' AFG										
LZ4[k]		D	3	6	12	Avg	B	1	2	4	Avg
LZ3[k] (and LZ4 curfew)		C	2	4	8	Avg	A	0.5	1	2	Avg
LZ2[k] (and LZ3 curfew)		B	1	2	4	Avg	-	0	0	0	
LZ1[k] (and LZ2 curfew)		A	0.5	1	2	Avg	-	0	0	0	
LZ0[k] (and LZ1 curfew)		-	0	0	0	Avg	-	0	0	0	

Table 28.2 | Hospitality and Entertainment Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1		☀			
	3:1		☀			
	3:1		☀			
	3:1		☀			
	3:1		☀			
3:1			☀	◪		
3:1			☀	◪		
3:1			☀	◪		
	4:1					
	4:1 (8:1)					
	4:1 (8:1)					
	4:1 (8:1)					
	4:1 (8:1)					
	4:1					
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b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 28.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◪ signals high likelihood; gray and white ◪ signals moderate likelihood; pale gray and white ◪ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. "High Light Setting" typically employed where exhibit displays have little or no internal lighting and where no theatrical rigging is used. "Low Light Setting" typically employed where exhibit displays have significant internal lighting or where theatrical rigging and instruments are used. "Low Light Setting" used for set-up, tear-down, and cleanup.

j. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

k. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

l. Make half the illuminance available from lamps exhibiting CCTs of 5000 K or 6500 K and CRI ≥85 and half from lamps exhibiting CCTs of 2700 K or 3000 K and CRI ≥85. Provide three control settings: for one CCT; for the other CCT; and for both CCTs to be energized for maximum viewing flexibility.

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Table 28.2 | Hospitality and Entertainment Facilities Illuminance Recommendations

Applications/Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
FITNESS CENTERS	Pools/Outdoor/Pool and hot tub deck (continued)										
◦ Low activity[j]	E_h @floor; E_v @5' AFG										
LZ4[k]		B	1	2	4	Avg	-	0	0	0	
LZ3[k] (and LZ4 curfew)		A	0.5	1	2	Avg	-	0	0	0	
LZ2[k] (and LZ3 curfew)		A	0.5	1	2	Avg	-	0	0	0	
LZ1[k] (and LZ2 curfew)		A	0.5	1	2	Avg	-	0	0	0	
LZ0[k] (and LZ1 curfew)		-	0	0	0	Avg	-	0	0	0	
• Showers	See TOILETS/LOCKER ROOMS/Showers										
• Sauna	See SPAS/Sauna										
• Spa	See SPAS										
• Toilet Rooms	See TOILETS/LOCKER ROOMS										
FOOD SERVICE	See 22 | LIGHTING FOR COMMON APPLICATIONS										
GAMING											
General Note:	Consult with gaming and surveillance specialists to establish/confirm illuminance criteria in gaming areas										
• Circulation Corridors											
• Back-of-house											
• Adjacency Passageways	E_h @floor; E_v @5' AFF	Avg ≥0.3 times task E_h of adjacent space or as cameras or live surveillance					Avg ≥0.3 times task E_v of adjacent space or as cameras or live				
• Independent Passageways	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	J	20	40	80	Avg
• Public	In other-than gaming areas; See GAMING/Gaming Areas										
• Accenting	See TRANSITION SPACES/Accenting										
• Adjacency Passageways	E_h @floor; E_v @5' AFF	Avg ≥0.2 times task E_h of adjacent space or as cameras or live surveillance require, but with min ≥10 lx					Avg ≥0.2 times task E_v of adjacent space or as cameras or live				
• Independent Passageways	E_h @floor; E_v @5' AFF		10	10	10	Min	I	15	30	60	Avg
• Concourse	E_h @floor; E_v @5' AFF		10	10	10	Min	I	15	30	60	Avg
• Guest											
◦ Mid-corridor	E_h @floor; E_v @5' AFF		10	10	10	Min	H	10	20	40	Avg
◦ Door thresholds	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Cleanup	E_h and E_v @2' 6" AFF	N	75	150	300	Avg	J	20	40	80	Avg
• Gaming Areas											
• General	E_h @floor; E_v @5' AFF	Avg ≥0.1 times task E_h of adjacent games or as cameras, live surveillance, or regulations require, but with min ≥10 lx					Avg ≥0.1 times task E_v of adjacent games or as cameras, live surveillance, or regulations require				
• Tables	Consult with gaming and surveillance specialists for illuminance criteria										
• Money Handling											
• ATMs	Consult with gaming and surveillance specialists for illuminance criteria										
• Cages											
• General	Consult with gaming and surveillance specialists for illuminance criteria										
• Transaction area	Consult with gaming and surveillance specialists for illuminance criteria										
• Count Rooms	Consult with gaming and surveillance specialists for illuminance criteria										

Table 28.2 | Hospitality and Entertainment Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1					
	3:1 (6:1)					
	3:1 (6:1)					
	3:1 (6:1)					
	3:1 (6:1)					
	2:1					
	2:1					
	2:1					
	3:1					
	3:1					
	2:1					
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	3:1					
	2:1					
see Table 12.6						

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e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

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		Horizontal (E_h) Targets					Vertical (E_v) Targets					
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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
GUEST ROOMS												
• Art	On artwork plane (typically vertical)								see Table 15.2			
• Bathroom												
• Shower/Tub	E_h @floor; E_v @3' - 5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Toilet	E_h @fixture top; E_v @3' - 5' AFF	J	20	40	80	Avg	G	7.5	15	30	Avg
• Vanity	E_h @3' AFF; E_v @3' - 5' AFF	O	100	200	400	Avg	O	100	200	400	Avg
• Closet	E_h and E_v @4' AFF @shelf face	I	15	30	60	Avg	H	10	20	40	Avg
• Dining Table	E_h @table plane; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Entrance/Foyer	E_h @floor; E_v @5' AFF	H	10	20	40	Avg	F	5	10	20	Avg
• Reading												
• Bed Headboard	E_h and E_v @3' AFF, small area	O	100	200	400	Avg	M	50	100	200	Avg
• Casual Chair	E_h and E_v @2' 6" at sitting areas	N	75	150	300	Avg	K	25	50	100	Avg
• Desk	E_h @desk; E_v @4' AFF	O	100	200	400	Avg	I	15	30	60	Avg
• General	E_h @floor; E_v @5' AFF	H	10	20	40	Avg	E	4	8	16	Avg
• Steps/Stairs	E_h @treads	J	20	40	80	Avg					
• Kitchenette	E_h and E_v @prep surfaces	R	250	500	1000	Avg	L	37.5	75	150	Avg
IT	See 22 | LIGHTING FOR COMMON APPLICATIONS											
PARKING	See 26 | LIGHTING FOR EXTERIORS											
PEDESTRIAN WAYS	See 26 | LIGHTING FOR EXTERIORS											
READING AND WRITING	See 22 | LIGHTING FOR COMMON APPLICATIONS											
SPAS												
• Changing Rooms	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	M	50	100	200	Avg
• Cleanup	E_h @floor; E_v @2' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Hamam (accent basin vicinity)	E_h @floor; E_v @5' AFF	H	10	20	40	Avg	C	2	4	8	Avg
• Locker Rooms	See TOILETS/LOCKER ROOMS											
• Make-up Stations	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	P	150	300	600	Avg
• Manicures												
• General	E_h @floor; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Hand Rest	E_h @hand rest; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg
• Pedicures												
• Foot Rest	E_h @foot rest; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg
• General	E_h @floor; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Pools	See FITNESS CENTER/Pools											

Table 28.2 | Hospitality and Entertainment Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
see 15.1.1.3			☀	↕	■	
3:1			☀		■	
2:1			☀		■	
2:1			☀		■	
3:1			☀			■
3:1			☀		■	
2:1			☀			■
						■
3:1			☀	↕	■	
see Table 12.6			☀	↕	■	
see Table 12.6			☀	↕	■	
4:1			☀			■
3:1			☀		■	
see Table 12.6			☀		■	
5:1			☀			■
3:1			☀			■
10:1			☀			■
see Table 12.6			☀		■	
2:1			☀			■
see Table 12.6			☀		■	
see Table 12.6			☀		■	
2:1			☀			■

Notes for Table 28.2

The table column headings are discussed in detail in 28.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 28.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 28.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 28.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ↕ signals high likelihood; gray and white ↕ signals moderate likelihood; pale gray and white ↕ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. "High Light Setting" typically employed where exhibit displays have little or no internal lighting and where no theatrical rigging is used. "Low Light Setting" typically employed where exhibit displays have significant internal lighting or where theatrical rigging and instruments are used. "Low Light Setting" used for set-up, tear-down, and cleanup.

j. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

k. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

l. Make half the illuminance available from lamps exhibiting CCTs of 5000 K or 6500 K and CRI ≥85 and half from lamps exhibiting CCTs of 2700 K or 3000 K and CRI ≥85. Provide three control settings: for one CCT; for the other CCT; and for both CCTs to be energized for maximum viewing flexibility.

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Table 28.2 | Hospitality and Entertainment Facilities Illuminance Recommendations

Applications/Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
SPAS	(continued)										
• Reception	See TRANSITION SPACES/Reception Lobbies										
• Salon											
• Barber Chair	E_h and E_v @4' AFF	R	250	500	1000	Avg	P	150	300	600	Avg
• Color Lab Chair[l]	E_h and E_v @4' AFF	S	375	750	1500	Avg	O	100	200	400	Avg
• General	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Wash	E_h and E_v @3' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Styling Chair	E_h and E_v @4' AFF	R	250	500	1000	Avg	P	150	300	600	Avg
• Sauna	This highly-specialized application is best addressed with equipment and layouts recommended by sauna or lighting vendors. Consult with respective vendors.										
• Steam Room	This highly-specialized application is best addressed with equipment and layouts recommended by steam room or lighting vendors. Consult with respective vendors.										
• Treatment											
• Cleanup	See SPAS/Cleanup										
• Dry and Wet Treatments											
• Room	E_h and E_v @3' AFF	C	2	4	8	Avg	B	1	2	4	Avg
• Table	E_h and E_v @3' AFF	C	2	4	8	Avg	B	1	2	4	Avg
• Pre- and Post-treatments	E_h and E_v @3' AFF	J	20	40	80	Avg	H	10	20	40	Avg
SUPPORT SPACES											
• Coat Check or Coat Rooms	E_h @3' 0"; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Copy/Print Rooms											
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Machines	E_h and E_v @3' 6" AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Housekeeping											
• Equipment/Supply Closet	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Linen											
• Closet	E_h @floor; E_v @4' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Room											
◦ General	E_h @floor; E_v @4' AFF	N	75	150	300	Avg	K	25	50	100	Avg
◦ Sewing	E_h @floor; E_v @4' AFF	R	250	500	1000	Avg	P	150	300	600	Avg
• Laundry	E_h and E_v @3' 6" AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Janitor's Closet	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Receiving/Shipping											
• Dock	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Receiving/Staging	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Storage											
• Food	See 22 | LIGHTING FOR COMMON APPLICATIONS/Food Service										
• Frequent Use	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Infrequent Use	E_h @floor; E_v @4' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Valet	Eh @3' 0"; Ev @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg

Table 28.2 | Hospitality and Entertainment Facilities Illuminance Recommendations continued next page

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
see Table 12.6						
see Table 12.6						
	3:1					
	2:1					
see Table 12.6						
	5:1					
	3:1					
	5:1					
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
see Table 12.6						
	3:1					
	3:1					
	2:1					
	2:1					
	3:1					
	3:1					
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d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

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j. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

k. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

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Table 28.2 | Hospitality and Entertainment Facilities Illuminance Recommendations

Applications/Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
THEATERS, FILM												
• Circulation	See TRANSITION SPACES											
• Cleanup	E_h and E_v @2' 6" AFF	N	75	150	300	Avg	J	20	40	80	Avg	
• Concessions	See 22 | LIGHTING FOR COMMON APPLICATIONS/Food Service											
• Control Booths	See CONTROL BOOTHS											
• Foyer	See Prefunction											
• House												
• Audience												
• During show	E_h @floor; E_v @5' AFF	B	1	2	4	Avg	A	0.5	1	2	Avg	
• Pre/Post-show, Intermission	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg	
• Previews	E_h @floor; E_v @5' AFF	F	5	10	20	Avg	C	2	4	8	Avg	
• Circulation	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.											
• During show	E_h @floor; E_v @5' AFF		2	2	2	Min	C	2	4	8	Avg	
• Pre/Post-show, Intermission	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg	
• Previews	E_h @floor; E_v @5' AFF		10	10	10	Min	F	5	10	20	Avg	
• Screen (front projection)	Cited values are for screen plane when screen is in use											
• During show								2	2	2	Max	
• Pre/Post-show, Intermission								30	30	30	Max	
• Previews								6	6	6	Max	
• Testing	See 24 | LIGHTING FOR EDUCATION/AUDITORIA/Multipurpose/Testing											
• Lobby	See TRANSITION SPACES											
• Prefunction	Anteroom or transition space adjoining theater											
• During event	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg	
• Pre-/Post-event, intermission	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg	
• Sound and light lock	Transition from lobby or transition space adjoining theater											
• During event	E_h @floor; E_v @5' AFF		2	2	2	Min	I	15	30	60	Avg	
• Pre/Post event, intermission	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg	
• Toilets	See TOILETS AND LOCKER ROOMS											
THEATERS, STAGE												
• Circulation	See TRANSITION SPACES											
• Cleanup	E_h and E_v @2' 6" AFF	N	75	150	300	Avg	J	20	40	80	Avg	
• Concessions	See 22 | LIGHTING FOR COMMON APPLICATIONS/Food Service											
• Control Booths	See CONTROL BOOTHS											
• Dressing Room												
• General	E_h and E_v @2' 6"	O	100	200	400	Avg	M	50	100	200	Avg	
• Reading	E_h and E_v @2' 6" at sitting areas	R	250	500	1000	Avg	P	150	300	600	Avg	
• Vanity	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	Q	200	400	800	Avg	
• Foyer	See Prefunction											
• Green Room												
• General	E_h and E_v @2' 6"	J	20	40	80	Avg	G	7.5	15	30	Avg	
• Reading	E_h and E_v @2' 6" at sitting areas	N	75	150	300	Avg	K	25	50	100	Avg	

Table 28.2 | Hospitality and Entertainment Facilities Illuminance Recommendations continued next page

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
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	2:1		☀			■
	2:1					■
	5:1/2:1				■	
	2:1		☀		■	
	5:1/2:1				■	
2:1					■	
2:1					■	
2:1					■	
	2:1		☀			■
	3:1		☀			■
	5:1/3:1					■
	3:1		☀			■
	3:1		☀			■
	2:1		☀			■
	see Table 12.6		☀		■	
	see Table 12.6		☀		■	
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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
THEATERS, STAGE	(continued)										
• House											
• Audience											
• During production	E_h @floor; E_v @5' AFF	B	1	2	4	Avg	A	0.5	1	2	Avg
• Pre/Post-show, Intermission	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Circulation	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• During production	E_h @floor; E_v @5' AFF		2	2	2	Min	C	2	4	8	Avg
• Pre/Post-show, Intermission	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Screen (front projection)	See THEATERS, FILM										
• Stage	Stage lighting by theater lighting designers; See IES DG-20 | Stage Lighting **A Guide to the Planning of Theatres and Auditoriums** for guidance on architectural and electrical infrastructure										
• Access ramps/stairs	See THEATERS, STAGE/House/Circulation										
• Professional productions	As designed by theater lighting designer										
• Testing	See 24 | LIGHTING FOR EDUCATION/AUDITORIA/Multipurpose/Testing										
• Lobby	See TRANSITION SPACES										
• Prefunction	Anteroom or transition space adjoining theater										
• During event	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Pre-/Post-event, intermission	E_h @floor; E_v @5' AFF	N	75	150	300	Avg	L	37.5	75	150	Avg
• Sound and light lock	Transition from lobby or transition space adjoining theater										
• During event	E_h @floor; E_v @5' AFF		2	2	2	Min	E	4	8	16	Avg
• Pre/Post event, intermission	E_h @floor; E_v @5' AFF	L	37.5	75	150	Avg	I	15	30	60	Avg
• Toilets	See TOILETS AND LOCKER ROOMS										
TOILETS/LOCKER ROOMS											
• Fixtures	E_h @top of plumbing fixture; E_v @3'-5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• General	E_h @floor; E_v @3' - 5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Lockers											
• Guest Lockers	E_h @floor; E_v @locker faces	H	10	20	40	Avg	H	10	20	40	Avg
• Sports Lockers	E_h @floor; E_v @locker faces	M	50	100	200	Avg	M	50	100	200	Avg
• Staff Lockers	E_h @floor; E_v @locker faces	O	100	200	400	Avg	O	100	200	400	Avg
• Showers	E_h @floor; E_v @3' - 5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Vanities	E_h @3' AFF; E_v @3' - 5' AFF	N	75	150	300	Avg	O	100	200	400	Avg
TRANSITION SPACES											
• Accenting	See 21 | LIGHTING FOR ART for preservation-worthy materials										
• Art	On artwork plane (typically vertical)							see Table 15.2			
• Feature Wall	On wall plane							see Table 15.2			
• Perimeter	On wall plane							see Table 15.2			
• Significant Focal Point	On focal point plane (typically vertical)							see Table 15.2			
• Circulation Corridors	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• Back-of-house											
• Adjacency Passageways	E_h @floor; E_v @5' AFF	Avg ≥0.3 times task E_h of adjacent space or as cameras require, but with min ≥10 lx					Avg ≥0.3 times task E_v of adjacent space or as cameras require				
• Independent Passageways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg

Table 28.2 | Hospitality and Entertainment Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1					
	2:1					
	5:1/2:1					
	2:1					
	3:1					
	3:1					
	5:1/3:1					
	3:1					
	2:1					
	4:1					
	2:1					
	2:1					
	2:1					
	2:1					
	2:1					
	see 15.1.1.3					
	see 15.1.1.3					
	see 15.1.1.3					
	see 15.1.1.3					
	2:1					
	2:1					

Notes for Table 28.2

The table column headings are discussed in detail in 28.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 28.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 28.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 28.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. "High Light Setting" typically employed where exhibit displays have little or no internal lighting and where no theatrical rigging is used. "Low Light Setting" typically employed where exhibit displays have significant internal lighting or where theatrical rigging and instruments are used. "Low Light Setting" used for set-up, tear-down, and cleanup.

j. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

k. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

l. Make half the illuminance available from lamps exhibiting CCTs of 5000 K or 6500 K and CRI ≥85 and half from lamps exhibiting CCTs of 2700 K or 3000 K and CRI ≥85. Provide three control settings: for one CCT; for the other CCT; and for both CCTs to be energized for maximum viewing flexibility.

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Table 28.2 | Hospitality and Entertainment Facilities Illuminance Recommendations

Applications/Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d] — Horizontal (E_h) Targets: Visual Ages of Observers (years) where **at least half** are					Vertical (E_v) Targets: Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
TRANSITION SPACES	Circulation Corridors (continued)										
• Public											
• Adjacency Passageways	E_h @floor; E_v @5' AFF	Avg ≥0.2 times task E_h of adjacent space or as cameras require, but with min ≥10 lx					Avg ≥0.2 times task E_v of adjacent space or as cameras require				
• Independent Passageways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Concourse	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Guest											
◦ Mid-corridor	E_h @floor; E_v @5' AFF		10	10	10	Min	H	10	20	40	Avg
◦ Door thresholds	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Elevators											
• Freight											
• Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Threshold											
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Passenger											
• Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Threshold											
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Entries	See BUILDING ENTRIES										
• Escalators/Moving Walkways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Lobbies											
• Circulation, Elevator Lobbies	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• General											
• At building entries	Close proximity to exterior. Lighting should assist with adaptation when passing to/from exterior..										
◦ Day	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
◦ Night	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Distant from entries	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Concierge/Car Rental		O	100	200	400	Avg	L	37.5	75	150	Avg
• Reading/Work Areas	E_h and E_v @2' 6" at sitting areas	N	75	150	300	Avg	K	25	50	100	Avg
• Reception Lobbies	For example, registration, business center, fitness center, spa, concierge lounge										
• Desk											
• Desk top		N	75	150	300		K	25	50	100	Avg
• Focal wall behind desk	On wall plane								see Table 15.2		
• Lounges											
• Clubs and Game Rooms											
• General	E_h and E_v @2' 6"	J	20	40	80	Avg	G	7.5	15	30	Avg
• Table games	E_h @table; E_v @5' AFF	P	150	300	600	Avg	K	25	50	100	Avg
• Video games	E_h @game controls; E_v @4' AFF	H	10	20	40	Avg	C	2	4	8	Avg
• Reading/Work Areas	E_h and E_v @2' 6" at sitting areas	N	75	150	300	Avg	K	25	50	100	Avg
• Social/Waiting Areas	E_h @floor; E_v @4' AFF	J	20	40	80	Avg	G	7.5	15	30	Avg
• Stairs	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• High activity[j]	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Live-surveillance	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Typical	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1					
	2:1					
	2:1					
	2:1					
	2:1					
	2:1					
	2:1					
	2:1					
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	2:1					
	4:1					
	4:1					
	4:1					
	3:1					
see Table 12.6						
	4:1					
see 15.1.1.3						
	4:1					
see Table 12.6						
see Table 12.6						
see Table 12.6						
	2:1					
	2:1					
	2:1					
	2:1					

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Figure 28.3 | Entries as Arrivals
The porte cochere on this 21-story urban hotel provides a unique and visually exciting arrival. The 1 W-blue-LED-lamped porte cochere acrylic cylinders and 3 W-6500 K-LED-lamped 10°-beam downlights ❶ integrated into the structure meet the illuminance recommendations for BUILDING ENTRIES/Porte Cocheres/High Activity/LZ4 in Table 22.2.

Various lighting effects are used to figuratively and literally lead people into the foyer and registration lobby. The criteria outlined in Table 28.2 under TRANSITION SPACES/Accents/Significant Focal Point were used on the interior feature wall ❷. This is lighted with a continuous wall slot lamped with 39W/PAR20/CMH 10°-beam spot lamps fitted with linear spread lenses to generate strong luminance for visual attraction. Lamp CCT is 3000 K and CRI is ≥82, a further contrast to the exterior porte cochere contributing to dimensional distinction and visual attraction.

» Image ©Kevin Beswick, www.ppt-photographics.com

28.2.5 Business Centers

Although business centers are a utilitarian amenity in hospitality facilities, their lighting can help distinguish these from uninspired back-room spaces. Every public space in a hospitality or entertainment facility contributes to the clientele's experience and overall satisfaction.

28.2.6 Conferencing

The lighting of conferencing facilities is addressed in 22 | LIGHTING FOR COMMON APPLICATIONS. In hospitality and entertainment facilities, conference spaces are most likely to be used by uninitiated clientele. Here, simple preset controls are best with two to four scenes and clearly marked keypad buttons (for example, MEET, AV, VIDEOCON, and OFF). If daylight control is necessary for any of these scenes, this too is automated with the lighting presets for convenience. A photocell may be interfaced with the preset lighting control system for optimal viewing conditions and energy savings. However, this may warrant introduction of a daylight control override which itself is likely to cause operator confusion. These are details to address with the client during programming and design.

Similar to situations involving ballrooms with no sound and light locks, the prefunction or circulation areas adjacent to conference centers may require close design scrutiny to avoid annoying distracting brightnesses as meeting attendees come and go. Lighting in adjacent circulation or prefunction areas can be tied into conference room presets. Alternatively, lighting effects and strategic location of low-reflectance surface finishes in adjacent circulation areas can limit visual distraction as conference room doors open and close.

28.2.7 Control Booths

Control booths are used wherever sound or light control or both are required from an isolated space with visual connection to the space under control. These may be used in auditoria, ballrooms, exhibit halls, and theaters. Control booths are also used in radio and broadcast studios. Programming must determine if the booth needs to be darkened and inconspicuous or if it is to be a part of the space under control where two-way viewing and observation is desirable. Where a dark booth is necessary during performances, steplights might be used to illuminate the floor with very discrete, optically well-controlled,

Table 28.3 | SI Dimensional Conversions

US Customary	SI
General	**Hard Conversion**
inches	mm [inches × 25.40]
feet	m [feet × 0.30]
Specific	**Convenient Conversions[a]**
2'	610 mm or 0.6 m
2' 6"	760 mm or 0.75 m
3'	915 mm or 0.9 m
3' 6"	1065 mm or 1.1 m
4'	1220 mm or 1.2 m
5'	1525 mm or 1.5 m

a. Hard conversions rounded for reporting convenience. Not to be confused with metric-sized luminaires or other building materials. Not for precision construction.

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and dimmable task lighting illuminating control boards and notes. If programming determines that the control board devices and readouts are backlighted and if notes are displayed on computer, then only floor illuminance is needed during performances. Significant illuminances may be necessary for cleanup and for set-up and tear-down, depending on the permanence of the equipment in the booth. Figure 28.4 illustrates a typical control booth location as seen from the house.

28.2.8 Exhibit Halls

Convention centers and some hotels have exhibit halls of varying sizes. These multipurpose facilities, depending on their size and geographic locale may temporarily house training sessions, trade shows, religious gatherings, vehicular and sports shows, and large corporate and union functions. The normal power architectural lighting system typically accommodates set-up, tear-down, and some amount or all of the functional requirements of some of these various events. Luminaires are typically controlled in small groups to allow for efficient operation of incrementally smaller or larger events or permit some degree of tuning of light levels to types of displays. However, considerable electrical and structural infrastructure is necessary for theatrical rigging and for exhibit-integrated lighting to accommodate all situations. Figure 28.5 identifies just a few basic approaches. These facilities are made more appropriate for activities beyond exhibit displays if wall and/or ceiling surfaces are lighted. This addresses some elements identified in 12.2 Spatial Factors.

28.2.9 Fitness Centers

The fitness center involves a number of situations where, although workout and conditioning are "the tasks," how people look and feel about themselves and their depth of engagement in exercising are as important. Lighting should be flattering and accommodate conversation and video-watching. Video watching may be susceptible to veiling reflections, so harsh directional lighting should be avoided. Well-shielded direct or totally indirect lighting are often appropriate given the potential for users looking to the ceiling during exercise sessions.

Many fitness centers, even in hotels, are a revenue stream and operate like a club. Here, reception and waiting, locker rooms and showers, and even retail areas are common. Lighting should be sympathetic to the fitness experience and to a club atmosphere. These facilities typically have swimming pools and hot tubs indoor or outdoor. Overlighting or gymnasia-like techniques should be avoided as these risk the potential for direct glare and wasted energy. For indoor pools, the anticipated activity level determines illuminance recommendations. See Table 22.4 for indoor activity level definitions. Lighting within the pools and hot tubs is necessary for observation of occupants and for comfortable use during dark-hours of operation or when daylight is insufficient. Vendors of such equipment should be consulted for recommendations on underwater luminaire wattage and lumen requirements for a given situation.

All pool criteria outlined in Table 28.2 are intended for relaxation and non-competitive exercising. For competitive situations, see 35 | LIGHTING FOR SPORTS AND RECREATION. Figure 28.6 illustrates an indoor hospitality pool application. Pool lighting should be planned with respect to maintenance and addressed with the client prior to final layouts and specifications.

Veiling reflections from pools are common in indoor and outdoor situations depending on view angles and sight lines. Daylighting and electric lighting can be arranged to limit veiling reflections, but this is practical where a fixed position view, such as that of a lifeguard can be planned or where polarized-lens eyewear is used as in outdoor situations.

With outdoor pools, the activity level and the nighttime outdoor lighting zone determine illuminance recommendations. See Table 22.4 for nighttime outdoor activity level

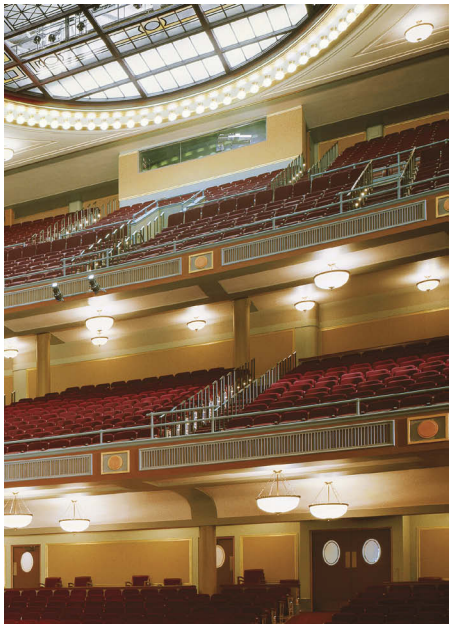


Figure 28.4 | Control Booth
The sound and light booth for this large auditorium (top center) houses sound and lighting control boards and can accommodate follow spots. Some of the theatrical lighting instruments controlled from the booth are just visible in a "seam" in the *laylight* (top left).
» Image ©Balthazar Korab Photography Ltd.

Laylight is an architectural feature or element that is a decorative light diffuser typically positioned below a skylight or roof monitor. Patterns of obscuring decorative glass or acrylic diffuse the light. Where no skylight or monitor exists or during dark hours, electric light is used to backlight the decorative diffuser [4].

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Figure 28.5 | Commercial Exhibit Halls
Techniques that have since made their way into retail and even into other architectural lighting applications are ceiling slots (in top photo) that can contain both exhibit accent lighting and general lighting for circulation, set-up, tear-down, and cleaning. Finished ceilings offer spatial definition and a refined appearance, but may only accommodate certain exhibits and clientele. These are aspects which must be explored in programming.

In the bottom photo, general lighting is achieved in a distinctly different manner. Theatrical rigging is used for mounting lighting instruments where exhibits require such focal lighting.

Although exhibit halls do not traditionally make use of daylight, novel approaches to daylighting combined with improved daylight media can provide a dynamic luminous environment that is characteristic of daylight along with energy savings.

» Top Image ©GARY CAMERON/X00044/Reuters/Corbis
» Bottom Image ©Car Culture/Corbis

definitions. Lighting within the pools and hot tubs is necessary for observation of occupants and for comfortable use.

Direct glare in any of the fitness applications can be minimized with approaches using low-wattage equipment, lensed or louvered equipment, deeply regressed optics, and indirect lighting.

Codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and the requirements and design of which must be coordinated amongst the design team.

28.2.10 Food Service

Food service lighting is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

Most pronounced and problematic is the transition from kitchen to dining room. Sound and light locks work well, but may create circulation problems for wait staff. Transition zones where no food preparation takes place can be used to segue from the dining room to the kitchen. A common problem is a lack of visual consistency and glare control between kitchen and dining room lighting. This can be avoided by selecting luminaires and lighting techniques that minimize glare as well as selecting lamps that are compatible with the color temperature and color rendering of those found in the dining room. Door operators that quickly and quietly swing shut also minimize any light disturbance from the kitchen.

Dining rooms and bars are lighted to engage the clientele or, in some instances, usher the process along. The intent must be established in programming. Subjective impressions outlined in Table 12.2 should guide the application of lighting effects. Illuminances associated with artwork and features that assist with these subjective impressions are identified as Accenting in Table 28.2. Figure 28.7 and 28.8 illustrate effects of accenting and feature lighting in dining and bar lighting applications on senses of preference and relaxation.

28.2.11 Gaming

In casinos the lighting establishes mood, directs and holds attention, provides task lighting for game involvement, and accommodates critical and necessary surveillance. Meeting the visual requirements of one or several of these functions might be straightforward, however, meeting requirements for all of these simultaneously is a complex undertaking. Although programming and scope outline the various applications, tasks, and activities involved, consultation with regulators and surveillance specialists is necessary to develop illuminance criteria. Illuminance levels and uniformities are extremely important. Assessment of tasks for veiling reflections is a requirement if tasks are to be visible to clientele and security personnel in situ or remote-monitoring positions. Lamp CCTs typically in the 2700 K to 3000 K range with CRI ≥82 are appropriate in these festive or club-like settings.

In the vicinity of game tables, vertical illuminances should softly and uniformly light players' faces. Tables are typically illuminated from a variety of positions to minimize shadowing and glare effects of single sources. This also allows for continuation of play should one luminaire fail. Gentle lighting of background surfaces or iconic or artistic features will limit harsh contrast between game areas and backgrounds.

Many games are internally illuminated and subject to veiling reflections. Task orientations must be analyzed with respect to lighting techniques and direction of light. This may involve a series of virtual-model studies and ultimately a physical mockup.

During criteria review with regulators and surveillance specialists, an assessment must be made of the likely visual ages expected of more than half the observers and how this affects illuminance determination for those observers and for surveillance. It is important to reconcile any disparities prior to any final design work.

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28.2.12 Guest Rooms

The guest experience begins at the entry to the hotel, continues to the registration lobby, the elevator lobby, corridor, and, finally, the guest room itself. The lighting of each of these spaces should be consistent with the desired experience as established during programming. The guest room serves as home-away-from-home and as a getaway if for pleasure or business. The lighting effects will be commensurate with:

- Hotel's desired stature, such as in travel ratings
- Marketplace, such as a resort, first-class business property, or economy lodging
- Pricing strategy
- Competition
- Guest's likely age

Even where the most basic of properties and amenities are involved, lighting must meet common needs of living. The illuminance criteria outlined in Table 28.2 are primarily intended as task-oriented. Multi-lamp overhead luminaires in the living area and bathroom generally result in inadequate and unsatisfactory lighting. Where table and floor luminaires are used, these should be lamped with dedicated-socket non-filament lamps for efficiency and system longevity. Although retrofits are considered an acceptable stop-gap measure on existing properties, new and renovation projects should seek portable lights that are listed and labeled as meeting UL/CSA/NOM requirements for dedicated socket lamps. Further, luminaire vendors should do heat testing to confirm lamp/ballast/driver configurations will remain within component manufacturers' tolerances for efficient, warranted operation.

Where quality art is an important part of the decor, accenting a piece can significantly improve the overall appearance of the room and enhance the relaxation experience or even offer a visual break from work tasks.

Lighting for reading at beds may take a number of forms, from the traditional table-side luminaire to the headboard-mounted LED gooseneck. Both require some amount of user adjustment either of the luminaire position or intensity or of the task orientation to achieve satisfactory results. The luminaire wattages, light distribution, and placement should be sufficient to meet illuminance criteria in Table 28.2. Although Figure 28.9 illustrates a guest suite bedroom at a 4-star hotel, the concepts illustrated for lighting at the head of bed are increasingly common in standard rooms.

Where steps are involved, lighting should be used to demarcate the tread elevation changes. Depending on the design of the step or steps, contrast stripes may suffice. Otherwise, contrast stripes with lighting from overhead or steplights integrated into side walls or risers or tread overhangs is necessary.

Care should be taken by the design team to accommodate a sleep cycle with no light. Nightlights might be appropriate in larger suites, rooms with steps, or where the bathroom is not directly aligned with the bed. A strategically placed architecturally-integrated steplight or several can serve this function. To limit sleep disturbance these should be tied to timers or photocells and occupancy sensors. To best limit the disturbance to the circadian rhythm during a middle-of-the-night quick-trip to the bathroom, long wavelength sources such as LEDs producing spectra between 600 and 620 nm are appropriate.

Closets can be problematic as these are usually tiny spaces where code limitations on luminaire placement and size may preclude all but a token luminaire over the door header. In these situations, luminaires outside, but immediately adjacent to the closet may be advantageous. At the least, closet lighting should consist of efficient, long-life lamping suitable for frequent switching cycles. Luminaires internal to closets should be controlled by door contact switches or occupancy sensors. Occupancy sensors must be positioned to immediately sense closet activity without false-starts from adjoining room activity.

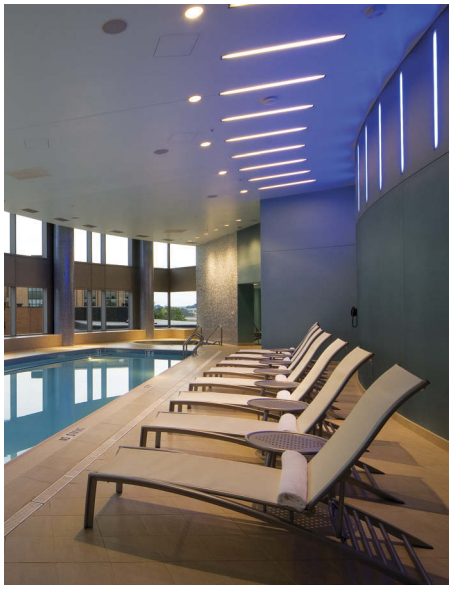


Figure 28.6 | Indoor Hotel Pool
The simple lighting scheme illustrated here involves narrow, discrete, ceiling recessed fluorescent luminaires and a wall-recessed version, wallwashers, accent spot luminaires, and general downlights. With the exception of the lamps in the wall-recessed luminaires, all lamps exhibit a CCT of 3000 K with CRI ≥82. Wall-recessed narrow slot lights at the right are lamped with blue linear fluorescent lamps for visual interest beyond the normal white-light-luminance-balance with the daylight media (such as the CMH wallwashers used at the far end). The narrow discrete, ceiling recessed fluorescent luminaires and the downlights are separately switched.

Veiling reflections are common with bodies of water. Eliminating or significantly controlling daylight is generally contrary to the premise behind daylighting of indoor pools. Early planning of daylight orientation, fixing key viewing positions, such as lifeguard locations, and arranging electric lighting accordingly is necessary if veiling reflections are to be minimized. Eyewear with polarized lenses can also minimize the effect of veiling reflections.

Illuminance criteria are applied to the deck and pool area noted in Table 28.2. Depending on pool size, room geometry, luminaire spacings and optics, there may be no need for luminaires over the body of water. This aids lamp and ballast maintenance.

» Image ©Kevin Beswick, www.ppt-photographics.com

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Figure 28.7 | Dining
Task lighting combines with decorative lighting to meet illuminance criteria and enhance the material and color variations in this dining room. With the exception of the curvilinear copper-colored neon slot and the fluorescent kitchen luminaires, lighting is achieved with 2700 K and 3000 K LEDs exhibiting CRIs ≥82. The slot detail paint color was matched to the neon lamp color through mockup for optimal visual effect. The open kitchen is illuminated with 2x2 recessed luminaires with deep ribbed-blade-louvers with overlay lenses to meet requirements of food preparation areas. Fluorescent lamps are 2700 K for a seamless light color with the dining room.
» Image ©Gary Steffy Lighting Design Inc.

A master control of all lighting within the guest room that is tied to occupancy is most effective at minimizing energy consumption and maximizing in-service life of the system. One system employs a card-key switch at the entry to the room which activates power to all light switches in the guest room once the guest places the room card key into the card-key slot. When the key is removed from the card-key slot, all power to all lights is cut.

28.2.13 IT

Lighting for IT facilities is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

28.2.14 Parking

Lighting for parking facilities is discussed in 26 | LIGHTING FOR EXTERIORS.

28.2.15 Pedestrian Ways

Lighting for pedestrian ways is discussed in 26 | LIGHTING FOR EXTERIORS.

28.2.16 Reading and Writing

Lighting for reading and writing is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. Reading and writing tasks occur within various applications. Familiarity with these tasks will aid with assessment of specific application tasks and activities. This may result in the recommendation of illuminance criteria different than that proposed in Table 28.2 for a particular application. For example, if the reception desk in a fitness center doubles as a work desk for employees, then a task citation of 8- and 10-pt. font on matte paper or with matte ink may be an appropriate recommendation and should be deliberated with the client.

28.2.17 Spas

Spas are the most indulgent of applications where the unquestionable goals of rest, relaxation, and esteem are achieved with pampering to body and mind. Perhaps in no other application is the performance of light so critical and where less illuminance is more. As with other hospitality applications, lamp CCTs of 2700 K to 3000 K with CRI ≥82 are appropriate to mimic the more comforting effects of traditional filament lighting.

High illuminances are necessary at the task areas where hair styling, manicures, and pedicures are performed. However, the illuminances associated with manicures and pedicures are best when limited closely to the approximate task area involved. Lighting equipment with well-controlled optics to avoid glare is best. For hair styling, an overall "head-glow" is necessary for the stylist's work and for the clientele's periodic mirror-reflection views. Here, lighting should be relatively soft and multi-directional from overhead and front. This avoids shadows and harsh glare and limits unbecoming shadows under eyes, noses, and chins. In the hair color lab, a combination lighting system is best where lamps with CCTs of 2700 K to 3000 K and CRIs ≥82 are available on one control zone and lamps with CCTs of 5000 K to 6500 K and CRIs ≥85 are available on a second control zone. This offers three conditions under which to review color.

Careful programming is required to establish which spaces demand wet-rated and IP-rated equipment. See Table 15.4 | IP Rating System.

Saunas and steam rooms are difficult environments for most lighting equipment, even that which is UL/NRTL wet-rated in the USA, for example. The steam is pervasive and the temperature swings can wick water into gasketed equipment. Where these spaces are involved, consult with the supplier of the room templates and equipment and with luminaire vendors prior to selection and specification.

Secondary lighting systems provide lighting necessary for cleanup in many of the treatment and other low-light spaces.

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28.2.18 Support Spaces

These relatively back-of-house citations are self-explanatory. For purposes of maintenance convenience and where these spaces adjoin occupied areas, lamp types and color qualities should match those used elsewhere in the facility under design.

28.2.19 Theaters

Film and stage theaters serve different functions and have different lighting requirements even though many of the application and task names are common to each. Stage theaters use lighting instruments selected, laid out, and controlled in accordance with professional theater lighting designers' specifications and plans in order to illuminate performers and scenery to the requirements of the specific production for the benefit of the audience's entertainment experience. This stage lighting requires an extensive infrastructure for mounting, power, and control.

The architectural or "house" lighting in the theater proper must exhibit excellent dimming range and very high color rendering (CRI ≥85). All lamps should be capable of tracking each other at similar, if not identical, rates and quality of dimming. Otherwise, abrupt lighting changes, unsynchronized dimming between luminaire types, such as decorative sconces and steplights and chandeliers, or unsettling color shifts, will diminish the quality of patrons' event experiences.

CCT and CRI of lamps in luminaires at the delivery and staging work areas should be similar if not identical to those used in the theatrical stage instruments to avoid undesirable color appearance of scenery and props at showtime.

Acoustics, dimming ranges, and the amount, if any, of remote hardware are important considerations when selecting lamps, luminaires, and controls for the architectural or house lighting for the theater proper, especially for live performance theaters. Acoustics alone may preclude the use of fluorescent and LED lamps in some applications. Carefully scrutinize lamp, luminaire, ballast, driver, transformer, and controls devices. Operational mockups are best. *Performance-quality dimming* is appropriate. Figure 28.10 is an illustration of house lighting in a stage theater with a few theatrical instruments energized to highlight or "warm" the curtain (hence, these are commonly called curtain warmers).

Aisle lighting requirements before, during, and after an event must be planned to allow for safe and convenient access into and out of the house at any time without creating disturbing shadows or reflections from people as they make their way to and from seats. When films are projected, as little ambient light as practical from the normal power architectural lighting system on the screen proper is best. Depending on jurisdictional requirements, the type of theater, and client programming requirements, use of direct-view floor-mounted miniature walk-over LED strip lighting may be appropriate to demarcate elevational changes.

28.2.20 Toilets/Locker Rooms

Lighting for toilets and locker rooms needs to meet the functional requirements of illuminance criteria outlined in Table 28.2. Addressing the plumbing fixture will provide sufficient light where needed without overlighting the entire toilet room. Vanities are most problematic when little or no vertical illuminance is designed to light an imaginary facial plane (roughly a zone of sufficient size to encompass faces) in front of the mirror. Wall sconces, small pendants between each sink, wall slot details illuminating light-colored upper walls above the mirror or some combination are all appropriate techniques. See Figure 22.7.

Vertical light over the faces of lockers will assist with locker use.



Figure 28.8 | Bar
There are times when, regardless of daylight availability, some lighting remains energized to simply identify an establishment as open-for-business. In this hotel bar, the back bar is illuminated as is the peninsula focal point. Decorative lighting overhead consists of multi-lamped pods arranged in a somewhat curvilinear and undulating pattern. The two-zone lamping allows for one zone to be extinguished while allowing the shades to glow. Alternating operating schedules of which zone is extinguished on which days can prolong in-service life of ballasts and lamps. This extends group relamping. Lamp CCT is 3000 K with CRI ≥82. Shade materials are color tuned with the CFL lamping to provide a filament-lamp color quality.
» Image ©Kevin Beswick, www.ppt-photographics.com

Performance-quality dimming as used here refers to smooth and continuous dimming from full output (100%) to extremely low output (≤0.1%) and vice versa. This dimming is achieved at a consistent and programmable or manual fade rate and can maintain a static steady state at any point along the continuum for a quality equal to that achieved when proper dimming of filament lamps is employed. Striations, visual steps, intermittent bright "surges", or sudden flashes or cutouts, color shifts, or other visual disturbances are unacceptable during dimming or static conditions. Performance quality dimming is appropriate where a continuous and complete fade to black is part of the experience, such as transitioning from intermission to show in a theater.

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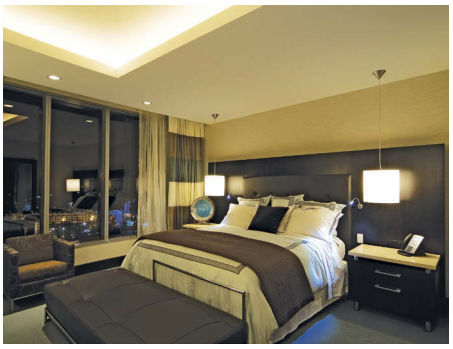


Figure 28.9 | Guest Suite
Bedside pendant luminaires and gooseneck LED reading luminaires are combined with the ambient lighting from a ceiling cove. Perimeter downlights provide sitting-area lighting. Preset scenes available from bedside and door-side keypads are DRESS, READ, TV, NIGHTLIGHT, and OFF.
» Image ©Kevin Beswick, www.ppt-photographics.com

28.2.21 Transition Spaces

In hospitality and entertainment facilities, a number of spaces transition from one application to another. Some of these are considered back-of-house and available to employees only. Most are public spaces and many of these might be of a particular sequence of passage, ceremonial in nature, or of special importance. To appropriately serve these roles, subjective impressions outlined in Table 12.2 should guide the application of lighting effects. Illuminances associated with artwork and features that assist with these subjective impressions are outlined in Table 28.2. Figures 28.11 and 28.12 illustrates a hotel lobby lighted to the illuminances outlined in Table 28.2 using ambient, task, and accent lighting systems. Figure 28.12 illustrates lighting of a motel lobby.

28.3 Illuminance Criteria

Illuminance criteria, when fully deployed, are a robust set of quantitative values that influence visibility, visual performance, and visual comfort and attention. Short-circuiting the criteria selection or designing to a single criterion value, such as horizontal illuminance, to address worst-case tasks will surely result in dissatisfaction. Even if clients accept the visual results, not getting the most from the energy expended or, worse, energy waste is a likely result. Following are notes related to various topics outlined in Table 28.2.

28.3.1 Applications and Tasks

Applications and tasks encountered on any given project may be different from those identified in Table 28.2 and may warrant different illuminance criteria. Cross-referencing closely-associated applications or tasks is appropriate. Sometimes naming trends or conventions for space types or functions change to conform to current practice, client programming, or architectural conventions, but the actual activities and tasks remain the same and this cross-referencing works. Failing this technique, reviewing the list in Table 28.2 may be in order to determine if any applications or tasks exhibit a similar visual-component to the unique applications or tasks. Otherwise, reviewing 4.12 An Illuminance Determination System and Table 4.1 is necessary to establish a task category based on the task characteristics or visual performance descriptions most closely associated with the unique applications or tasks. These exercises as well as any deviations from recommendations the designer intends to make should be carefully documented for the record.

28.3.2 Notes

The notes in Table 28.2 may refer to other task headings in the table or to other handbook chapters as appropriate. Where some degree of clarification is warranted, notes are made.

28.3.3 Recommended Maintained Illuminance Targets

Values cited are maintained on the area of coverage for the task under consideration. Illuminance is additive. Where practical and without negatively affecting the intended application of light, target values are achieved with any combination of daylighting and/or electric lighting in whatever mix of ambient, task, and accent lighting is deemed appropriate to meet these and the other lighting goals established during design. See 12 | COMPONENTS OF LIGHTING DESIGN and see 10.7.1 Light Loss Factors.

With respect to light loss factors, account for anticipated losses through the point in time at which group relamping and cleaning should occur. Group relamping and cleaning should be standard practice, though these need not occur at the same frequency. Periodic cleaning and group relamping essentially maintain the illuminance at criteria and make the most efficient use of the installed equipment. For purposes of sustainability, cleaning and group relamping can no longer be presumed to be infrequent or unlikely. Maintenance procedures must be part of the design discussions with the client. See the IES document

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Figure 28.10 | Theater
Renovation of this theater involved reuse of existing ceiling downlights, introduction of a catwalk at the proscenium, and new seating, flooring, and walls. Prior to the renovation, only downlighting existed as house lighting. To brighten the house and introduce visual interest for the pre-show and intermission, a sequence of linear wall brackets with varying sizes and spacings of sconces was introduced.

Sconces consist of a modular glass luminaire (right detail) used in single and multiple groupings as the design team deemed necessary to flow with the wall height, floor slope, and balcony configurations. Each sconce module is lamped with halogen filament lamps selected for quiet operation, smooth, continuous, and deep dimming, and no remote equipment requirements. Lamp reflections from the satin wood finish are usually considered acceptable if not desirable from the "point source" of the halogen filament lamps. However, reflections from "tiny point source" LEDs and from "large area source" fluorescent lamps are typically undesirable.

The catwalk, added to introduce better stage lighting positions, forced removal of a row of downlights. To maintain lighting at the orchestra seating positions, architectural light slots were introduced. Existing downlights were relamped with lower wattage halogenIR_{120V} PAR38 lamps.

A few theatrical instruments are also energized in this view to highlight or "warm" the curtain (hence, these are commonly called curtain warmers).

» Image ©Ron Blunt Photography

IESNA/NALMCO RP-36 Recommended Practice for Planned Indoor Lighting Maintenance for additional information. Where maintenance is deferred or practiced poorly or not at all, the actual illuminance values will fall below criteria targets. This is inefficient, unsustainable, and may be unsafe while adversely affecting users' quality of life or work. Ratcheting initial illuminances higher is poor practice and not recommended. Maintenance procedures may be especially problematic with LEDs where promises of extraordinarily long life may be offered, but usually with the caveat that lamp lumen depreciation (LLD) at that rated life is 70% or perhaps even as low as 50% of initial rating. If replacement cycles are presumed to be rated life, then LLD alone must be 0.7 or 0.5 or whatever lumen rating is certified by the LED vendor. See 13.3 Life and Lumen Maintenance.

Targets cited are consensus and recommended for respective functional activity. For some applications, IES recommendations are within 10% of code requirements. This apparently is an artifact of metrication. Footcandle conversions of any values cited in Table 28.2 should be made at 1 fc to 10 lx. This soft conversion avoids a redundant diminishing of illuminance values after multiple citations and conversions over time. This also eliminates a false sense of accuracy advanced by an ever-increasing number of decimal places and a false sense of urgency advanced by eccentric fractional values introduced by hard conversions. Nevertheless, a lighting design must meet code and the mechanics of which must be coordinated amongst the design team. The IES recommendations should not, do not, and cannot reflect all of the various code requirements in force in all jurisdictions at any given time.

Targets are intended to apply to the dominant plane of the task, typically, but not always, horizontal or vertical. In some situations, illuminance criteria are cited for one plane, such as the vertical plane for lighting white boards, while the other plane is blank. The blank signifies that illuminance on that plane is unimportant and may be a consequence of the illuminance of other tasks within the vicinity or by whatever illuminance results from meeting the target illuminance for the prescribed plane of interest.

In some situations, no light is anticipated on at least one plane of a task. A 0 indicates no light or zero light is recommended for the task or application.

28.3.3.1 Target Planes

Many, though certainly not all, tasks are performed with the task in roughly a horizontal orientation or vertical orientation. A dominant orientation must be assigned and the illuminance target determined accordingly. There may be situations where the IES recommended target relating to the typical planar mode of a task must be applied to a different plane.

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Figure 28.11 | Hotel Lobby
A multi-story lobby/lounge/registration area is lighted using ambient, task, and accent lighting approaches combined. This view is of the lounge as seen from the registration lobby. Ambient lighting is based on illuminance criteria from Table 28.2 for TRANSITION SPACES/Lounges/Social/Waiting Areas. Task lighting is based on illuminance criteria from TRANSITION SPACES/Lounges/Reading/Work Areas. Accent lighting is based on TRANSITION SPACES/Accenting/Feature Wall Table 15.2/Soft (~5-to-1 from feature wall E_v to ambient E_h).

To introduce contrast beyond that achieved with accenting, colored light is used. The linear ambient luminaires are ceiling slots generating an indirect glow using T5HO blue fluorescent lamps. All other luminaires are lamped with CFL or CMH lamps exhibiting CCT 3000 K and CRI ≥82.

» Image ©Kevin Beswick, www.ppt-photographics.com

Nearly all tasks are expected to have both a horizontal illuminance component (E_h) and a vertical illuminance component (E_v). This allows some degree of task flexibility for off-plane viewing and accommodates various aspects of the task. In some applications, like conventional art studios accommodating a variety of media, art forms, and genres, horizontal- and vertical-plane illuminances address the common studio situation where simultaneously some work or some portion of the work is on horizontal planes while other work or portion is on vertical planes.

Where illuminance targets are intended at differing planar elevations, this is indicated under "Notes." For example, for most corridors (TRANSITION SPACES/Circulation Corridors), horizontal illuminances apply to the floor plane while vertical illuminances apply to standing-face-plane height of 5' AFF oriented in the two main directions of travel. Although the nature of architectural lighting in many corridors is such that the target illuminance will coincidentally be met at the elevations of 3' and 4' AFF, the designer may elect to set the criteria elevation for vertical illuminance at 3' AFF or a range of 3'-5' AFF to assure facial lighting for children and those in wheelchairs meets target. Establishing and tracking task orientations and addressing both horizontal and vertical illuminance is necessary. If orientations in the project under consideration are programmed to be flipped from what might be considered normal-viewing, then criteria must be adjusted accordingly. If a task is scheduled to be oriented on some plane off axis from horizontal or vertical by more than 10°, say, then the illuminance criteria must be applied to that off-axis orientation. This is an important distinction for luminaire optical selection and aiming capabilities and for layout, calculations, and field measurements.

For planes related to vertical illuminance targets, some guidance is indicated under "Notes." However, the designer may elect to use alternate or multiple vertical planes. In some situations the vertical planes could be oriented in a number of directions and the designer must determine which are most appropriate for the situation. For example, in an exhibition hall, for E_v (EXHIBIT HALLS/General Exhibition for both High Light Setting and Low Lighting Setting), the number and orientation of vertical planar points assessed depends on the exhibit hall layout. For most, a universal layout is appropriate and, therefore, at least four vertical planes are of interest. One in each of the four cardinal directions of the plan.

28.3.3.2 Visual Ages of Observers

Illuminance criteria are based on the visual ages of more than half the intended observers. This aspect should be resolved during programming with the client. It may be determined that illuminance criteria for an age group other than that representing the majority of the intended observers is appropriate. However, this may result in overlighting, underlighting, harsh lighting, visual displeasure, or visual discomfort for many of the observers. See 12.5.5 Illuminance and 4.12 An Illuminance Determination System for additional information and guidance. In some situations, such as video conferencing, lighting must meet the requirements of the camera technology and, therefore, is not tied to ages of observers.

28.3.3.3 Illuminance Categories

Illuminance categories are designated by letters A through Y. These are shown in Table 28.2 for more convenient reference to Table 4.1 | Recommended Illuminance Targets should the designer wish to explore other criteria targets or if applications or tasks on a specific project are not readily correlated to the table citations.

28.3.3.4 Gauge

The common gauge for determining illuminance target compliance is cited for each application. All gauges presume that point-by-point techniques are used for predictive calculations and presume that uniformity criteria are closely monitored. Where an average illuminance value over the area of coverage can satisfy target compliance, "Avg" is cited. In applications or tasks where a minimum or maximum target is necessary, the gauge for compliance is "Min" or "Max" respectively.

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The designer may elect to use other methods to evaluate target compliance, such as criterion rating (CR) or coefficient of variation (C_v). See 4.12.4.5 Tasks at Uncertain Locations Over a Large Area.

In any event, once illuminance targets and uniformities are established, then any calculated deviation from them should be limited. Standard engineering allowance of ±10% might be acceptable for targets gauged as average unless contractual or code obligations demand otherwise. Minima and maxima must be achieved as intended.

Designs should be adjusted until predictions are within allowance for averages and meet minima and maxima. For additional information, see 4.12.4.1 Recommended Illuminances at Design Time, 4.12.5 Illuminance Ratios, 9.15.1.1 Average Illuminance, and 10.8 Assessing Computed Results.



Figure 28.12 | Motel Lobby
Well-spaced downlights exhibiting a flood distribution at the registration desk can provide effective illuminance on the wall for accent and on the registration counter for task. Downlighting concentrated at seating and feature areas provides ambient light, but with some degree of accent highlight that would be lost with a general pattern of downlighting. Decorative pendant and sconces themselves provide some accent and help with human scale and visual interest and soften the harshness of downlighting alone.
» Image ©Jonathan Ross/Space Images/Corbis

28.3.4 Uniformity Targets

Illuminance uniformity targets work in conjunction with luminance uniformities and surface reflectances all of which must be addressed as part of the design to avoid visual discomfort, glare, and strain. Uniformity ratios are targets that define the widest recommended ranges. In many situations, uniformity ratio criteria are those between average values of an array of points and the minimum value in the same array of points. Uniformity targets apply to both horizontal and vertical illuminances over the area of coverage. Where horizontal uniformity criterion is different from vertical uniformity criterion, two ratios are reported with the first value for horizontal illuminance (E_h). In some situations, notably those with regard to exterior illuminances, two uniformity values are cited. The first value addresses the primary cited application or task. The parenthetical value references the parenthetical application or task, such as a curfew situation associated with nighttime outdoor lighting.

Generally the more important speed and accuracy and the more demanding the visual task, the tighter the ratio.

28.3.4.1 Maximum-to-average

This is the recommended ratio of maximum illuminance to the average illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations sensitive to even a relatively small degree of overlighting.

28.3.4.2 Average-to-minimum

This is the recommended ratio of average illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where illuminance too far below average conditions is noticeable and detrimental to task performance or inconsistent with normal expectations.

28.3.4.3 Maximum-to-minimum

This is the recommended ratio of maximum illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where too much variation in illuminance is considered undesirable and untenable from a performance or safety perspective.

28.3.5 Daylighting Advancement

Generally, design strategies should embrace any combination of daylighting and electric lighting to achieve target values during daylight hours. The preference is for daylighting to provide all or most of the recommended illuminance presuming that all aspects of daylighting are properly addressed. A sunburst icon depicts those applications and tasks where daylighting is considered a strategic candidate. Use photocells and stepped-dimming or continuous dimming to reduce or eliminate electric lighting during daylight hours. See 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Even for those applications where daylighting is not traditionally a strategic candi-

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date, it may be determined that very careful and coordinated design will offer great sustainability opportunities along with positive influences associated with daylight and views.

28.3.6 Veiling Reflections

Tasks with specular components, such as some video game consoles and display monitors, which may be in different planes, are prone to veiling reflections. The likelihood of particular applications/tasks predisposed to veiling reflections is indicated by a "reflected light" icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood. Veiling reflections are minimized by controlling the overall amount and direction of daylight with respect to the task locations and orientations. Alternatively, tasks sensitive to veiling reflections can be screened or isolated. Employing indirect soft, diffuse electric lighting or direct electric lighting with multiple low-output luminaires, or positioning tasks and luminaires and luminance patterns to avoid harsh reflections from tasks can be effective.

28.3.7 Defining Areas of Coverage

In addition to establishing planes of task orientation, the areas of coverage to which targets apply must be determined. Typical areas of task illuminance coverage are identified here, but these may not be appropriate to specific project situations. One area of coverage is "task proper or task area." Here, the illuminance criteria are applied to the task itself or to a relatively small area to which the task is confined. See 12.5.5.1 Tasks and Applications and Figure 12.21 | Task Coverage Example. In some situations, such as accenting, the "task" area may consist of the entire wall when "feature wall" or "perimeter" accenting is desired. It is important to remember that illuminance is additive, that is, task illuminance can be achieved with some combination of ambient lighting, task lighting, and/or accent lighting, providing that the total illuminance on the task proper or task area meets the illuminance criteria outlined in Table 28.2.

Another area of coverage is "room or designated area." In this situation, illuminance criteria are applied to the room or an area of fairly substantive size representing the zone in which the applications/tasks are expected to occur. The designated area is typically established by the furniture layout, for example, or might be established by the design team or client. The area-of-coverage citations in Table 28.2 are based on traditional notions. So, for example, it may be determined that a "task proper or task area" coverage would result in some amount of LPD reduction when compared to "room or designated area" coverage. If the task can be confined to one area rather then multiple areas, if the room or area in which the task is located is itself relatively small, such as a single-occupant office, and if the other design goals and criteria outlined in 12 | COMPONENTS OF LIGHTING DESIGN are addressed, then this strategy of redefining area of coverage has merit.

An assessment and determination must be made on which area of coverage best satisfies the lighting goals on a particular project.

IESH/10e Economics Resources

> 15.3.3 Budgets
- for more on budgets and value engineering

> 18 | ECONOMICS
- for more on estimating costs
- for more on life cycle costs
- for more on paybacks and rates of return

28.4 Designing

Information provided here is specific to hospitality and entertainment facilities and should be used as part of the design and documentation processes outlined in Chapters 12, 15, and 20. For outdoor applications, lamps and ballasts, transformers, and drivers must be selected for ambient temperature conditions, some of which are extremely hot and others extremely cold. See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY for additional information on respective aspects. Addressing all code requirements is a must. Energy efficient and sustainable practices are an integral part of all IES recommendations. Key design tenets include, but are not limited to:

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- designing for the satisfaction of the observers intended to use the project
- using baseline reflectances of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively) in interior production and work-oriented spaces
- using daylighting that meets luminance and illuminance criteria
- using highest-efficacy lamps that meet color, optical and electrical control, and output criteria
- using highest-efficiency luminaires that meet aesthetic and luminance criteria
- using accenting to provide luminance balancing or improve brightness perceptions where necessary
- using controls liberally, preferably automated varieties such as presets, occupancy and vacancy sensors, astronomical time clocks, and photocells
- establishing IES-recommended illuminance criteria to meet programmed tasks
- establishing layouts that just meet IES-recommended illuminance criteria
- addressing outdoor environmental needs
- using calculations, photometrically-realistic renderings, and operational samples and mockups to prove concepts
- identifying and designing to code-specific requirements, if any, for ambient, task, and accent lighting
- documenting all code-, energy-, sustainability-, and IES-criteria compliance
- documenting criteria and design deviations and rationale and subsequent disposition by team, client, or AHJ
- documenting clearly the layouts, controls, and luminaire and lamp selections

Designing for the satisfaction of the observers is the paramount design tenet and must be kept in perspective during all aspects of design. If the observers' expectations are not fulfilled, then how much energy could be saved is moot, as is how many fewer earth resources were spared, as is how much the whole affair cost or how much value engineering saved or the photogenic qualities of the project. See sidebar references for additional guidance on the key tenets. The design effort must be undertaken with coordinated and realistic expectations by all involved on initial and life cycle costs. Budgeting should include designer input and dialogue with the team and client at project commencement and design milestones. In other words, and paraphrasing Thomas Edison, genius is, indeed, just 1% inspiration and 99% perspiration.

IESH/10e Energy Efficiency Resources

> 17.2 New Construction
- for more on designing for daylighting
- for more on electric lighting equipment
- for more on lighting controls

> 17.4 Lighting Codes, Regulations and Standards
- for more on application standards
- for more on equipment regulations

IESH/10e Lighting Exteriors Resources

> 12.5.5.6 Nighttime Outdoor Illuminances
- for more on lamp efficacies under mesopic adaptation

> 26 | LIGHTING FOR EXTERIORS
- for more on criteria

IESH/10e Sustainability Resources

> 13.11 Sustainability
- for more on lamps

> 19 | SUSTAINABILITY
- for more on controls
- for more on earth resources
- for more on energy
- for more on life cycle analyses
- for more on lighting design
- for more on recycling

28.5 References

[1] [DOE] US Department of Energy, Energy Information Administration. 2008. Table E5A. In: Electricity Consumption (kWh) by End Use for All Buildings, 2003 [Internet]. DOE. [cited December 2008]. Available from: http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html#enduse03.

[2] Mark S. Rea, ed. 2000. The IESNA lighting handbook: Reference and application. 9th Edition. New York: IESNA. Ch 13, 15.

[3] [IESNA] Illuminating Engineering Society. 2009. Stage Lighting - A guide to the planning of theatres and auditoriums DG-20-09. New York: IESNA. 32 p.

[4] Steffy G. 2008. Architectural lighting design. 3rd edition. Hoboken: John Wiley & Sons. p 161.

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29 | LIGHTING FOR LIBRARIES

Books are the ever burning lamps of accumulated wisdom.
George William Curtis, 19th Century American Writer

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Libraries fulfil the information needs of a wide public. For example, in the United States in 2007, circulation was near 2.2 billion, with children's circulation accounting for about 35% of that. 292 million Americans were served by public libraries. [1] Libraries are an integral component of education, whether the school library or the public community library. Libraries are reference archives, interest-free lending institutions, gateways to the World Wide Web, and living rooms and study halls. Lighting plays a role to entice people to use libraries and, once there, to use library resources with efficiency and comfort. Engaging and functional are broad attributes to which library lighting design must aspire. Daylighting and views can make powerful contributions. What follows is a discussion of the key aspects affecting lighting: project status; space types; activities; application-specific design goals, and illuminance criteria in library facilities.

Comprehensive design efforts involve the information in this chapter combined with material in 12 | COMPONENTS OF LIGHTING DESIGN, 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS, 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Design tenets deemed appropriate from those chapters must be identified and lighting goals and strategies developed accordingly. This chapter primarily addresses illuminance criteria for libraries which should influence luminaire optical selections, lampings, and final layouts based on design thought-starters (see 15.2 A Lighting Scheme). Use of the material in this chapter to the exclusion of material in Chapters 12, 13, 14, and 15 will likely lead to unsatisfactory results. Previous and current IES related documents serve as archival and reference sources. [2] [3].

Deliberate thought must be given to details beyond the recommended illuminances in this chapter. For example, in audio listening rooms, the quality of the sitting room must compel potential patrons to enter and engage in the process. Visual interest is appropriate and cannot generally be achieved simply on the basis of task or application illuminance criteria. Accenting is in order or spectacular views both day and night. Another example: shelving in periodicals demands vertical illuminances to attract and hold the patron's attention. Achieving these with ceiling mounted or recessed wallwashers or accents may only lead to a shadow problem as patrons approach the shelving to view periodicals. These situations must be studied carefully before solutions are recommended, particularly those that seem obvious. These kinds of specific details are not enumerated for most tasks. Table 29.1 offers a checklist of IES lighting topics and criteria. The design team is responsible for determining and addressing indoor and outdoor lighting and energy criteria set forth by authorities having jurisdiction (AHJ) which may be different from and supersede IES criteria. See also 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

29.1 Project Type and Status

Before any design work, an understanding of the project type and scope is necessary. This will establish the extent to which daylighting can address most or many or some of the lighting goals. New, renovation, and restoration projects each offer varying opportunities.

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Table 29.1 | Library Lighting Checklist

Topics
✔ Criteria and Design Resources
Accenting
15.1.1.3 Accent Lighting
Table 12.2 | Subjective Impressions
Table 15.2 | Accent Illuminance Ratios
Table 22.2 | Common Applications Illuminance Recommendations
Appearance
12.2 Spatial Factors
Color
12.5.6 Color Considerations
Controls
16 | LIGHTING CONTROLS
Daylighting
14 | DESIGNING DAYLIGHTING
Electric Lighting
15 | DESIGNING ELECTRIC LIGHTING
Flicker
4.6 Flicker and Temporal Contrast Sensitivity
Glare
4.10.1 Discomfort Glare
4.10.2 Disability Glare
Illuminance
This Chapter: Table 29.2
12.5.5.1 Applications and Tasks
Table 12.6 | Default Illuminance Ratio Recommendations
Figure 12.22 | Task Coverage Example
Light Distribution
12.3.2 Subjective Impressions
Luminances
12.5.2 Luminance
Table 12.5 | Default Luminance Ratio Recommendations
Maintenance
15.4.4 Installation and Maintenance
Nighttime Outdoor Environment
Table 15.6 | Nighttime Operational Strategies for Improved Outdoor Environmental Regard
Systems Integration
12.6 Systems Factors
Veiling Reflections
This Chapter: Section 29.3.6
12.5.4 Veiling Reflections
Visual Tasks
This Chapter: Section 29.2
This Chapter: Table 29.2
Table 11.2 | Programming: Inventory Scope and Specific Examples
12.5.1 Visual Tasks
Table 12.3 | Sample Visual Task Survey

See 11.2 Planning, 11.3.1 Pre-design, and 11.3.2 Schematic Design. At every opportunity the lighting designer should give every consideration to daylighting as a light source. Given hours of operation of K-12 schools and public libraries, daylighting can be a primary light source for many libraries. Critically, this means addressing the host of lighting design factors identified in 12 | COMPONENTS OF LIGHTING DESIGN. Daylight demands determined attention to moderate or eliminate glare and balance visible and thermal energy.

29.2 Application Types

To develop lighting solutions that meet quality, quantity, and operational criteria, an inventory is made of the library space types under consideration and the anticipated occupants, functions, and tasks (see Table 11.2 | Programming: Inventory Scope and Specific Examples and Table 12.3 | Sample Visual Task Survey). Otherwise, lighting cannot be best targeted to the users, their expectations, functions and tasks.

Space type definitions are required early in the project design in order to track design efforts that include inventorying the project knowns, anticipated functions, and tasks and calculating lighting, power, and energy compliance. Room names, from which functions can be deduced, and numbers for tracking should be clearly marked on architectural backgrounds. The applications and tasks cited in Table 29.2 | Library Facilities Illuminance Recommendations should be reviewed against the project knowns and correlated with the named space types and functions to establish recommended illuminance criteria. Seek clarification with the client where discrepancies occur between programming information, the list of room names, and the available application and task citations in Table 29.2.

The following discussion is keyed to major application headings in Table 29.2. Couple this with topics in Table 29.1 for comprehensive qualitative and quantitative criteria.

29.2.1 Accenting

Accenting affects people's brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. Default accent lighting criteria are discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. Also see 15.1.1.3 Accent Lighting.

29.2.2 Administration

Lighting for administrative areas is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. The architectural scheme and even task specifics will vary based on the associated library facility, from school to public to community college to college and university to senior housing complexes. These distinctions may affect the lighting design—from kinds of lighting effects to lighting equipment styling to luminances and illuminances.

Library administration may be dispersed throughout a facility or campus or may be centralized into a single area, wing, or building. Depending on client wishes and architectural desires, this centralization or decentralization may affect the degree to which the lighting design in administrative areas is sympathetic to or different from that of the other applications at the library facility. Some libraries may not have a dedicated administrative area, but share administration with the larger entity, such as school or senior housing complex.

29.2.3 Auditoria

Lighting for auditoria is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. For public libraries, auditoria function as lecture halls, informational presentations and public messages, testing sites, debate forums, and community boards' meeting facilities. Controls and their ease of use are particularly important in these public settings where library staff may not be available and users are unfamiliar with the lighting system operation. Here, simple 3- or 4-scene presets with well-labeled keypads

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available at ingress/egress points and at or near the presentation position are appropriate. All the use of the system is simple and convenient, the design to achieve this simplicity must accommodate the various tasks expected in each scene. For example, in an AV PRESENTATION scene, house lights might be very dim or off if aisle lights are available. Speaker accents are energized, perhaps to a dimmed level. However, this accenting must be designed so that spill light is not present on the adjacent or nearby AV screen. Therefore, this speaker accenting may be achieved with different luminaires and lamps than used in a LECTURE scene where no AV is involved. The designer must track the various tasks and address each, perhaps differently, in each scene. Figure 29.1 illustrates a small auditorium with fixed seating at a community library.

29.2.4 Building Entries

Lighting for building entries is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. Since many libraries are used extensively in the evening hours, levels of activity can be high at entries. Hours of operation may change based on the day of the week. This information should be evident from the program and lighting criteria should address the level of activity. Another variable demanding attention prior to recommending illuminance criteria is the outdoor nighttime lighting zone. All of this may demand a control system capable of addressing various settings on various evenings through manual intervention, automated time clock, and photocell functions.

The nighttime outdoor lighting zone within which the facility is located or to which the team and client elect to design affects the illuminance criteria for outdoor tasks. Nighttime outdoor lighting zone designations vary by local ordinance, sustainability guides, or the team's own definition of place. These are discussed in 26 | LIGHTING FOR EXTERIORS. Also see Table 15.6 | Nighttime Operational Strategies for Improved Outdoor Environmental Regard.

After-hours security needs, such as on-site or remote monitoring, may require that some luminaires at building entries remain energized through the night. Control zones and time clock functions must be designed accordingly. Where remote monitoring is done with infrared cameras, lighting may be unnecessary if not undesirable.

29.2.5 Classrooms

Lighting for classrooms is discussed in 24 | LIGHTING FOR EDUCATION.

29.2.6 Conferencing

The lighting of conferencing facilities is addressed in 22 | LIGHTING FOR COMMON APPLICATIONS. In multipurpose meeting rooms, preset controls establish appropriate settings for various tasks. Controls should be simple to operate and clearly labeled. Where meeting rooms are likely to be used for hobby interests, such as stamp and coin collecting or knitting and quilting, the designer should review the likelihood and frequencies as well as the design implications with the client. Criteria for these specific tasks in a meeting or conference room must then be determined by the designer. Criteria may be available from other application chapters, such as 33 | LIGHTING FOR RESIDENCES where citations of RESIDENTIAL INTERIORS/Arts, Crafts and Collecting and RESIDENTIAL INTERIORS/Sewing/Hand Sewing or Knitting can be found.

29.2.7 Exhibit Galleries

Lighting for exhibit galleries is covered in 21 | LIGHTING FOR ART. Many libraries possess collections of history, memorabilia, distinguished, if not rare, books, and popular culture. Libraries also have access to visiting exhibits. Dedicated exhibit spaces are common as are placeholders for temporary exhibits which are interspersed throughout the book collections. Lighting must be planned accordingly for these permanent and temporary exhibits and displays. Lighting solutions should limit or eliminate UV and IR radiation



Figure 29.1 | Library Auditoria
As part of a larger conference center for this community library, a fixed-seating auditorium is used for lectures and presentations. Lighting flexibility is important, but need not include more than three or four scenes (such as BRIGHT [shown here], DIM, AV, and OFF). Indirect lighting from the coves offers soft diffuse light and when combined with the downlighting provides good facial modeling which is important for feedback purposes to a lecture speaker or panel.

From this view, specular reflection of the cove lighting occurs in the wood ceiling. This is not seen by the audience except as people exit the auditorium. Matte finishes would reduce the effect, but the trade-off is a loss in depth and texture of the wood grain.

» Image ©2005 Gene Meadows



Figure 29.2 | Library Exhibits
For large libraries, temporary and permanent exhibits are an important part of community service and attracting patrons. Here, a temporary exhibit in 2007 at the Santa Monica Public Library showcases the best of Nordic furnishings and lighting. Lighting must be planned into the architecture and controlled in the event no exhibits are on display but other programmed functions take place, such as reading areas between exhibit cycles.

Programming might call for permanent display cases to be interspersed throughout book collections or located in dedicated exhibit galleries where walls might accommodate hanging art or displays. Lighting must be developed to support these applications.

» Image ©Kenneth Johansson/Corbis

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Table 29.2 | Library Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
ACCENTING	Accenting influences observers' overall brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. See 22 | LIGHTING FOR COMMON APPLICATIONS/ACCENTING for default accenting criteria for consideration in any application.											
ADMINISTRATION	See 22 | LIGHTING FOR COMMON APPLICATIONS											
AUDITORIA	See 24 | LIGHTING FOR EDUCATION											
BUILDING ENTRIES	See 22 | LIGHTING FOR COMMON APPLICATIONS											
CLASSROOMS	See 24 | LIGHTING FOR EDUCATION											
CONFERENCING	See 22 | LIGHTING FOR COMMON APPLICATIONS											
EXHIBIT GALLERIES	See 21 | LIGHTING FOR ART											
EXTERIORS	**OUTDOOR** applications and tasks cited here. Also see 26 | LIGHTING FOR EXTERIORS											
• Book Return Bin												
• General	General lighting should address a task area comprising the return box and a margin of 1' 6" beyond all exposed sides											
• LZ4[i]	E_h and E_v @3' AFG	H	10	20	40	Avg	F	5	10	20	Avg	
• LZ3[i] (and LZ4 curfew)	E_h and E_v @3' AFG	G	7.5	15	30	Avg	E	4	8	16	Avg	
• LZ2[i] (and LZ3 curfew)	E_h and E_v @3' AFG	F	5	10	20	Avg	D	3	6	12	Avg	
• LZ1[i] (and LZ2 curfew)	E_h and E_v @3' AFG	E	4	8	16	Avg	C	2	4	8	Avg	
• LZ0 (and LZ1[i] curfew)	E_h and E_v @3' AFG	D	3	6	12	Avg	B	1	2	4	Avg	
• Book Return/Pickup	Presumed under cover											
• General	General lighting should address the area under cover											
• LZ4[i]	E_h and E_v @3' AFG	K	25	50	100	Avg	H	10	20	40	Avg	
• LZ3[i] (and LZ4 curfew)	E_h and E_v @3' AFG	J	20	40	80	Avg	G	7.5	15	30	Avg	
• LZ2[i] (and LZ3 curfew)	E_h and E_v @3' AFG	I	15	30	60	Avg	F	5	10	20	Avg	
• LZ1[i] (and LZ2 curfew)	E_h and E_v @3' AFG	H	10	20	40	Avg	E	4	8	16	Avg	
• LZ1[i] curfew	E_h and E_v @3' AFG	G	7.5	15	30	Avg	D	3	6	12	Avg	
FOOD SERVICE	See 22 | LIGHTING FOR COMMON APPLICATIONS											
IT	See 22 | LIGHTING FOR COMMON APPLICATIONS											
LIBRARY PROPER												
• Audio Listening Rooms	E_h @2' 6" AFF; E_v @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg	
• Book Lending												
• Book Stacks	During hours of operation, vacancy sensors should be used to reduce illuminance values to half the citations here, but not to off.											
• General	E_h @floor of Book Stacks proper	O	100	200	400	Min						
• Shelving												
◦ 1' 0" AFF	E_v @front face of shelving						M	50	100	200	Min	
◦ 2' 6" AFF	E_h and E_v @front face of shelving	P	150	300	600	Avg	O	100	200	400	Avg	

Table 29.2 | Library Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
4:1	2:1				■	
4:1	2:1 (4:1)				■	
3:1	2:1 (4:1)				■	
3:1	2:1 (4:1)				■	
2:1					■	
4:1	2:1				■	
4:1	2:1 (4:1)				■	
3:1	2:1 (4:1)				■	
3:1	2:1 (4:1)				■	
2:1					■	
	2:1		■			■
	2:1		■		■	
4:1	2:1		■		■	
4:1 E_v only	2:1		■	■	■	

Notes for Table 29.2

The table column headings are discussed in detail in 29.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 29.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 29.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 29.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

j. Alternatively, design to specific tasks, if known, from READING AND WRITING.

k. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

l. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

m. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 29.2 | Library Facilities Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
LIBRARY PROPER	(Book Lending continued)											
• Circulation Desk	See LIBRARY PROPER/Book Lending/Lending Desk											
• Compact Book Stacks	During hours of operation, vacancy sensors should be used to reduce illuminance values to half the citations here, but not to off.											
◦ 2' 6" AFF	E_h and E_v @front face of shelving	P	150	300	600	Avg	O	100	200	400	Avg	
• Lending Desk												
◦ Self-service	E_h @2' 6" AFF; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg	
◦ Staffed	E_h @2' 6" AFF; E_v @5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
• Periodicals												
◦ Shelving												
▫ 1' 0" AFF	E_v @front face of shelving						M	50	100	200	Min	
▫ 2' 6" AFF	E_v @front face of shelving						O	100	200	400	Avg	
• Book Drop	E_h @2' 6" AFF; E_v @5' AFF	N	75	150	300	Avg	K	25	50	100	Avg	
• Book Processing	E_h @2' 6" AFF; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg	
• Book Repair and Binding	See SUPPORT SPACES/Staff Workrooms											
• Cafe												
◦ General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg	
◦ Internet Browsing	E_h @2' 6" AFF; E_v @ 4' AFF											
◦ Patrons' Devices	Laptop with CSA/ISO Type I and II negative polarity screens or electronic readers with LCD or LED screens.[j]	N	75	150	300	Avg	K	25	50	100	Avg	
◦ Public Computers	CSA/ISO Type I and II positive polarity screens.[j]	P	150	300	600	Avg	M	50	100	200	Avg	
◦ Reading Hardcopy	E_h @2' 6" AFF; E_v @ 4' AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Computer Center	CSA/ISO Type I and II positive polarity screens.[j] E_h @2' 6"; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Genealogy												
◦ General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg	
◦ Reference Tables	E_h @2' 6" AFF; E_v @ 4' AFF	R	250	500	1000	Avg	M	50	100	200	Avg	
• General	E_h @floor; E_v @ 5' AFF	M	50	100	200	Avg	I	15	30	60	Avg	
• Gift Shop/Library Store	See 34 | LIGHTING FOR RETAIL											
• Information Desk	See TRANSITION SPACES/Lobbies/Information Desk											
• Music Practice Rooms												
◦ General	E_h @2' 6" AFF; E_v @4' AFF	N	75	150	300	Avg	L	37.5	75	150	Avg	
◦ Music Stands	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	R	250	500	1000	Avg	
• Reading Areas	Alternatively, see READING AND WRITING tasks and normalize to illuminance of most important task or most common task											
◦ Arm Chairs	E_h @2' 6" AFF; E_v @ 4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
◦ Grand Reading Room	E_h @2' 6" AFF; E_v @ 4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
◦ Stack Reading Areas	E_h @2' 6" AFF; E_v @ 4' AFF	R	250	500	1000	Avg	M	50	100	200	Avg	
◦ Study Carrels	E_h @2' 6" AFF; E_v @ 4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
◦ Tables and Chairs	E_h @2' 6" AFF; E_v @ 4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	

Table 29.2 | Library Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1		☀			
	2:1		☀	◪		
	2:1		☀	◪		
	2:1		☀	◪		
	2:1		☀	◪		
	2:1		☀			
	2:1		☀			
	3:1		☀			
	2:1		☀	■		
	2:1		☀	◪		
	3:1		☀	◪		
	2:1		☀	◪		
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Notes for Table 29.2

The table column headings are discussed in detail in 29.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 29.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 29.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 29.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◪ signals high likelihood; gray and white ◪ signals moderate likelihood; pale gray and white ◪ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

j. Alternatively, design to specific tasks, if known, from READING AND WRITING.

k. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

l. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

m. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 29.2 | Library Facilities Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
LIBRARY PROPER	(continued)											
• Special Collections	Filter UV and IR from electric lighting and daylighting in Special Collections; During hours of operation, vacancy sensors should be used to switch off lighting.											
• Archival Storage	E_h and E_v @3' AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Conservation	E_h and E_v @3' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
• Rare Books	E_h and E_v @3' AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Reserve Reading	E_h and E_v @3' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
• Teen Services												
• Reading Rooms												
• General	E_h @floor; E_v @ 5' AFF	N	75	150	300	Avg	K	25	50	100	Avg	
• Reading	E_h @2' 6" AFF; E_v @ 4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
• Study Rooms												
• General	E_h @floor; E_v @ 5' AFF	N	75	150	300	Avg	K	25	50	100	Avg	
• Reading	E_h @2' 6"; E_v @ 4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
• Youth Services												
• Reading Rooms												
• General	E_h @floor; E_v @ 5' AFF	N	75	150	300	Avg	K	25	50	100	Avg	
• Reading	E_h @2' 6" AFF; E_v @ 4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
• Story Rooms												
• General	E_h @floor; E_v @ 3' AFF	N	75	150	300	Avg	K	25	50	100	Avg	
• Reading	E_h @floor; E_v @ 2' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
PARKING	See 26 | LIGHTING FOR EXTERIORS											
PEDESTRIAN WAYS	See 26 | LIGHTING FOR EXTERIORS											
READING AND WRITING												
• Computer	See READING AND WRITING/VDT Screen and Keyboard											
• Electronic Readers												
• Electronic Ink Devices	E_h and E_v @height of device	P	150	300	600	Avg	N	75	150	300	Avg	
• LCD or LED Devices	E_h and E_v @height of device	N	75	150	300	Avg	K	25	50	100	Avg	
• Facsimile												
• Analog	E_h @2' 6" AFF; E_v @4' AFF[l]	R	250	500	1000	Avg	M	50	100	200	Avg	
• Digital	E_h @2' 6" AFF; E_v @4' AFF[l]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Handwritten Work	Based on fair-to-good penmanship/hand print on white or canary paper											
• Pencil												
• Graphite/HB	E_h @2' 6" AFF; E_v @4' AFF[l]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Red	E_h @2' 6" AFF; E_v @4' AFF[l]	R	250	500	1000	Avg	M	50	100	200	Avg	
• Ballpoint/Rollerpoint/Felt-tip												
• Black	E_h @2' 6" AFF; E_v @4' AFF[l]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Red, Green, Blue	E_h @2' 6" AFF; E_v @4' AFF[l]	Q	200	400	800	Avg	L	37.5	75	150	Avg	
• Laptop	See READING AND WRITING/VDT Screen and Keyboard											
• Microforms (Projected)		L	37.5	75	150	Avg	I	15	30	60	Avg	

Table 29.2 | Library Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1					
see Table 12.6						
see Table 12.6						
see Table 12.6						
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	2:1				k	k
	2:1				k	k
see Table 12.6					k	k
see Table 12.6					k	k
see Table 12.6					k	k
see Table 12.6					k	k
see Table 12.6					k	k
see Table 12.6					k	k
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Notes for Table 29.2

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b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 29.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

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		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
READING AND WRITING	(continued)										
• Print Media	Digital-printing-press-generated, white paper										
• 6-pt Font											
• Matte paper and ink	E_h @2' 6" AFF; E_v @4' AFF[l]	R	250	500	1000	Avg	L	37.5	75	150	Avg
• Specular paper and ink	E_h @2' 6" AFF; E_v @4' AFF[l]	R	250	500	1000	Avg	L	37.5	75	150	Avg
• 8- and 10-pt Font											
• Matte paper and ink	E_h @2' 6" AFF; E_v @4' AFF[l]	P	150	300	600	Avg	K	25	50	100	Avg
• Specular paper and ink	E_h @2' 6" AFF; E_v @4' AFF[l]	P	150	300	600	Avg	K	25	50	100	Avg
• 12-pt Font											
• Matte paper and ink	E_h @2' 6" AFF; E_v @4' AFF[l]	O	100	200	400	Avg	K	25	50	100	Avg
• Specular paper and ink	E_h @2' 6" AFF; E_v @4' AFF[l]	O	100	200	400	Avg	K	25	50	100	Avg
• VDT Screen and Keyboard											
• CSA/ISO Types I and II	See Figure 12.16 | CSA/ISO Computer Screen Qualities										
• Positive polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[l]	P	150	300	600	Avg	N	75	150	300	Avg
• Negative polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[l]	N	75	150	300	Avg	K	25	50	100	Avg
• CSA/ISO Type III	See Figure 12.16 | CSA/ISO Computer Screen Qualities										
• Positive polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[l]	N	75	150	300	Avg	K	25	50	100	Avg
• Negative polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[l]	L	37.5	75	150	Avg	I	15	30	60	Avg
• White Board											
• Analog or Digital											
• Reading (reference)							N	75	150	300	Avg
• Reading (with presenter)	Presenter at white board						P	150	300	600	Avg
• Xerograph	Copier- and printer-generated on white paper										
• ≥8-pt type, common graphics	Select progressively next-higher letter category of illuminance for each 2-point-type decrease in fonts/graphics)										
• Color											
◦ Analog	E_h @2' 6" AFF; E_v @4' AFF[l]	R	250	500	1000	Avg	M	50	100	200	Avg
◦ Digital	E_h @2' 6" AFF; E_v @4' AFF[l]	P	150	300	600	Avg	L	37.5	75	150	Avg
• Grayscale and/or B+W Print											
◦ Analog	E_h @2' 6" AFF; E_v @4' AFF[l]	P	150	300	600	Avg	L	37.5	75	150	Avg
◦ Digital	E_h @2' 6" AFF; E_v @4' AFF[l]	O	100	200	400	Avg	K	25	50	100	Avg
SUPPORT SPACES											
• Book Truck/Sorting Room	E_h and E_v @2' 6" AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Coat Check	E_h @3' 0"; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Computer Training Center	E_h @2' 6" AFF; E_v @4' 0" AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Copy/Print Rooms											
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Machines	E_h and E_v @3' 6" AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Janitor's Closet	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Kitchenette	E_h and E_v @prep surfaces	R	250	500	1000	Avg	L	37.5	75	150	Avg

Table 29.2 | Library Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
see Table 12.6					[k]	[k]
see Table 12.6					[k]	[k]
see Table 12.6					[k]	[k]
see Table 12.6					[k]	[k]
see Table 12.6					[k]	[k]
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see Table 12.6					[k]	[k]
see Table 12.6					[k]	[k]
3:1						
3:1						
see Table 12.6					[k]	[k]
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3:1						
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3:1						
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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
SUPPORT SPACES	(continued)										
• Receiving/Shipping											
• Immediate Exterior[i]	Width of dock door; E_h @grade; E_v @5' AFG in direction of ingress or security camera										
• LZ4[i]		F	5	10	20	Avg	D	3	6	12	Avg
• LZ3[i] (and LZ4 curfew)		E	4	8	16	Avg	C	2	4	8	Avg
• LZ2[i] (and LZ3 curfew)		D	3	6	12	Avg	B	1	2	4	Avg
• LZ1[i] (and LZ2 curfew)		C	2	4	8	Avg	A	0.5	1	2	Avg
• LZ0[i] (and LZ1 curfew)		B	1	2	4	Avg	-	0	0	0	
• Interior											
• Dock											
◦ General	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
◦ Supplemental	Use articulated-arm luminaire to direct additional light to interior of truck body										
• Receiving/Shipping Area	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Staff-dedicated Areas											
• Lounges	Alternatively for the reading areas, see READING AND WRITING tasks and normalize to illuminance of most important task or most common task										
• General	E_h and E_v @2' 6" at sitting areas	N	75	150	300	Avg	K	25	50	100	Avg
Reading	E_h and E_v @2' 6" at sitting areas	R	250	500	1000	Avg	O	100	200	400	Avg
• Workrooms											
• General	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	O	100	200	400	Avg
• Task Areas	E_h @2' 6"; E_v @4' 0" AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Book Repair and Binding	E_h @2' 6"; E_v @3' 0" AFF	T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Stockrooms	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Storage											
• Food	See 22 | LIGHTING FOR COMMON APPLICATIONS										
• Frequent Use	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Infrequent Use	E_h @floor; E_v @4' AFF	K	25	50	100	Avg	H	10	20	40	Avg
TOILETS/ LOCKER ROOMS	See 22 | LIGHTING FOR COMMON APPLICATIONS										
TRANSITION SPACES											
• Circulation Corridors	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• Back-of-house											
• Adjacency Passageways	E_h @floor; E_v @5' AFF	Avg ≥0.3 times task E_h of adjacent space or as cameras require, but with min ≥10 lx					Avg ≥0.3 times task E_v of adjacent space or as cameras require				
• Independent Passageways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Public											
• Adjacency Passageways	E_h @floor; E_v @5' AFF	Avg ≥0.2 times task E_h of adjacent space or as cameras require, but with min ≥10 lx					Avg ≥0.2 times task E_v of adjacent space or as cameras require				
• Independent Passageways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg

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4:1	2:1					
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j. Alternatively, design to specific tasks, if known, from READING AND WRITING.

k. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

l. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

m. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 29.2 | Library Facilities Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
TRANSITION SPACES	(continued)										
• Elevators											
• Freight											
• Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Threshold											
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Passenger											
• Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Threshold											
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Entries	See 22 | LIGHTING FOR COMMON APPLICATIONS/BUILDING ENTRIES										
• Escalators/Moving Walkways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Lobbies											
• Circulation, Elevator Lobbies	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• General											
• At building entries	Close proximity to exterior. Lighting should assist with adaptation when passing to/from exterior..										
◦ Day	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
◦ Night	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Distant from entries	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Information Desk	E_h @2' 6"; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Security											
• Desk top	E_h @2' 6"; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Screening	E_h @2' 6"; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Lounges											
• Clubs and Game Rooms											
• General	E_h and E_v @2' 6"	J	20	40	80	Avg	G	7.5	15	30	Avg
• Table games	E_h @table; E_v @5' AFF	P	150	300	600	Avg	K	25	50	100	Avg
• Video games	E_h @game controls; E_v @4' AFF	H	10	20	40	Avg	C	2	4	8	Avg
• Stairs	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• High Activity[m]	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Live-surveillance	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Typical	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1					
	2:1					
	2:1					
	2:1					
	2:1					
	2:1					
	2:1					
	2:1					
	2:1					
	2:1					
	2:1					
	2:1					
	2:1					
	4:1					
see Table 12.6						
see Table 12.6						
	2:1					
	2:1					
	2:1					

Notes for Table 29.2

The table column headings are discussed in detail in 29.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 29.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 29.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 29.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

j. Alternatively, design to specific tasks, if known, from READING AND WRITING.

k. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

l. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

m. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 29.3 | SI Dimensional Conversions

US Customary	SI
General	**Hard Conversion**
inches	mm [inches × 25.40]
feet	m [feet × 0.30]
Specific	**Convenient Conversions[a]**
2'	610 mm or 0.6 m
2' 6"	760 mm or 0.75 m
3'	915 mm or 0.9 m
3' 6"	1065 mm or 1.1 m
4'	1220 mm or 1.2 m
5'	1525 mm or 1.5 m

a. Hard conversions rounded for reporting convenience. Not to be confused with metric-sized luminaires or other building materials. Not for precision construction.

in the vicinity of exhibits. This may require careful lamp selection or selecting luminaires with filter options. Exhibits and their scale relate to the size of the library and community interests. Figure 29.2 illustrates a relatively large temporary exhibit.

29.2.8 Exteriors

Exterior lighting beyond building entries, including site paths, parking, facades, landscape, and flags, are addressed in 26 | LIGHTING FOR EXTERIORS. Also see Table 15.6 | Nighttime Operational Strategies for Improved Outdoor Environmental Regard. The program should outline the library site, intended functions, and hours of operation. This information, the anticipated levels of activity, and outdoor nighttime lighting zones will be used to determine appropriate illuminance criteria for the various applications.

Nighttime book drop or book pickup and drop facilities deserve attention. Illuminance criteria for these are outlined in Table 29.2. Lighting for book bins of either the drive-up or walk-up variety should encompass the book bin and a margin extending 1' 6" beyond all exposed sides of the bins. Lighting should be positioned to avoid strong shadows on the drop aperture or drop-door handle as a vehicle or pedestrian approaches. Bins should be sufficiently freestanding from obstructions or plants to avoid shadows or areas of cover for potential perpetrators. If bins are screened in any way, lighting should be developed to reduce areas of cover and minimize shadowing. This does not require and should not result in high wattage, direct-beam spot lights or flood lights nor result in illuminances greater than those cited in Table 29.2. Such techniques would compound the problem and introduce adaptation issues experienced when viewing from bright to shadowed areas.

29.2.9 Food Service

Food service lighting is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

29.2.10 IT

Lighting for IT facilities is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

29.2.11 Library Proper

Applications and tasks which relate most directly to public use of the library are outlined as those of Library Proper in Table 29.2. Horizontal and vertical illuminances and

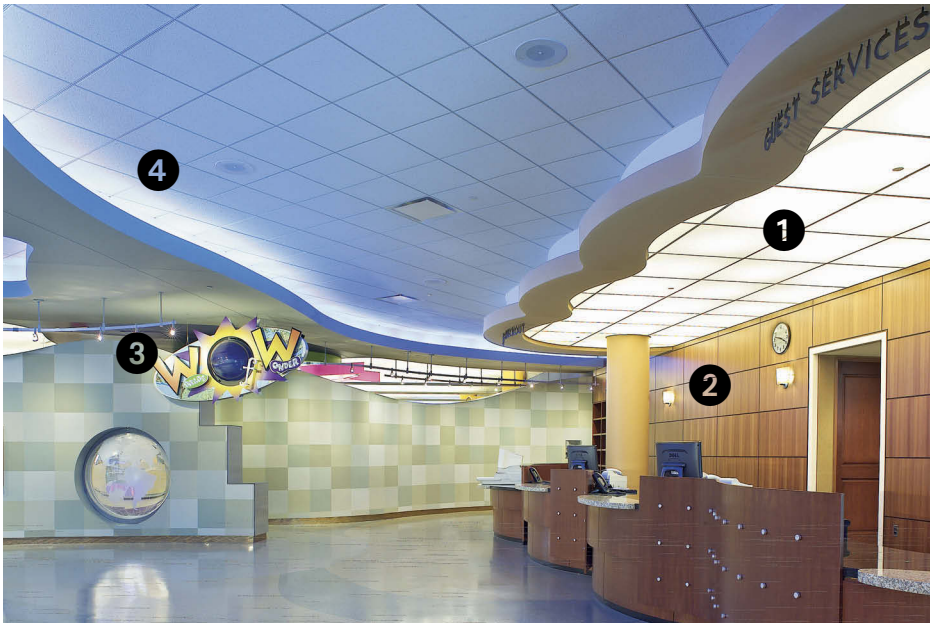


Figure 29.3 | Service Desks
At this relatively large public library a long desk serves two functions—book checkout at the far end and guest services at the near end. 40 W long CFLs are used above the luminous ceiling ❶. Wall sconces are lamped with CFLs ❷. Super graphics are lighted with halogenIR$_{LV}$ lamps ❸. 40 W, 4100 K, long CFLs with blue gels in the cove illuminate the ceiling ❹. The cove and luminous ceiling combine to meet the general and task illuminance criteria. The sconces are decorative. The "WOW" graphic lighting was designed to meet the "moderate attraction" criterion in Table 15.2. For a sign anticipated to have a reflectance >50%, the illuminance on "WOW" was designed to meet a focal-to-task illuminance ratio of 5-to-1. The lobby floor illuminance was considered that of the "task".
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respective uniformities should all be addressed. Vertical illuminances assist with various task orientations as patrons adjust positions from time to time. Vertical illuminances also assist with facial recognition. Cited uniformities are used to establish baseline conditions while accenting will introduce visual interest and spatial contrast.

Figure 29.3 illustrates lighting at a desk serving dual functions: guest services and checkout. The luminous ceiling illuminates the desk top, the back wall, and faces in the vicinity. The luminance of the backlighted panels attracts attention. Figure 29.4 illustrates lighting of a feature within youth services. An adult group reading area is shown in Figure 29.5.

In addition to task visibility and facilitating visual performance, library lighting influences attention and the desire to remain engaged. Define and address all anticipated visual tasks while recognizing the variability of task orientation, from horizontal to near-vertical, and task types including hardcopy, electronic books, and computers. Although the effects of task lighting should not be the focus of attention, task lighting should help the patrons maintain focus and attention on specific task areas as the library program defines.

Daylighting success in libraries is facilitated when there is seamless operation of electric lighting and daylighting mechanisms, such as automated continuous dimming and shade control respectively. Functional variation, including room-darkening for those spaces using AV or where dimness is functionally desirable, must be easily available to the occupants or staff. These aspects, several of which are excerpted from 24.2.5 Classrooms, deserve particular attention:

1. Automate dimming preferably with continuous-dimming functionality for least visual disruption
2. Great care in design of any east- and west-elevation daylighting relative to glare
3. Automate window treatment with quiet and slow continuous-roller-operation with long change cycles
4. Avoid daylight designs requiring near-continual/complete shade deployment
5. Arrange primary reading positions or display/presentation positions perpendicular to daylight apertures
6. Maintain some degree of exterior view
7. Perform daylight simulations to limit areas of overlighting and assist with glazing transmittance and shading treatment selections
8. Eliminate direct solar penetration in all but transitional circulation spaces distant from reading areas
9. Use matte high reflectance architectural finishes to best distribute and diffuse daylight
10. Use matte high reflectance table finishes in reading areas

Automated control systems are key to achieving daylight integration. Where fluorescent luminaires are extinguished on a frequent basis, such as 3 times or more in a typical work day for reasons of daylighting or occupancy-sensing, program start ballasts minimize premature lamp failures. Consult ballast, lamp, and controls vendors on these aspects prior to finalizing designs. See 7.3.6.3 Lamp Life and Failure Mechanism. Figures 29.6 and 29.7 illustrate some reading room electric lighting and daylighting techniques.

Larger libraries contain a number of collections of such size that it is not practical to combine these into a single area. Adult, youth, and teen services are typically distinguished. Figure 29.8 illustrates a youth services area in a library. For visual interest in situations where these collections themselves are rather large, architectural planes, details, and finishes are varied to some degree within each collection. Lighting within each collection should also follow this approach. The challenge is to limit wild fluctuations in aesthetic style of



Figure 29.4 | Features
Colorful playful areas are lighted to encourage reading and play. HalogenIR_{LV} lamps of 3000 K and 100 CRI on flexible track rail highlight the patchwork wall and signage. The lime-green ceiling corkscrew detail is lighted with 3000 K and 82 CRI neon tubing to conform to the detail shape while exhibiting low-glare when directly viewed. 40 W, 4100 K long CFLs with blue gels uplight the lay-in ceiling from a cove detail.
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Figure 29.5 | Reading Areas
Lap-height illuminances are achieved with ambient lighting in the perimeter coves and task lighting from the overhead chandelier. Coves are lamped with 28 W T5 lamps of 3500 K and 85 CRI and chandeliers with six 26 W CFL lamps of 2700 K CCT and 82 CRI. An adjacent background wall is accented with 20 W PAR20 CMH lamps of 3000 K and 81 CRI.

Lamp CCT selection should be deliberate. On many projects, there is rationale to select one common CCT for all lamps. On some projects, there may be a rationale for employing different CCTs. In this setting, lighting considered "background" architectural (cove and recessed luminaires) were assigned a neutral CCT of 3500 K. "Decorative" architectural lighting, that which is physically closer to patrons, were assigned a very warm incandescent-like CCT of 2700 K for a more home-like and familiar look. Accent lighting employing CMH lamps is only available in 3000 K or 4000 K. To better blend with the decorative architectural lighting, the 3000 K CCT was selected. Since exact CCT matches are impractical, then CCTs across different lamp types that are within 200 K or 300 K of each other are considered "matching". However, when seen side-by-side, and also depending on CRI (lamp CRIs should also be matched), few of these are very good matches. Such are the inequities between technologies and manufacturers' processes.

The lighting from the chandelier and coves provides both horizontal and vertical illuminances suitable for reading 8- and 10-pt font printed material or electronic readers and also for assessing facial detail without glare.

» Image ©Balthazar Korab Photography Ltd.

the luminaires and quality of light within a collection. These are eye-of-the-designer issues that are vetted with the design team, by reviewing luminaire samples or mockups, and by experiencing and evaluating existing settings.

Figure 29.9 illustrates a story room where lighting effects are used to engage patrons and where lighting controls are used to establish scenes for personal reading time or story time.

For rare book and history collections, care must be taken on UV and IR exposure and time duration exposure to visible light. See 21 | LIGHTING FOR ART.

Perhaps the most significant challenge in lighting libraries centers around reading media. Print materials, electronic readers, and computers are all readily available. Designing to one media or to a single-value illuminance will likely yield unsatisfactory results. Programming may address these various media (and others as new technologies evolve or are developed) through variety of space types and variety of areas within space types. An "e-reader lounge" might be programmed into the Teen Reading Room, for example. The designer must review the available technologies and determine the most common e-reader screen type or, alternatively, design to the worst-case screen type. Flexibility through controls may be appropriate, though issues of access to the controls and how the change from one setting to another is determined may require uncomfortable or complicated decisions. Establishing multiple e-reader lounges to accommodate LCD and LED readers (backlighted) as one category and to accommodate electronic-ink readers (front-lighted) as another category combined with zoned area controls to allow long-term planning changes may be most appropriate.

Computer rooms, also known as labs, centers, or lounges, must be designed to address the likely computer task and, where appropriate, the related paperwork, such as notetaking or reading of supplementary print materials. Computers might be any one of several types cited in Table 29.2 or even newer, evolved technologies. Programming these possibilities is important to developing a lighting design tailored to the intended uses. Controls and the use of task and ambient lighting systems may be most effective in achieving satisfactory results and allowing for future technology advancements. Figure 29.10 illustrates a library computer center. A library teen lounge with computers is illustrated in Figure 29.11.

Just like online searches and retrievals can be sticking points when using the Internet, the storage and retrieval of books can be a sticking point for patrons in the process of visiting the library. The more convenient the access to these stored books and the easier to survey and identify titles, the greater the likelihood of exploration of the stacks. For those with a distinct title in mind, lighting can greatly limit time-to-retrieval. Figure 29.12 illustrates a stack lighting example.

29.2.12 Parking

Lighting for parking facilities is discussed in 26 | LIGHTING FOR EXTERIORS.

29.2.13 Pedestrian Ways

Lighting for pedestrian ways is discussed in 26 | LIGHTING FOR EXTERIORS.

29.2.14 Reading and Writing

Reading and writing tasks occur within various applications. Familiarity with these tasks will aid with assessment of specific application tasks and activities. This may result in the recommendation of illuminance criteria different than that proposed in Table 29.2 for a particular application. For example, if the reading tasks in LIBRARY PROPER/Teen Services/Reading Rooms are anticipated to be electronic readers, and especially of the LCD or LED variety identified in READING AND WRITING/Electronic Readers, then the illuminances at reading task locations should correspond to those cited for electronic

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readers. Otherwise, the task area will likely be overlighted and uncomfortable. Alternatively, if reading rooms or study rooms have a need to accommodate both hardcopy reading tasks and electronic readers, lighting and controls should be designed accordingly.

Glare, especially in reading areas, is unacceptable. In libraries, lamps should be concealed behind lensing or within indirect luminaires or carefully shielded with louvers or baffles or of low wattage and relatively large area and difficult to see; table luminaire size and geometry can limit seated patrons' sight lines to lamps. An exposed low wattage CFL or linear fluorescent lamp is typically more tolerable to the eye when seen only periodically or intermittently than is a LED lamp of equivalent output. CMH and LED luminaires intended for long throws and strong effects should employ reflectors and lenses to control light. Relatively deep ceiling trim cones can be effective for recessed CMH and LED equipment. Surface mounted CMH and LED accent luminaires, such as monopoints or trackheads, should be fitted with snoots, barn doors, or louvers where they are in close proximity to and aimed in the general direction of readers. The conundrum is that luminaires with glare control are less efficient than those with the brute force of bare or nearly-bare lamping. A setting will be more sustainable if users actually want to and do use it than if it is uncomfortable and intolerable, but deemed "efficient." Glare aspects are best judged through sample reviews and mockups and experience within various settings.

29.2.15 Support Spaces

These relatively back-of-house citations are self-explanatory. For dock areas, outdoor nighttime lighting zones determine which illuminance criteria are appropriate. In any event, these are applied immediately at the exterior of the dock overhead door. Lighting equipment should direct all light downward (see Figure 22.4). Lighting the outdoor parking or dock staging area should conform to criteria identified in 26 | LIGHTING FOR EXTERIORS.

29.2.16 Toilets/Locker Rooms

Lighting for toilets and locker rooms is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. Addressing the plumbing fixtures (for example, toilets, urinals, vanities) as recommended works in conjunction with low-level general lighting throughout the toilet rooms to provide sufficient light where needed without overlighting the entire toilet room.

29.2.17 Transition Spaces

Most of these spaces are self-explanatory, but one deserves discussion. Adjacency passageways refer to a condition where circulation areas are encompassed by larger areas. Given their potential adjacency to the open and visually accessible reading areas, their illuminances, confined to the passageway proper, should be ratios of the nearby task illuminances. This avoids annoying contrasts within the work setting.

29.3 Illuminance Criteria

Illuminance criteria, when fully deployed, are a robust set of quantitative values that influence visibility, visual performance, and visual comfort and attention. Short-circuiting the criteria selection or designing to a single criterion value, such as horizontal illuminance, to address worst-case tasks will surely result in dissatisfaction. Even if clients accept the visual results, not getting the most from the energy expended or, worse, energy waste is a likely result. Following are notes related to various topics outlined in Table 29.2.

29.3.1 Applications and Tasks

Applications and tasks encountered on any given project may be different from those identified in Table 29.2 and may warrant different illuminance criteria. Cross-referencing closely-associated applications or tasks is appropriate. Sometimes naming trends or

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Figure 29.6 | Reading Rooms
Ambient lighting requirements can be partially or fully met by daylighting during daytime hours. Orientation and glazing selection are critical to success. Luminaires at reading tables can provide task lighting. Local switching at task luminaires or occupancy dimming or switching can further reduce energy use. However, the design of these controls must be evaluated for potential disruption and ease-of-use for patrons. Occupancy sensor coverages must be carefully tuned to table sizes, number of patrons per table, and spacings between tables. Mockups are best before finalizing designs of these approaches.
» Image ©Art on File/Corbis

conventions for space types or functions change to conform to current practice, client programming, or architectural conventions, but the actual activities and tasks remain the same and this cross-referencing works. Failing this technique, reviewing the list in Table 29.2 may be in order to determine if any applications or tasks exhibit a similar visual-component to the unique applications or tasks. Otherwise, reviewing 4.12 An Illuminance Determination System and Table 4.1 is necessary to establish a task category based on the task characteristics or visual performance descriptions most closely associated with the unique applications or tasks. These exercises as well as any deviations from recommendations the designer intends to make should be carefully documented for the record.

29.3.2 Notes

The notes in Table 29.2 may refer to other task headings in the table or to other handbook chapters as appropriate. Where some degree of clarification is warranted, notes are made.

29.3.3 Recommended Maintained Illuminance Targets

Values cited are maintained on the area of coverage for the task under consideration. Illuminance is additive. Where practical and without negatively affecting the intended application of light, target values are achieved with any combination of daylighting and/or electric lighting in whatever mix of ambient, task, and accent lighting is deemed appropriate to meet these and the other lighting goals established during design. See 12 | COMPONENTS OF LIGHTING DESIGN and see 10.7.1 Light Loss Factors.

With respect to light loss factors, account for anticipated losses through the point in time at which group relamping and cleaning should occur. Group relamping and cleaning should be standard practice, though these need not occur at the same frequency. Periodic cleaning and group relamping essentially maintain the illuminance at criteria and make the most efficient use of the installed equipment. For purposes of sustainability, cleaning and group relamping can no longer be presumed to be infrequent or unlikely. Maintenance procedures must be part of the design discussions with the client. See the IES document IESNA/NALMCO RP-36 Recommended Practice for Planned Indoor Lighting Maintenance for additional information. Where maintenance is deferred or practiced poorly or not at all, the actual illuminance values will fall below criteria targets. This is inefficient, unsustainable, and may be unsafe while adversely affecting users' quality of life or work.

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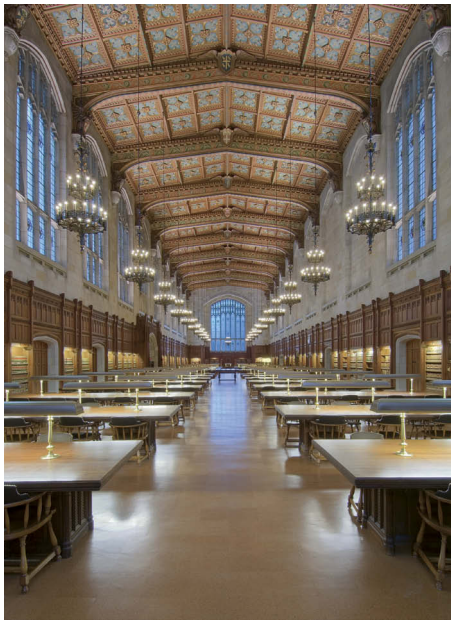


Figure 29.7 | Historic Reading Rooms
After 80 years of dirt build-up, the ceiling in this reading room provided little reflectance and created a high-contrast interior with luminance imbalance (far left). White paper and CSA/ISO positive-polarity laptop tasks were too bright relative to the architectural surfaces. Daylight no longer met the expected norms for lighting when reading and writing. A lighting renovation was undertaken and the ceiling cleaned, the floor replaced, and the tables refinished. Surface reflectances improved significantly. Table lights were retrofitted with 28 W T5 lamps of 3000 K and 85 CRI; stack lights retrofitted with 18 W long CFLs of 3000 K and 82 CRI. New luminaires lamped with 39 W PAR20 CMH lamps of 3000 K and 86 CRI were added at window sills to uplight the cleaned ceiling and better balance luminances. Uplights and table task lights are step-switched in accordance with daylight availability. Also see Figure 21.7.
» Images ©Curt Clayton

Ratcheting initial illuminances higher is poor practice and not recommended. Maintenance procedures may be especially problematic with LEDs where promises of extraordinarily long life may be offered, but usually with the caveat that lamp lumen depreciation (LLD) at that rated life is 70% or perhaps even as low as 50% of initial rating. If replacement cycles are presumed to be rated life, then LLD alone must be 0.7 or 0.5 or whatever lumen rating is certified by the LED vendor. See 13.3 Life and Lumen Maintenance.

Targets cited are consensus and recommended for respective functional activity. For some applications, IES recommendations are within 10% of code requirements. This apparently is an artifact of metrication. Footcandle conversions of any values cited in Table 29.2 should be made at 1 fc to 10 lx. This soft conversion avoids a redundant diminishing of illuminance values after multiple citations and conversions over time. This also eliminates a false sense of accuracy advanced by an ever-increasing number of decimal places and a false sense of urgency advanced by eccentric fractional values introduced by hard conversions. Nevertheless, a lighting design must meet code and the mechanics of which must be coordinated amongst the design team. The IES recommendations should not, do not, and cannot reflect all of the various code requirements in force in all jurisdictions at any given time.

Targets are intended to apply to the dominant plane of the task, typically, but not always, horizontal or vertical. In some situations, illuminance criteria are cited for one plane, such as the vertical plane for lighting white boards, while the other plane is blank. The blank signifies that illuminance on that plane is unimportant and may be a consequence of the illuminance of other tasks within the vicinity or by whatever illuminance results from meeting the target illuminance for the prescribed plane of interest.

In some situations, no light is anticipated on at least one plane of a task. A 0 indicates no light or zero light is recommended for the task or application.

29.3.3.1 Target Planes

Many, though certainly not all, tasks are performed with the task in roughly a horizontal orientation or vertical orientation. A dominant orientation must be assigned and the illuminance target determined accordingly. There may be situations where the IES recommended target relating to the typical planar mode of a task must be applied to a different plane.

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Figure 29.8 | Youth Services
Architectural variety is used within one area to maintain visual interest and help define specific activity zones. Lighting techniques vary accordingly, however, the overall visual effect and illuminances maintain an aesthetic consistency. In this youth services area, the main information and circulation desk is featured with an overhead architectural chandelier of colorful graphics panels. These are lighted from above with 100 W PAR38 CMH lamps of 3000 K and 81 CRI and are fitted with snoots and neutral density filters to control light spill and intensity. The graphic art panels act to limit direct view to most of these lamps. These CMH accents also produce a significant proportion of the task lighting at the desk area.
» Image ©Balthazar Korab Photography Ltd.



Figure 29.9 | Story Rooms
Art accent lighting from a 70 W CMH-lamped ellipsoidal theatrical highlights the astronaut model in this story room. 39 W PAR30 CMH downlights on several control zones allow for varying illuminances at the floor for story-telling or personal reading. Colored LED downlights and in-floor uplights are used for visual interest.
» Image ©2003 Gene Meadows

Nearly all tasks are expected to have both a horizontal illuminance component (E_h) and a vertical illuminance component (E_v). This allows some degree of task flexibility for off-plane viewing and accommodates various aspects of the task. In some applications, like youth services (Table 29.2 LIBRARY PROPER/Youth Services/Reading Rooms), general horizontal illuminance is intended for application at floor plane and general vertical illuminance is intended for application at 5' AFF—which is roughly face height for an adult. Although facial recognition and discrimination of an adult's facial features are important for a child, the designer and client may determine that facial recognition and discrimination by children of other children or by adults of children are a better priority. In which case general vertical illuminance at 3' AFF is appropriate. A similar assessment of criteria at reading tables is in order. Are table tops at 2' 6" AFF? Are seated face heights at 4' AFF?

For planes related to vertical illuminance targets, some guidance is indicated under "Notes." However, the designer may elect to use alternate or multiple vertical planes. In some situations the vertical planes could be oriented a number of directions and the designer must determine which are most appropriate for the situation.

29.3.3.2 Visual Ages of Observers

Ages of observers must be deliberated with care in libraries. A sense of comfort and place as well as appropriate energy use can only be achieved if illuminance levels are targeted for the intended audience. Illuminance criteria are presented based on age groupings associated with at least half the observers in a particular application. The designer is always at liberty to reselect criteria based on her own experience or on client direction. In libraries, collections are typically categorized by age group. Arguably, lighting should then be developed specific to the age group targeted within each collection. An item which must be resolved by the designer and client is which illuminance age grouping to use for youth services and teen services. It might be argued that although more than half the observers are under 25 years of age, those in charge of overseeing these areas may be in the 25-to-65-year-old-range. However, unless full-time live surveillance of the areas is deemed necessary or these areas are also to be available to older observers, it is unlikely illuminances must cater to the older category at all task locations. Where older observers are stationed, however, such as at information or circulation desks, illuminance criteria should be based on the anticipated age group of at least half of those older observers. Where age group-

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ings conflict, such as might happen with the use of various conference rooms or computer training sessions, lighting controls allow for appropriate and efficient lighting to address several age groups providing, of course, the room function and time of use are coordinated by age group.

In any event, implications to energy use are significant. This aspect of visual ages should be resolved during programming with the client. It may be determined that illuminance criteria for an age group other than that representing the majority of the intended observers is appropriate. However, this may result in overlighting, underlighting, harsh lighting, visual displeasure, or visual discomfort for many of the observers. See 12.5.5 Illuminance and 4.12 An Illuminance Determination System for additional information and guidance.

29.3.3.3 Illuminance Categories

Illuminance categories are designated by letters A through Y. These are shown in Table 29.2 for more convenient reference to Table 4.1 | Recommended Illuminance Targets should the designer wish to explore other criteria targets or if applications or tasks on a specific project are not readily correlated to the table citations.

29.3.3.4 Gauge

The common gauge for determining illuminance target compliance is cited for each application. All gauges presume that point-by-point techniques are used for predictive calculations and presume that uniformity criteria are closely monitored. Where an average illuminance value over the area of coverage can satisfy target compliance, "Avg" is cited. In applications or tasks where a minimum or maximum target is necessary, the gauge for compliance is "Min" or "Max" respectively.

The designer may elect to use other methods to evaluate target compliance, such as criterion rating (CR) or coefficient of variation (C_v). See 4.12.4.5 Tasks at Uncertain Locations Over a Large Area.

In any event, once illuminance targets and uniformities are established, then any calculated deviation from them should be limited. Standard engineering allowance of ±10% might be acceptable for targets gauged as average unless contractual or code obligations demand otherwise. Minima and maxima must be achieved as intended.

Designs should be adjusted until predictions are within allowance for averages and meet minima and maxima. For additional information, see 4.12.4.1 Recommended Illuminances at Design Time, 4.12.5 Illuminance Ratios, 9.15.1.1 Average Illuminance, and 10.8 Assessing Computed Results.

29.3.4 Uniformity Targets

Illuminance uniformity targets work in conjunction with luminance uniformities and surface reflectances all of which must be addressed as part of the design to avoid visual discomfort, glare, and strain. Uniformity ratios are targets that define the widest recommended ranges. In many situations, uniformity ratio criteria are those between average values of an array of points and the minimum value in the same array of points. Uniformity targets apply to both horizontal and vertical illuminances over the area of coverage. Where horizontal uniformity criterion is different from vertical uniformity criterion, two ratios are reported with the first value for horizontal illuminance (E_h). In some situations, notably those with regard to exterior illuminances, two uniformity values are cited. The first value addresses the primary cited application or task. The parenthetical value references the parenthetical application or task, such as a curfew situation associated with nighttime outdoor lighting.

Generally the more important speed and accuracy and the more demanding the visual task, the tighter the ratio.

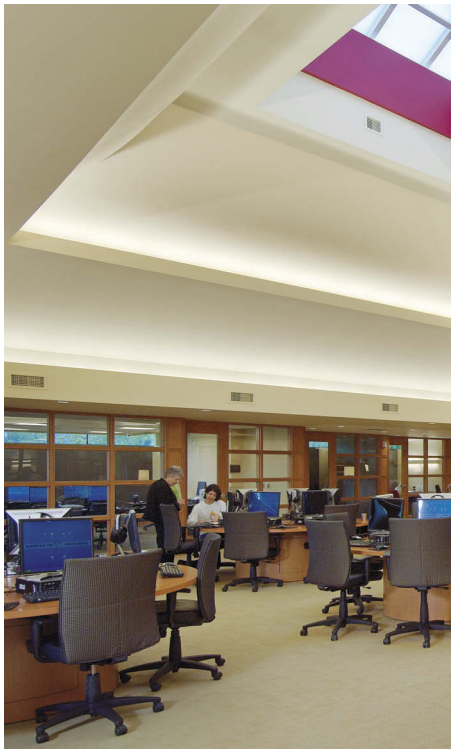


Figure 29.10 | Computer Center
Large, flat-screen monitors exhibiting CSA/ISO Type I finishes are available in this library computer center. Internet content is streamed in its native positive- or negative-contrast form. The electric-light coves splay to the relatively small skylight kept purposely somewhat out of direct field of view.
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Figure 29.11 | Teen Lounge
This teen lounge exhibits low general lighting (see Table 31.2 TRANSITION SPACES/ Lounges/Clubs and Game Rooms) and low surface reflectances for a setting conducive to web surfing and table games. Gelled fluorescent lamps in coves indirectly light a lay-in ceiling which is above a secondary ceiling plane of open mesh metal panels.

General lighting of the floor and task lighting at table height is accomplished with 39 W PAR30 CMH flood-lamp downlights above the metal mesh ceiling plane. These provide a pattern of light and dark areas.

Lighting from 70 W CMH ellipsoidal framing projectors fitted with pattern gobos create the luminous pattern effects on the foreground floor. These were not included as part of the design to meet illuminance criteria, but contribute significantly in defining place and, therefore, desirability to users.

» Image ©2003 Gene Meadows

IESH/10e CSA/ISO

> 12.5 Task Factors
- for information on CSA/ISO computer screen qualities

29.3.4.1 Maximum-to-average

This is the recommended ratio of maximum illuminance to the average illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations sensitive to even a relatively small degree of overlighting.

29.3.4.2 Average-to-minimum

This is the recommended ratio of average illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where illuminance too far below average conditions is noticeable and detrimental to task performance or inconsistent with normal expectations.

29.3.4.3 Maximum-to-minimum

This is the recommended ratio of maximum illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where too much variation in illuminance is considered undesirable and untenable from a performance or safety perspective.

29.3.5 Daylighting Advancement

Generally, design strategies should embrace any combination of daylighting and electric lighting to achieve target values during daylight hours. The preference is for daylighting to provide all or most of the recommended illuminance presuming that all aspects of daylighting are properly addressed. A sunburst icon depicts those applications and tasks where daylighting is considered a strategic candidate. Use photocells and stepped-dimming or continuous dimming to reduce or eliminate electric lighting during daylight hours. See 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Even for those applications where daylighting is not traditionally a strategic candidate, it may be determined that very careful and coordinated design will offer great sustainability opportunities along with positive influences associated with daylight and views.

29.3.6 Veiling Reflections

Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper or, worse, both, are prone to veiling reflections. The likelihood of particular applications and tasks predisposed to veiling reflections is indicated by a "reflected light" icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood. Veiling reflections are minimized by controlling the overall amount and direction of light with respect to the task locations and orientations. Alternatively, tasks sensitive to veiling reflections can be screened or isolated. Effective strategies include employing indirect soft, diffuse electric lighting or direct electric lighting with multiple low-output luminaires, or positioning tasks and luminaires and luminance patterns to avoid harsh reflections from tasks. Addressing luminance recommendations (see Table 12.4 | Default Luminance and Luminaire Intensity Recommendations for VDT Applications) minimizes veiling reflections. Changing the task will reduce or eliminate veiling reflections, such as use of CSA/ISO Type I or II computer screens and matte paper versus their specular counterparts.

29.3.7 Defining Areas of Coverage

In addition to establishing planes of task orientation, the areas of coverage to which targets apply must be determined. Typical areas of task illuminance coverage are identified here, but these may not be appropriate to specific project situations. One area of coverage is "task proper or task area." Here, the illuminance criteria are applied to the task itself or to a relatively small area to which the task is confined. See 12.5.5.1 Tasks and Applications and Figure 12.22 | Task Coverage Example. In some situations, such as accenting, the "task" area may consist of the entire wall when "feature wall" or "perimeter" accenting is desired. It is important to remember that illuminance is additive, that is, task illuminance can be achieved with some combination of ambient lighting, task lighting, and/or

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Figure 29.12 | Stacks
Stack illuminance criteria outlined in Table 29.2 under LIBRARY PROPER/Book Circulation/Conventional Book Stacks are demanding. This assures sufficient illuminance across the length and height of the stack face for reading of spines and, if pulled from the shelf, for reading of cover, flap, or body text excerpts. Light-toned floors help by reflecting light to the lower shelves. Stack lights can be continuously dimmed (preferred) or step-dimmed during times of vacancy. The design of these control techniques must account for the annoyance factor to nearby or even somewhat distant readers with peripheral view of these areas. This may determine if continuous dimming is used, the duration of dimming cycles (which may be different on the ramp-to-dim scene from the ramp-to-bright scene), and the total dimmed illuminance level selected.

The relatively dark ceiling shown here (not normally desired for efficient light distribution) helps define the stacks as focal area. If the book spines were primarily white, the ceiling would then need to be white for balance. In this situation, some ambient illuminance is generated with the cove lighting and the wood ceiling, but this is proportionally small. The ceiling cove serves the purpose of defining the background architectural planes and establishing some background luminance. The stack task lighting is accomplished with totally-direct luminaires mounted at the top of the stacks—the wood ceiling plane has little to do with the efficiency of the stack lighting.
» Image www.jmaconochie.com

accent lighting, providing that the total illuminance on the task proper or task area meets the illuminance criteria outlined in Table 29.2.

Another area of coverage is "room or designated area." In this situation, illuminance criteria are applied to the room or an area of fairly substantive size representing the zone in which the applications and tasks are expected to occur. The designated area is typically established by the furniture layout, for example, or might be established by the design team or client. The area-of-coverage citations in Table 29.2 are based on traditional notions. So, for example, it may be determined that a "task proper or task area" coverage would result in some amount of LPD reduction when compared to "room or designated area" coverage. If the task can be confined to one area rather then multiple areas, if the room or area in which the task is located is itself relatively small, such as a single-occupant office, and if the other design goals and criteria outlined in 12 | COMPONENTS OF LIGHTING DESIGN are addressed, then this strategy of redefining area of coverage has merit.

An assessment and determination must be made on which area of coverage best satisfies the lighting goals on a particular project.

29.4 Designing

Information provided here is specific to library facilities and should be used as part of the design and documentation processes outlined in Chapters 12, 15, and 20. Equipment selection and location strategies may need to address the possibility of lighting equipment abuse. For outdoor applications, lamps and ballasts, transformers, and drivers must be selected for ambient temperature conditions, some of which are extremely hot and others extremely cold. See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY for additional information on respective aspects. Addressing all code requirements is a must. Energy efficient and sustainable practices are an integral part of all IES recommendations. Key design tenets include, but are not limited to:

- designing for the satisfaction of the observers intended to use the project
- using baseline reflectances of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively) in interior production and work-oriented spaces

IESH/10e Economics Resources

> 15.3.3 Budgets
  - for more on budgets and value engineering

> 18 | ECONOMICS
  - for more on estimating costs
  - for more on life cycle costs
  - for more on paybacks and rates of return

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IESH/10e Energy Efficiency Resources

> 17.2 New Construction
- for more on designing for daylighting
- for more on electric lighting equipment
- for more on lighting controls

> 17.4 Lighting Codes, Regulations and Standards
- for more on application standards
- for more on equipment regulations

IESH/10eLightingExteriorsResources

> 12.5.5.6 Nighttime Outdoor Illuminances
- for more on lamp efficacies under mesopic adaptation

> 26 | LIGHTING FOR EXTERIORS
- for more on criteria

IESH/10e Sustainability Resources

> 13.11 Sustainability
- for more on lamps

> 19 | SUSTAINABILITY
- for more on controls
- for more on earth resources
- for more on energy
- for more on life cycle analyses
- for more on lighting design
- for more on recycling

- using daylighting that meets luminance and illuminance criteria
- using highest-efficacy lamps that meet color, optical and electrical control, and output criteria
- using highest-efficiency luminaires that meet aesthetic and luminance criteria
- using accenting to provide luminance balancing or improve brightness perceptions where necessary
- using controls liberally, preferably automated varieties such as presets, occupancy and vacancy sensors, astronomical time clocks, and photocells
- establishing IES-recommended illuminance criteria to meet programmed tasks
- establishing layouts that just meet IES-recommended illuminance criteria
- addressing outdoor environmental needs
- using calculations, photometrically-realistic renderings, and operational samples and mockups to prove concepts
- identifying and designing to code-specific requirements, if any, for ambient, task, and accent lighting
- documenting all code-, energy-, sustainability-, and IES-criteria compliance
- documenting criteria and design deviations and rationale and subsequent disposition by team, client, or AHJ
- documenting clearly the layouts, controls, and luminaire and lamp selections

Designing for the satisfaction of the observers is the paramount design tenet and must be kept in perspective during all aspects of design. If the observers' expectations are not fulfilled, then how much energy could be saved is moot, as is how many fewer earth resources were spared, as is how much the whole affair cost or how much value engineering saved or the photogenic qualities of the project. See sidebar references for additional guidance on the key tenets. The design effort must be undertaken with coordinated and realistic expectations by all involved on initial and life cycle costs. Budgeting should include designer input and dialogue with the team and client at project commencement and design milestones. In other words, and paraphrasing Thomas Edison, genius is, indeed, just 1% inspiration and 99% perspiration.

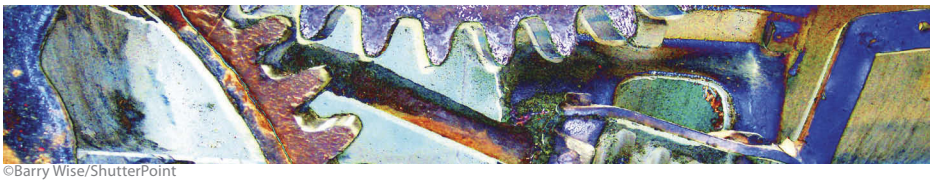
29.5 References

[1] [ALM] American Library Association. 2009. The condition of U.S. libraries: Trends, 1999-2009 [Internet]. ALA. [cited September 11, 2010]. Available from: ala.org/ala/research/initiatives/Condition_of_Libraries_1999.20.pdf.

[2] Mark S. Rea, ed. 2000. The IESNA lighting handbook: Reference and application. 9th Edition. New York: IESNA. Ch 12.

[3] [IESNA] Illuminating Engineering Society of North America. Lighting for Educational Facilities RP-3-00(R2006). New York: IESNA. 47 p.

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30 | LIGHTING FOR MANUFACTURING

There exist limitless opportunities in every industry. Where there is an open mind, there will always be a frontier.

Charles Kettering, Inventor

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30.1 Project Type and Status. . . 30.1
30.2 Application Types 30.2
30.3 Illuminance Criteria 30.74
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A well-designed lighting system makes an important contribution to the success of an industrial facility. Lighting helps provide the visibility necessary for complex, often three-dimensional tasks that must be performed efficiently and safely. Industrial applications present some of the most difficult, dangerous, and demanding tasks that are performed, and appropriate lighting is essential. The industrial environments in which these lighting systems must perform are unique: extremes of temperature, difficult maintenance, high-speed movement, and recessed or shadowed immediate work areas are often encountered. All represent a lighting design challenge that requires extensive information and good planning.

Comprehensive design efforts involve the information in this chapter combined with material in 12 | COMPONENTS OF LIGHTING DESIGN, 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS, 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Design tenets deemed appropriate from those chapters must be identified and lighting goals and strategies developed accordingly. This chapter primarily addresses illuminance criteria for industrial applications which should influence luminaire optical selections, lampings, and final layouts based on design thought-starters (see 15.2 A Lighting Scheme). Use of the material in this chapter to the exclusion of material in Chapters 12, 13, 14, and 15 will likely lead to unsatisfactory results. Previous IES related documents serve as archival reference sources [1] [2].

Deliberate thought must be given to details beyond the recommended illuminances in this chapter. For example, in INSPECTION/Difficult, the illuminance citations do not reveal the need to understand the requirement for either diffuse or directional illumination. Either form can produce the requisite illuminance, but a detailed knowledge of the task at hand usually dictates the directional requirements of the illumination: whether to highlight a pulled thread with grazing light, show a scratch with many small sources, or reveal the graduations on a caliper with diffuse light. Each of these types of illumination can achieve the target illuminance, but each has an appropriate geometry dictated by the task that can require different equipment and different placements. Such specific details are not enumerated for all tasks. Table 30.1 offers a checklist of IES lighting topics and criteria. The design team is responsible for determining and addressing indoor and outdoor lighting and energy criteria set forth by authorities having jurisdiction (AHJ) which may be different from and supersede IES criteria. See also 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

30.1 Project Type and Status

Before any design work, an understanding of the project type and scope is necessary. This will establish the extent to which daylighting can address some of the lighting goals, particularly in some industrial facilities such as warehouses and office spaces. New, renova-

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Table 30.1 | Industrial Lighting Checklist

Topics
✔ **Criteria and Design Resources**
Color
6.3 Color Rendition
6.4.4 Safety Colors
12.5.6 Color Considerations
Controls
16 | LIGHTING CONTROLS
Daylighting
14 | DESIGNING DAYLIGHTING
Electric Lighting
15 | DESIGNING ELECTRIC LIGHTING
Flicker
4.6 Flicker and Temporal Contrast Sensitivity
Glare
4.10.1 Discomfort Glare
4.10.2 Disability Glare
Illuminance
This Chapter: Table 30.2
12.5.5.1 Applications and Tasks
Table 12.6 | Default Illuminance Ratio Recommendations
Figure 12.22 | Task Coverage Example
Luminaires
8.3.2 Industrial Luminaires
Luminances
12.5.2 Luminance
Table 12.5 | Default Luminance Ratio Recommendations
Maintenance
15.4.4 Installation and Maintenance
Veiling and Specular Reflections
1.5.1.1 Reflection
This Chapter: Section 30.3.6
12.5.4 Veiling Reflections
Visual Tasks
This Chapter: Section 30.2
This Chapter: Table 30.2
Table 11.2 | Programming: Inventory Scope and Specific Examples
12.5.1 Visual Tasks
Table 12.3 | Sample Visual Task Survey

tion, and restoration projects each offer varying opportunities. See 11.2 Planning, 11.3.1 Pre-design, and 11.3.2 Schematic Design. At every opportunity the lighting designer should give every consideration to daylighting as a light source. For some applications and tasks, daylighting can be the primary light source. Critically, this means addressing the host of lighting factors identified in 12 | COMPONENTS OF LIGHTING DESIGN. Daylight demands attention to moderate or eliminate glare and balance visible and thermal energy.

Manufacturing environments can be quite complex, involving significant infrastructure and multiple building systems vying for the same locations. These facilities demand attention to systems integration and planning. See Figure 30.1.

30.2 Application Types

To develop lighting solutions that meet quality, quantity, and operational criteria, an inventory is made of the spaces under consideration and the anticipated occupants, functions, and tasks (see Table 11.2 | Programming: Inventory Scope and Specific Examples and Table 12.3 | Sample Visual Task Survey). Otherwise, lighting cannot be best targeted to the users, their expectations, functions and tasks.

Space type definitions are required early in the project design in order to track design efforts that include inventorying the project knowns, anticipated functions, and tasks and calculating lighting, power, and energy compliance. The applications and tasks cited in Table 30.2 | Industrial Illuminance Recommendations should be reviewed against the project knowns and correlated with the space types, tasks, and functions to establish recommended illuminance criteria. Seek clarification with the client where discrepancies occur between programming information and the available application and task citations in Table 30.2.

The following sections describe identifiable application areas and general task types commonly found in industrial environments. These discussions, those identified in Table 30.1, and the available applications and tasks identified in Table 30.2 offer comprehensive qualitative and quantitative criteria.

30.2.1 Administration and Management

Many industrial facilities with have buildings or parts of buildings that house administrative and management functions, and typically include circulation, conferencing, lounges, filing or records, interviewing, lobbies, mail sorting, and officing. Each of these in turn may involve a number of specifics including some form or degree of acknowledgment, conversation, reading, periods of respite or relaxation, and writing—all tasks within applications. Acknowledgement of other people and conversation, for example, require some vertical illuminance at face height (seating or standing depending on the nature of the application). Vertical illuminance criteria are cited for such applications.

The architectural scheme and even task specifics will vary based on the associated facility function and type. These variations should affect the lighting design—from kinds of lighting effects to lighting equipment styling to luminances and illuminances.

The administrative and management areas may be dispersed throughout a facility or complex or may be centralized into a single area, wing, or building. Depending on client wishes and architectural desires, this centralization or decentralization may affect the degree to which the lighting design in administrative and management areas is sympathetic to or different from that of other applications.

See also 32 | LIGHTING FOR OFFICES.

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Figure 30.1 | Complex Manufacturing Environments
Industrial environments are often voluminous, filled with large machinery and supporting structure for conveyors, catwalks, and cableways that are suspended at varying elevations. This arrangement makes luminaire placement difficult. The machinery can be occluded by other equipment or structure and getting proper illumination to machines and inspection and control stations from a general lighting system is challenging.

High reflectance surfaces can improve the condition by increasing the interreflected component of light in the space. This also helps balance luminances and control uniformity ratios.

Modern machinery is often operated while being viewed through protective transparent panels. These can pose serious veiling reflections at the direct-view working position if luminaires are improperly placed.

Great mounting heights and suspended-equipment and support sructure make lighting system maintenance difficult. Luminaire locations, lamping, and the affect of lighting system maintenance on production should all be addressed with the client during design.

» Image ©Serge Kozak/Corbis

30.2.2 Areas with Extreme Humidity or Temperatures, or with Corrosive Atmospheres

High humidity or corrosive atmospheres are likely to be present in at least some areas in a typical plant. Such areas usually require special luminaires. Further, outdoor lighting locations may be exposed to rain, snow, fog, wind, high humidity and salt-laden sea air.

The usual methods to protect against these atmospheres include the use of materials that resist corrosion, special surface preparations and corrosion resistant coatings or paint for luminaires such as epoxy, polyester or polyvinyl chloride. In addition, robust modes of paint application such as electrostatic coating or powder coating may be used. Luminaries that have non-metallic outer housings are also available. Some luminaries for classified locations are constructed in a manner that makes them suitable for high-corrosion areas.

Abnormally high ambient temperatures are often present in industrial applications, especially near the ceiling where the luminaries are installed. Industrial luminaries are available with ratings for ambient temperature conditions of 40° C, 55° C and 65° C (104° F, 131° F, 149° F). The temperature rating of the selected luminaire is important and should be at least as high as the temperature in which it is to operate during the warmest season of the year. The limiting factor can be any of several components within the luminaire. If the limiter is a ballast component, the ballast housing may often be remotely mounted in a cooler location.

Except for ignitor-start lamps (high pressure sodium and pulse-start metal halide), the only distance limitation to remote ballast location is the wire gauge. This is sized for the distance, according to the ballast manufacturer's recommendation, to hold voltage drops to a comfortable minimum.

With any system that has a pulse-igniter, the maximum distance the ignitor can be removed from the lamp is limited. In some cases the igniter can be placed in a compartment that has suitable heat sinking and remain with the optical portion of the luminaire (the other heat-sensitive components can be mounted remotely). Otherwise, a "long range ignitor" should be used to increase the remote distance. The ballast manufacturer should be consulted for exact limitations.

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Table 30.2 | Industrial Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b,c,d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
BASIC INDUSTRIAL TASKS											
ASSEMBLY											
• Difficult		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Exacting		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Simple		P	150	300	600	Avg	P	150	300	600	Avg
BUILDING ENTRIES	See 22 | LIGHTING FOR COMMON APPLICATIONS										
BUILDING LIGHTING											
• Break rooms/areas	See 22 | LIGHTING FOR COMMON APPLICATIONS										
• Conveyance aisles		M	50	100	200	Avg	K	25	50	100	Avg
• Entries	See 22 | LIGHTING FOR COMMON APPLICATIONS										
• Food service	See 22 | LIGHTING FOR COMMON APPLICATIONS										
• General shop areas		N	75	150	300	Avg	L	37.5	75	150	Avg
• Laboratories											
• Benches	Eh @3' AFF; Ev @4' 6" AFF	T	500	1000	2000	Avg	R	250	500	1000	Avg
• General	Eh @3' AFF; Ev @4' 6" AFF	R	250	500	1000	Avg	P	150	300	600	Avg
• Locker rooms	See 22 | LIGHTING FOR COMMON APPLICATIONS										
• Offices	See 32 | LIGHTING FOR OFFICES										
• Paper work areas (Line side)	See 22 | LIGHTING FOR COMMON APPLICATIONS										
• Parts storage		N	75	150	300	Avg	L	37.5	75	150	Avg
• Receiving area	See 22 | LIGHTING FOR COMMON APPLICATIONS										
COMPONENT MANUFACTURING											
• Fine		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Large		P	150	300	600	Avg	P	150	300	600	Avg
• Medium		R	250	500	1000	Avg	R	250	500	1000	Avg
CONTROL PANEL AND VDT OBSERVATION	See 22 | LIGHTING FOR COMMON APPLICATIONS										
INSPECTION											
• Difficult		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Exacting		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Simple		P	150	300	600	Avg	P	150	300	600	Avg
LOADING/UNLOADING PLATFORMS - OUTDOOR		O	100	200	400	Avg	M	50	100	200	Avg
• Freight car interiors		M	50	100	200	Avg	K	25	50	100	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
		3:1				
		3:1				
		3:1				
	3:1					
	3:1					
	3:1					
	3:1					
	5:1					
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	5:1					
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f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

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Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b,c,d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
MACHINING											
• Fine bench or machine work		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Fine grinding		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Medium bench or machine work		R	250	500	1000	Avg	R	250	500	1000	Avg
• Rough bensh or machine work		P	150	300	600	Avg	P	150	300	600	Avg
MAINTENANCE		R	250	500	1000	Avg	N	75	150	300	Avg
MANUAL CRAFTING	Engraving, carving, painting, stitching, cutting, pressing, knitting, polishing, or woodworking										
• Coarse		P	150	300	600	Avg	P	150	300	600	Avg
• Exacting		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Fine		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Medium		R	250	500	1000	Avg	R	250	500	1000	Avg
MATERIALS HANDLING											
• Loading	Inside truck and freight cars	M	50	100	200	Avg	I	15	30	60	Avg
• Picking stock, classifying		M	50	100	200	Avg	K	25	50	100	Avg
• Wrapping, packing, and labeling		P	150	300	600	Avg	N	75	150	300	Avg
MOTOR AND EQUIPMENT OBSERVATION		P	150	300	600	Avg	P	150	300	600	Avg
RAW MATERIAL PROCESSING	Cleaning, cutting, crushing, sorting, or grading										
• Coarse		M	50	100	200	Avg	M	50	100	200	Avg
• Medium		P	150	300	600	Avg	P	150	300	600	Avg
• Fine		R	250	500	1000	Avg	R	250	500	1000	Avg
• Very fine		T	500	1000	2000	Avg	T	500	1000	2000	Avg
SERVICE SPACES											
• Elevators, freight and passenger	See 22 | LIGHTING FOR COMMON APPLICATIONS										
• Stairways, corridors	See 22 | LIGHTING FOR COMMON APPLICATIONS										
• Toilets and wash rooms	See 22 | LIGHTING FOR COMMON APPLICATIONS										
SHIPPING AND RECEIVING	See 22 | LIGHTING FOR COMMON APPLICATIONS										
WAREHOUSING AND STORAGE											
• Inactive		K	25	50	100	Avg	H	10	20	40	Avg
• Active: bulky items; large labels		M	50	100	200	Avg	K	25	50	100	Avg
• Active: small items; small labels		P	150	300	600	Avg	N	75	150	300	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
WELDING											
• Orientation		P	150	300	600	Avg	P	150	300	600	Avg
• Precision manual arc-welding		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
SPECIFIC INDUSTRIAL TASKS											
AIRCRAFT MAINTENANCE											
• Docking	All activities required to dock	S	375	750	1500	Avg	O	100	200	400	Avg
• Painting	Cleaning, prime painting, and final painting exterior	S	375	750	1500	Avg	S	375	750	1500	Avg
• Modifications to systems		S	375	750	1500	Avg	S	375	750	1500	Avg
• Ramp lighting		I	15	30	60	Avg	E	4	8	16	Avg
• Predocking activities		S	375	750	1500	Avg	S	375	750	1500	Avg
• Specialty shops	Instruments, electrical, plastics, upholstery, and inspection	U	750	1500	3000	Avg	Q	200	400	800	Avg
• Systems operations and checks	Requireing activation of power systems	S	375	750	1500	Avg	S	375	750	1500	Avg
• System repairs	After operations and close up preparation	S	375	750	1500	Avg	S	375	750	1500	Avg
• System restoration	Including new component installation	S	375	750	1500	Avg	S	375	750	1500	Avg
AIRCRAFT MANUFACTURING											
• Fabrication	Preparation for assembly										
• Drilling, riveting, fastening		S	375	750	1500	Avg	S	375	750	1500	Avg
• Layout and template work	Shaping and smoothing small parts for fuselage, wing sections, cowling	S	375	750	1500	Avg	S	375	750	1500	Avg
• Scribing		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Plating		P	150	300	600	Avg	P	150	300	600	Avg
• General											
• Rough easy seeing		P	150	300	600	Avg	L	37.5	75	150	Avg
• Rough difficult seeing		S	375	750	1500	Avg	O	100	200	400	Avg
• Medium		S	375	750	1500	Avg	O	100	200	400	Avg
• Fine		U	750	1500	3000	Avg	Q	200	400	800	Avg
• Extra fine		W	1500	3000	6000	Avg	S	375	750	1500	Avg
• First manufacturing operations	See Sheet metal works										
• Flight test and delivery area		I	15	30	60	Avg	I	15	30	60	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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		3:1				
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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
AUTOMOTIVE INDUSTRIES FACILITIES											
• Battery manufacturing		R	250	500	1000	Avg	R	250	500	1000	Avg
• Casting furnace area		P	150	300	600	Avg	P	150	300	600	Avg
• Chassis, body assembly		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Clay enamel and glazing		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Clay mold and kiln rooms		P	150	300	600	Avg	P	150	300	600	Avg
• Coal yards, oil storage		D	3	6	12	Avg	A	0.5	1	2	Avg
• Control and dispatch rooms		S	375	750	1500	Avg	O	100	200	400	Avg
• Exterior active storage areas		O	100	200	400	Avg	K	25	50	100	Avg
• Exterior inactive storage		G	7.5	15	30	Avg	C	2	4	8	Avg
• Exterior pedestrian entrances		K	25	50	100	Avg	G	7.5	15	30	Avg
• Final assembly	Body finishing, difficult inspectic	V	1000	2000	4000	Avg	V	1000	2000	4000	Avg
• Fine difficult inspection	Casting cracks	X	2500	5000	10000	Avg	X	2500	5000	10000	Avg
• Forgings, casting, and pouring		R	250	500	1000	Avg	R	250	500	1000	Avg
• Frame assembly		R	250	500	1000	Avg	R	250	500	1000	Avg
• General paint manufacturing, plating		P	150	300	600	Avg	P	150	300	600	Avg
• Glass cutting and inspection		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Glass furnace rooms		P	150	300	600	Avg	L	37.5	75	150	Avg
• Grinding and chipping		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• HVAC and substation rooms		P	150	300	600	Avg	L	37.5	75	150	Avg
• Inactive interior storage areas		K	25	50	100	Avg	G	7.5	15	30	Avg
• Large casting, molding areas	Engine casting	S	375	750	1500	Avg	S	375	750	1500	Avg
• Loading docks		P	150	300	600	Avg	L	37.5	75	150	Avg
• Locker rooms	See 22 | LIGHTING FOR COMMON APPLICATIONS										
• Machining operations	Engine parts	S	375	750	1500	Avg	S	375	750	1500	Avg
• Maintenance and machine repair		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Medium casting, molding areas	Crankshafts	T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Outdoor substations		G	7.5	15	30	Avg	C	2	4	8	Avg
• Parking areas	See 26 | LIGHTING FOR EXTERIORS										
• Parts inspection stations		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Plating		P	150	300	600	Avg	P	150	300	600	Avg
• Polishing and burnishing		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Powerhouse		R	250	500	1000	Avg	R	250	500	1000	Avg
• Press rooms		R	250	500	1000	Avg	N	75	150	300	Avg
• Railroad switching points		G	7.5	15	30	Avg	G	7.5	15	30	Avg
• Service garages		R	250	500	1000	Avg	N	75	150	300	Avg
• Sheet steel rolling		P	150	300	600	Avg	P	150	300	600	Avg
• Sorting		R	250	500	1000	Avg	R	250	500	1000	Avg
• Steel furnace areas		O	100	200	400	Avg	K	25	50	100	Avg
• Truck maneuvering areas		K	25	50	100	Avg	G	7.5	15	30	Avg
• Upholstering		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Waste treatment facilities	Interior	P	150	300	600	Avg	P	150	300	600	Avg

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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
AUTOMOTIVE BEST PRACTICES											
• Bodyweld											
• Process lighting		N	75	150	300	Avg	N	75	150	300	Avg
• Brazing		R	250	500	1000	Avg	R	250	500	1000	Avg
• Inspection area	Bench or table										
• Manual Welder Work area											
• Loading		P	150	300	600	Avg	P	150	300	600	Avg
• Welding		R	250	500	1000	Avg	R	250	500	1000	Avg
• Unloading		P	150	300	600	Avg	P	150	300	600	Avg
• Robot Welding Cell											
• Quality											
• Quality lab, general		R	250	500	1000	Avg	N	75	150	300	Avg
• Quality lab	Test bench or hood area	T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Casting											
• Building lighting											
• Stamped parts storage		N	75	150	300	Avg	N	75	150	300	Avg
• Process Lighting											
• Annealing		P	150	300	600	Avg	P	150	300	600	Avg
• Cleaning		P	150	300	600	Avg	P	150	300	600	Avg
• Core Making											
• Fine		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Medium		S	375	750	1500	Avg	S	375	750	1500	Avg
• Cupola		P	150	300	600	Avg	P	150	300	600	Avg
• Grinding and chipping		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Molding											
• Large		S	375	750	1500	Avg	S	375	750	1500	Avg
• Medium		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Pouring		S	375	750	1500	Avg	S	375	750	1500	Avg
• Shakeout		P	150	300	600	Avg	P	150	300	600	Avg
• Sorting		N	75	150	300	Avg	N	75	150	300	Avg
• Paint											
• Building lighting											
• Oven deck/area		N	75	150	300	Avg	J	20	40	80	Avg
• Paint Mix		R	250	500	1000	Avg	R	250	500	1000	Avg
• Paint storage room		O	100	200	400	Avg	O	100	200	400	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
		5:1				
		3:1				
		3:1				
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		3:1				
		3:1				
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Table 30.2 | Industrial Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
AUTOMOTIVE BEST PRACTICES	(Paint, continued)										
• Process lighting											
• Paint Booth											
• Prep zone		R	250	500	1000	Avg	R	250	500	1000	Avg
• Manual painting											
• Cleaning		Q	200	400	800	Avg	Q	200	400	800	Avg
• Production		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Robot Painting											
• Cleaning		R	250	500	1000	Avg	R	250	500	1000	Avg
• Maintenance		R	250	500	1000	Avg	R	250	500	1000	Avg
• Production		N	75	150	300	Avg	N	75	150	300	Avg
• Inspection		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Flash Off											
• Cleaning		P	150	300	600	Avg	P	150	300	600	Avg
• Production		P	150	300	600	Avg	P	150	300	600	Avg
• Paint Hospital											
• General Shop area		R	250	500	1000	Avg	N	75	150	300	Avg
• Painting cell or area		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Ovens											
• Controls		P	150	300	600	Avg	P	150	300	600	Avg
• Preparation											
• Cleaning		R	250	500	1000	Avg	R	250	500	1000	Avg
• Degrease		K	25	50	100	Avg	K	25	50	100	Avg
• Controls		P	150	300	600	Avg	P	150	300	600	Avg
• ED Coat		K	25	50	100	Avg	K	25	50	100	Avg
• Controls		P	150	300	600	Avg	P	150	300	600	Avg
• Small Booths											
• Cleaning		R	250	500	1000	Avg	R	250	500	1000	Avg
• Production		R	250	500	1000	Avg	R	250	500	1000	Avg
• Off-line Repair											
• Painting area		T	500	1000	2000	Avg	P	150	300	600	Avg
• Inspection		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Plastics											
• Building lighting											
• Oven deck/area		N	75	150	300	Avg	J	20	40	80	Avg
• Paint Mix		R	250	500	1000	Avg	R	250	500	1000	Avg
• Paint storage room		O	100	200	400	Avg	O	100	200	400	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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		3:1				
		3:1				
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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
AUTOMOTIVE BEST PRACTICES	(Plastics, continued)										
• Process lighting											
• Paint Booth											
• Prep zone		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Manual painting											
• Cleaning		R	250	500	1000	Avg	R	250	500	1000	Avg
• Production		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Robot Painting											
• Cleaning		R	250	500	1000	Avg	R	250	500	1000	Avg
• Maintenance		R	250	500	1000	Avg	R	250	500	1000	Avg
• Production		N	75	150	300	Avg	N	75	150	300	Avg
• Inspection		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Flash Off											
• Cleaning		P	150	300	600	Avg	P	150	300	600	Avg
• Production		P	150	300	600	Avg	P	150	300	600	Avg
• Ovens											
• Controls		P	150	300	600	Avg	P	150	300	600	Avg
• Small booths		R	250	500	1000	Avg	R	250	500	1000	Avg
• Off Line Repair		P	150	300	600	Avg	P	150	300	600	Avg
• Painting area		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Inspection		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• IMM											
• Control Panel		P	150	300	600	Avg	P	150	300	600	Avg
• Die Loading area		R	250	500	1000	Avg	R	250	500	1000	Avg
• IMM Equipment areas		P	150	300	600	Avg	P	150	300	600	Avg
• Loading area		R	250	500	1000	Avg	R	250	500	1000	Avg
• Parts Unloading area		R	250	500	1000	Avg	R	250	500	1000	Avg
• Die Repair											
• Inspection cell		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Repair cell		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Shop area		P	150	300	600	Avg	P	150	300	600	Avg
• Powertrain											
• Process lighting											
• Annealing		R	250	500	1000	Avg	R	250	500	1000	Avg
• Assembly		R	250	500	1000	Avg	R	250	500	1000	Avg
• Control Panel		P	150	300	600	Avg	P	150	300	600	Avg
• Heat treat		P	150	300	600	Avg	P	150	300	600	Avg
• Inspection cells/zones		R	250	500	1000	Avg	R	250	500	1000	Avg
• Maintenance Shop		P	150	300	600	Avg	L	37.5	75	150	Avg
• Machine lines											
• Maintenance		Q	200	400	800	Avg	Q	200	400	800	Avg
• Normal Operations		N	75	150	300	Avg	N	75	150	300	Avg
• Tool change		R	250	500	1000	Avg	R	250	500	1000	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
AUTOMOTIVE BEST PRACTICES	(Powertrain/machine lines, continued)										
• Tool repair shop											
• Shop Area		P	150	300	600	Avg	L	37.5	75	150	Avg
• Tool repair benches		M	50	100	200	Avg	M	50	100	200	Avg
• Quality											
• Quality lab, general		R	250	500	1000	Avg	R	250	500	1000	Avg
• Quality lab	Test bench or hood area	T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Test Cells		R	250	500	1000	Avg	R	250	500	1000	Avg
• Press											
• Building lighting											
• Die Storage		N	75	150	300	Avg	N	75	150	300	Avg
• Press Pits		O	100	200	400	Avg	O	100	200	400	Avg
• Stamped parts storage		N	75	150	300	Avg	N	75	150	300	Avg
• Process lighting											
• Automated Stamping Press											
• Control Panel		N	75	150	300	Avg	N	75	150	300	Avg
• Die Loading area		N	75	150	300	Avg	N	75	150	300	Avg
• Parts Unloading area		N	75	150	300	Avg	N	75	150	300	Avg
• Press Crown		N	75	150	300	Avg	N	75	150	300	Avg
• Press Equipment areas		N	75	150	300	Avg	N	75	150	300	Avg
• Press Interior		N	75	150	300	Avg	N	75	150	300	Avg
• Sheet Loading area		N	75	150	300	Avg	N	75	150	300	Avg
• Manually Stamping Press											
• Control Panel		P	150	300	600	Avg	P	150	300	600	Avg
• Die Loading area		P	150	300	600	Avg	P	150	300	600	Avg
• Parts Unloading area		P	150	300	600	Avg	P	150	300	600	Avg
• Press Crown		N	75	150	300	Avg	N	75	150	300	Avg
• Press Equipment areas		P	150	300	600	Avg	P	150	300	600	Avg
• Press Interior		P	150	300	600	Avg	P	150	300	600	Avg
• Sheet Loading area		P	150	300	600	Avg	P	150	300	600	Avg
• Die Repair											
• Repair cell		R	250	500	1000	Avg	R	250	500	1000	Avg
• Shop area		P	150	300	600	Avg	P	150	300	600	Avg
• Inspection cell		R	250	500	1000	Avg	R	250	500	1000	Avg
• Utilities, exterior											
• Exterior areas											
• Cooling towers		N	75	150	300	Avg	N	75	150	300	Avg
• General area, ground		O	100	200	400	Avg	O	100	200	400	Avg
• Guage reading areas		N	75	150	300	Avg	N	75	150	300	Avg
• Ladders and stairs, unoccupied		N	75	150	300	Avg	N	75	150	300	Avg
• Loading stations		K	25	50	100	Avg	K	25	50	100	Avg
• Roadways, high use		K	25	50	100	Avg	K	25	50	100	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
AUTOMOTIVE BEST PRACTICES	(continued)										
• Utilities											
• Building lighting											
• Electrical substation		R	250	500	1000	Avg	R	250	500	1000	Avg
• General floor area		N	75	150	300	Avg	J	20	40	80	Avg
• Process Areas											
• Boiler, control area		P	150	300	600	Avg	L	37.5	75	150	Avg
• Chiller, control area		P	150	300	600	Avg	L	37.5	75	150	Avg
• Compressor, control area		P	150	300	600	Avg	L	37.5	75	150	Avg
• Guage reading areas		O	100	200	400	Avg	O	100	200	400	Avg
• Office spaces	See 32 | LIGHTING FOR OFFICES										
• WWT Controls		P	150	300	600	Avg	P	150	300	600	Avg
BAKERIES											
• Decorating and icing											
• Mechanical		P	150	300	600	Avg	P	150	300	600	Avg
• Hand		S	375	750	1500	Avg	S	375	750	1500	Avg
• Fermentation room		P	150	300	600	Avg	P	150	300	600	Avg
• Fillings and other ingredients		P	150	300	600	Avg	P	150	300	600	Avg
• Make-up room											
• Bread		P	150	300	600	Avg	P	150	300	600	Avg
• Sweet yeast-raised products		P	150	300	600	Avg	P	150	300	600	Avg
• Mixing room		P	150	300	600	Avg	L	37.5	75	150	Avg
• Face of shelves		P	150	300	600	Avg	P	150	300	600	Avg
• Inside of shelves		P	150	300	600	Avg	P	150	300	600	Avg
• Oven room		P	150	300	600	Avg	P	150	300	600	Avg
• Proofing room		P	150	300	600	Avg	L	37.5	75	150	Avg
• Scales and thermometers		P	150	300	600	Avg	P	150	300	600	Avg
• Wrapping		P	150	300	600	Avg	P	150	300	600	Avg
BOOK BINDING											
• Cutting, punching, stitching		S	375	750	1500	Avg	S	375	750	1500	Avg
• Embossing and inspection		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Folding, assembly, pasting		P	150	300	600	Avg	P	150	300	600	Avg
BREWERIES											
• Boiling and keg washing		P	150	300	600	Avg	P	150	300	600	Avg
• Brew house		P	150	300	600	Avg	L	37.5	75	150	Avg
• Filling	Bottles, cans, or kegs	P	150	300	600	Avg	P	150	300	600	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
		3:1	☀			
		5:1	☀			
		3:1				
		3:1				
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		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
BUILDING CONSTRUCTION	Outdoor										
• Excavation work		H	10	20	40	Avg	H	10	20	40	Avg
• General construction		M	50	100	200	Avg	I	15	30	60	Avg
• Entrances											
• Active	Pedestrian or conveyance	K	25	50	100	Avg	K	25	50	100	Avg
• Inactive	Normally locked and infrequently used	F	5	10	20	Avg	F	5	10	20	Avg
• Vital locations or structures		K	25	50	100	Avg	K	25	50	100	Avg
• Building surrounds		F	5	10	20	Avg	F	5	10	20	Avg
CANDY MAKING											
• Chocolate department		P	150	300	600	Avg	L	37.5	75	150	Avg
• Cream making		P	150	300	600	Avg	L	37.5	75	150	Avg
• Hand decorating		P	150	300	600	Avg	P	150	300	600	Avg
• Hard candy - cutting, sorting		S	375	750	1500	Avg	S	375	750	1500	Avg
• Milling		P	150	300	600	Avg	P	150	300	600	Avg
CANNING AND PRESERVING											
• Canning											
• Continuous belt canning		S	375	750	1500	Avg	S	375	750	1500	Avg
• Sink canning		S	375	750	1500	Avg	S	375	750	1500	Avg
• Hand packing		P	150	300	600	Avg	P	150	300	600	Avg
• Olives		S	375	750	1500	Avg	S	375	750	1500	Avg
• Can unscramblers		S	375	750	1500	Avg	S	375	750	1500	Avg
• Container handling											
• Cutting and pitting		S	375	750	1500	Avg	S	375	750	1500	Avg
• Examination of canned samples		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Final sorting		S	375	750	1500	Avg	S	375	750	1500	Avg
• Initial grading	Raw material samples	P	150	300	600	Avg	P	150	300	600	Avg
• Color grading and cutting rooms		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Tomatoes		S	375	750	1500	Avg	S	375	750	1500	Avg
• Inspection		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Labeling and cartoning		P	150	300	600	Avg	P	150	300	600	Avg
• Preparation											
• Preliminary sorting											
• Apricots and peaches		P	150	300	600	Avg	P	150	300	600	Avg
• Olives		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Tomatoes		S	375	750	1500	Avg	S	375	750	1500	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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		10:1				
		5:1				
		5:1				
		10:1				
		5:1				
		10:1				
		3:1				
		3:1				
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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
CASTING	See Foundries										
CENTRAL STATIONS	See Elecctric Generating Stations										
CHEMICAL PLANTS	See Petroleum and Chemical Plants										
CLAY AND CONCRETE PRODUCTS											
• Color and glazing - fine work		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Color and glazing - rough work		S	375	750	1500	Avg	S	375	750	1500	Avg
• Enameling		S	375	750	1500	Avg	S	375	750	1500	Avg
• Grinding filter presses, kiln rooms		N	75	150	300	Avg	N	75	150	300	Avg
• Molding, pressing, cleaning, trimming		P	150	300	600	Avg	P	150	300	600	Avg
CLEANING AND PRESSING INDUSTRY											
• Checking and sorting		S	375	750	1500	Avg	S	375	750	1500	Avg
• Dry and wet cleaning		S	375	750	1500	Avg	S	375	750	1500	Avg
• Inspection and spotting		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Pressing		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Repair and alteration		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Steaming		S	375	750	1500	Avg	S	375	750	1500	Avg
CLOTHING MANUFACTURE	See also Sewn Products										
• Cutting		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Examining	Perching	X	2500	5000	20000	Avg	X	2500	5000	10000	Avg
• Fitting, bundling, shading, stitching		P	150	300	600	Avg	P	150	300	600	Avg
• Measuring		P	150	300	600	Avg	P	150	300	600	Avg
• Pattern making		S	375	750	1500	Avg	S	375	750	1500	Avg
• Preparation of trimming, piping		S	375	750	1500	Avg	S	375	750	1500	Avg
• Piling up and marking		S	375	750	1500	Avg	S	375	750	1500	Avg
• Pressing		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Receiving, opening, storing, shipping		P	150	300	600	Avg	P	150	300	600	Avg
• Shops		U	750	1500	3000	Avg	Q	200	400	800	Avg
• Sponging, decating, winding		P	150	300	600	Avg	P	150	300	600	Avg
• Work with canvas, padding		S	375	750	1500	Avg	S	375	750	1500	Avg
COAL YARDS OUTDOOR, PROTECTIVE		B	1	2	4	Avg	B	1	2	4	Avg

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		3:1			■	
		3:1		■	■	
		5:1			■	
		3:1			■	
		3:1	■		■	
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CONTROL ROOMS	See Electric Generating Stations - Interior										
DAIRY FARMS	See Farms										
DAIRY PRODUCTS											
• Boiler room		P	150	300	600	Avg	L	37.5	75	150	Avg
• Bottle storage		P	150	300	600	Avg	P	150	300	600	Avg
• Bottle sorting		S	375	750	1500	Avg	S	375	750	1500	Avg
• Bottle washers		P	150	300	600	Avg	P	150	300	600	Avg
• Can washers		P	150	300	600	Avg	P	150	300	600	Avg
• Cooling equipment		P	150	300	600	Avg	P	150	300	600	Avg
• Filling-inspection		S	375	750	1500	Avg	S	375	750	1500	Avg
• Fluid milk industry											
• Gauges, meters, thermometers	On instrument face	S	375	750	1500	Avg	S	375	750	1500	Avg
• Laboratories		S	375	750	1500	Avg	S	375	750	1500	Avg
• Pasteurizers		P	150	300	600	Avg	P	150	300	600	Avg
• Separators		P	150	300	600	Avg	P	150	300	600	Avg
• Storage refrigerator		P	150	300	600	Avg	P	150	300	600	Avg
• Tanks, vats											
• Light interiors		N	75	150	300	Avg	N	75	150	300	Avg
• Dark interiors		S	375	750	1500	Avg	S	375	750	1500	Avg
• Weighing room		P	150	300	600	Avg	L	37.5	75	150	Avg
• Scales		S	375	750	1500	Avg	S	375	750	1500	Avg
DISPATCH BOARDS	See Electric Generating Stations										
DREDGING - OUTDOOR		H	10	20	40	Avg	H	10	20	40	Avg
ELECTRICAL EQUIPMENT MANUFACTURING											
• Impregnating		P	150	300	600	Avg	P	150	300	600	Avg
• Insulating: coil winding		S	375	750	1500	Avg	S	375	750	1500	Avg

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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
ELECTRIC GENERATING STATIONS - INTERIOR	See also Nuclear Power Plants										
• Air-conditioning equipment		L	37.5	75	150	Avg	L	37.5	75	150	Avg
• Air preheater and fan floor		L	37.5	75	150	Avg	L	37.5	75	150	Avg
• Ash sluicing		L	37.5	75	150	Avg	L	37.5	75	150	Avg
• Auxiliaries	Pumps, tanks, compressors, and gauge areas	N	75	150	300	Avg	J	20	40	80	Avg
• Battery rooms		P	150	300	600	Avg	L	37.5	75	150	Avg
• Boiler platforms		L	37.5	75	150	Avg	H	10	20	40	Avg
• Burner platforms		N	75	150	300	Avg	J	20	40	80	Avg
• Cable room		L	37.5	75	150	Avg	H	10	20	40	Avg
• Floors	For condensers, deaerators , evaporators, heaters	L	37.5	75	150	Avg	H	10	20	40	Avg
• Control rooms											
• Maintenance and wiring area		P	150	300	600	Avg	L	37.5	75	150	Avg
• Emergency operating lighting		N	75	150	300	Avg	N	75	150	300	Avg
• Gauge reading		P	150	300	600	Avg	P	150	300	600	Avg
• Hydrogen and CO_2 manifold area		N	75	150	300	Avg	N	75	150	300	Avg
• Mmotor control centers		P	150	300	600	Avg	P	150	300	600	Avg
• Precipitators		L	37.5	75	150	Avg	L	37.5	75	150	Avg
• Screen house		N	75	150	300	Avg	N	75	150	300	Avg
• Soot or slag blower platform		N	75	150	300	Avg	N	75	150	300	Avg
• Steam headers and trottles		L	37.5	75	150	Avg	L	37.5	75	150	Avg
• Switchgear		P	150	300	600	Avg	P	150	300	600	Avg
• Telecom equipment rooms		P	150	300	600	Avg	P	150	300	600	Avg
• Tunnels or galleries	For pipe and electrical	L	37.5	75	150	Avg	L	37.5	75	150	Avg
• Turbine building											
• Operating floor		P	150	300	600	Avg	P	150	300	600	Avg
• Below, operating floor		N	75	150	300	Avg	N	75	150	300	Avg
• Visitor's gallery		P	150	300	600	Avg	P	150	300	600	Avg
• Water treating area		P	150	300	600	Avg	P	150	300	600	Avg
ELECTRIC GENERATING STATIONS-EXTERIOR	See also Nuclear Power Plants										
• Boiler areas											
• Catwalks, general area		H	10	20	40	Avg	D	3	6	12	Avg
• Stairs, platforms		K	25	50	100	Avg	G	7.5	15	30	Avg
• Ground level areas	Including precipitators, FD and ID fans, bottom ash hoppers	K	25	50	100	Avg	G	7.5	15	30	Avg
• Cooling towers											
• Fan deck		K	25	50	100	Avg	G	7.5	15	30	Avg
• Platforms, stairs, valve areas		K	25	50	100	Avg	G	7.5	15	30	Avg
• Pump areas		H	10	20	40	Avg	D	3	6	12	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
ELECTRIC GENERATING STATIONS-EXTERIOR	(continued)										
• Fuel handling											
• Unloading	Barges , dumpers, trucks	K	25	50	100	Avg	G	7.5	15	30	Avg
• Pumps and gas metering		K	25	50	100	Avg	K	25	50	100	Avg
• Convetors		H	10	20	40	Avg	H	10	20	40	Avg
• Storage tanks		F	5	10	20	Avg	B	1	2	4	Avg
• Coal storage piles, ash dumps		B	1	2	4	Avg	A	0.5	1	2	Avg
• Hydroelectric											
• Inlet and discharge water area		B	1	2	4	Avg	B	1	2	4	Avg
• Powerhouse	Roof, stairs, platform, decks	K	25	50	100	Avg	G	7.5	15	30	Avg
• Intake structures											
• Deck and laydown area		K	25	50	100	Avg	K	25	50	100	Avg
• Inlet water area		B	1	2	4	Avg	B	1	2	4	Avg
• Value pits		H	10	20	40	Avg	H	10	20	40	Avg
• Substation											
• Horizontal general area		H	10	20	40	Avg					
• Vertical tasks							K	25	50	100	Avg
• Transformer yards											
• Horizontal general area		H	10	20	40	Avg					
• Vertical tasks							K	25	50	100	Avg
• Turbine areas											
• Building surrounds		H	10	20	40	Avg	D	3	6	12	Avg
• Entrances, stairs and platforms		K	25	50	100	Avg	G	7.5	15	30	Avg
• Turbine and heater decks		K	25	50	100	Avg	K	25	50	100	Avg
• Uunloading bays		K	25	50	100	Avg	K	25	50	100	Avg
EXPLOSIVES MANUFACTURING											
• Boiling tanks		P	150	300	600	Avg	P	150	300	600	Avg
• Evaporators		P	150	300	600	Avg	P	150	300	600	Avg
• Extractors		P	150	300	600	Avg	P	150	300	600	Avg
• Filtration		P	150	300	600	Avg	P	150	300	600	Avg
• Generators and stills		P	150	300	600	Avg	P	150	300	600	Avg
• Hand furnaces		P	150	300	600	Avg	P	150	300	600	Avg
• Mechanical crystllizers		P	150	300	600	Avg	P	150	300	600	Avg
• Mechanical driers		P	150	300	600	Avg	P	150	300	600	Avg
• Mechanical furnace		P	150	300	600	Avg	P	150	300	600	Avg
• Nirtrators		P	150	300	600	Avg	P	150	300	600	Avg
• Percolators		P	150	300	600	Avg	P	150	300	600	Avg
• Staionary driers		P	150	300	600	Avg	P	150	300	600	Avg
• Stationary, gravity crystallizers		P	150	300	600	Avg	P	150	300	600	Avg
• Tanks for cooking		P	150	300	600	Avg	P	150	300	600	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
FARMS-DAIRY											
• Farm shop area											
• Active storage area		L	37.5	75	150	Avg	H	10	20	40	Avg
• General shop area	Machinery repair, rough sawing	P	150	300	600	Avg	L	37.5	75	150	Avg
• Rough bench,machine work	Painting, sheet metal work, welding, medium bench work	P	150	300	600	Avg	L	37.5	75	150	Avg
• Medium bench, machine work	Fine woodworking, drill press, metal lathe, grinder	S	375	750	1500	Avg	O	100	200	400	Avg
• Feeding area	Stall, barn, feed alley, pens, loose housing feed area	N	75	150	300	Avg	N	75	150	300	Avg
• Feed storage area-forage											
• Haymow		I	15	30	60	Avg	I	15	30	60	Avg
• Hay inspection area		N	75	150	300	Avg	N	75	150	300	Avg
• Ladders and stairs		N	75	150	300	Avg	J	20	40	80	Avg
• Silo		I	15	30	60	Avg	I	15	30	60	Avg
• Silo room		N	75	150	300	Avg	J	20	40	80	Avg
• Feed storage area											
• Grain bin		I	15	30	60	Avg	I	15	30	60	Avg
• Concentrate storage area		L	37.5	75	150	Avg	H	10	20	40	Avg
• Feed processing area		L	37.5	75	150	Avg	L	37.5	75	150	Avg
• Livestock housing area	Community, maternity, individual calf pens and loose housing, and resting area	L	37.5	75	150	Avg	L	37.5	75	150	Avg
• Machine storage area	Garage and machine shed										
• Inactive		L	37.5	75	150	Avg	H	10	20	40	Avg
• Active		N	75	150	300	Avg	J	20	40	80	Avg
• Small items		P	150	300	600	Avg	L	37.5	75	150	Avg
• Large items		P	150	300	600	Avg	L	37.5	75	150	Avg
• Milking operation area	Parlor and stall barn										
• General		N	75	150	300	Avg	J	20	40	80	Avg
• Cow's udder		P	150	300	600	Avg	P	150	300	600	Avg
• Milk handling equipment and storage area	Milk house or milk room										
• General		N	75	150	300	Avg	J	20	40	80	Avg
• Washing area		S	375	750	1500	Avg	S	375	750	1500	Avg
• Bulk tank interior		S	375	750	1500	Avg	S	375	750	1500	Avg
• Loading platform		N	75	150	300	Avg	N	75	150	300	Avg
• Miscellaneous areas											
• Farm office	See 32 | LIGHTING FOR OFFICES										
• Pumphouse		N	75	150	300	Avg	J	20	40	80	Avg
FARMS-POULTRY	See Poultry Industry										

Table 30.2 | Industrial Illuminance Recommendations continued next page

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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
FLOUR MILLS											
• Aisleways and walkways		P	150	300	600	Avg	P	150	300	600	Avg
• Bin checking		P	150	300	600	Avg	P	150	300	600	Avg
• Cleaning screens		P	150	300	600	Avg	P	150	300	600	Avg
• Man lifts		P	150	300	600	Avg	P	150	300	600	Avg
• Packing		P	150	300	600	Avg	L	37.5	75	150	Avg
• Product control		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Rolling, sifting, purifying		S	375	750	1500	Avg	S	375	750	1500	Avg
FORGE SHOPS		S	375	750	1500	Avg	S	375	750	1500	Avg
FOUNDRIES											
• Annealing furnaces		P	150	300	600	Avg	L	37.5	75	150	Avg
• Cleaning		P	150	300	600	Avg	P	150	300	600	Avg
• Core making											
• Fine		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Medium		S	375	750	1500	Avg	S	375	750	1500	Avg
• Cupola		N	75	150	300	Avg	N	75	150	300	Avg
• Grinding and chipping		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Molding											
• Medium		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Large		S	375	750	1500	Avg	S	375	750	1500	Avg
• Pouring		S	375	750	1500	Avg	S	375	750	1500	Avg
• Sorting		S	375	750	1500	Avg	S	375	750	1500	Avg
• Shakeout		P	150	300	600	Avg	P	150	300	600	Avg
GARAGES-PARKING	See 26 | LIGHTING FOR EXTERIORS										
GARAGES-SERVICE											
• Active traffic areas		N	75	150	300	Avg	J	20	40	80	Avg
• Repairs		S	375	750	1500	Avg	S	375	750	1500	Avg
• Write-up		P	150	300	600	Avg	L	37.5	75	150	Avg
GLASS WORKS											
• Glass-blowing machines		N	75	150	300	Avg	N	75	150	300	Avg
• Mix and furnace rooms		N	75	150	300	Avg	N	75	150	300	Avg
• Pressing and lehr		N	75	150	300	Avg	N	75	150	300	Avg
GLOVE MANUFACTURING	See Sewn Products										

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		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
HAT MANUFACTURING											
• Cleaning, refining		S	375	750	1500	Avg	S	375	750	1500	Avg
• Dyeing, stiffening, braiding		S	375	750	1500	Avg	S	375	750	1500	Avg
• Forming, pouncing, ironing		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Sizing, flanging, finishing		U	750	1500	3000	Avg	U	750	1500	3000	Avg
IRON AND STEEL MANUFACTURING											
• Open hearth		M	50	100	200	Avg	M	50	100	200	Avg
• Buggy and door repair		P	150	300	600	Avg	P	150	300	600	Avg
• Calcining building		M	50	100	200	Avg	M	50	100	200	Avg
• Charging floor		O	100	200	400	Avg	K	25	50	100	Avg
• Checker cellar		M	50	100	200	Avg	M	50	100	200	Avg
• Hot top		P	150	300	600	Avg	P	150	300	600	Avg
• Hot top storage		M	50	100	200	Avg	M	50	100	200	Avg
• Mixer building		P	150	300	600	Avg	P	150	300	600	Avg
• Mold yard		K	25	50	100	Avg	K	25	50	100	Avg
• Pouring slide											
◦ Control platforms		P	150	300	600	Avg	L	37.5	75	150	Avg
◦ Slag pits		O	100	200	400	Avg	O	100	200	400	Avg
• Scrap stockyard		M	50	100	200	Avg	I	15	30	60	Avg
• Skull cracker		M	50	100	200	Avg	M	50	100	200	Avg
• Stock yard		O	100	200	400	Avg	K	25	50	100	Avg
• Stripping yard		O	100	200	400	Avg	K	25	50	100	Avg
• Rolling mills											
• Blooming, slabbing		P	150	300	600	Avg	P	150	300	600	Avg
• Cold strip, plate		P	150	300	600	Avg	P	150	300	600	Avg
• Hot strip, hot sheet		P	150	300	600	Avg	P	150	300	600	Avg
• Merchant and sheared plate		P	150	300	600	Avg	P	150	300	600	Avg
• Pipe, rod, tube, wire drawing		R	250	500	1000	Avg	R	250	500	1000	Avg
• Tin plate mills											
• Cols strip rolling		R	250	500	1000	Avg	R	250	500	1000	Avg
• Tinning and galvanizing		R	250	500	1000	Avg	R	250	500	1000	Avg
• Motor room, machine room		P	150	300	600	Avg	L	37.5	75	150	Avg
• Inspection											
• Black plate		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Bloom and billet chipping		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Tin plate, other bright surfaces		V	1000	2000	4000	Avg	V	1000	2000	4000	Avg
JEWELRY AND WATCH MANUFACTURING		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
		3:1				
		3:1				
		3:1				
		3:1				
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d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or polished metalic surfaces, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

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		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
LAUNDRIES											
• Flat work ironing, weighing, listing, marking		P	150	300	600	Avg	P	150	300	600	Avg
• Fine hand ironing		S	375	750	1500	Avg	S	375	750	1500	Avg
• Machine and press finishing, sorting		S	375	750	1500	Avg	S	375	750	1500	Avg
• Washing		P	150	300	600	Avg	P	150	300	600	Avg
LEATHER WORKING											
• Grading, matching, cutting, scarfing, sewing		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Pressing, winding, glazing		U	750	1500	3000	Avg	U	750	1500	3000	Avg
LOGGING - OUTDOOR	See also Saw Mills										
• Active log handling area	Water	H	10	20	40	Avg	H	10	20	40	Avg
• LZ4[i]		H	10	20	40	Avg	H	10	20	40	Avg
• LZ3[i] (and LZ4 curfew)		H	10	20	40	Avg	H	10	20	40	Avg
• LZ2[i] (and LZ3 curfew)		G	7.5	15	30	Avg	G	7.5	15	30	Avg
• LZ1[i] (and LZ2 curfew)		F	5	10	20	Avg	F	5	10	20	Avg
• LZ0[i] (and LZ1 curfew)		-	0	0	0	-	-	0	0	0	-
• Active log storage area	Land										
• LZ4[i]		D	3	6	12	Avg	D	3	6	12	Avg
• LZ3[i] (and LZ4 curfew)		D	3	6	12	Avg	D	3	6	12	Avg
• LZ2[i] (and LZ3 curfew)		D	3	6	12	Avg	D	3	6	12	Avg
• LZ1[i] (and LZ2 curfew)		C	2	4	8	Avg	C	2	4	8	Avg
• LZ0[i] (and LZ1 curfew)		-	0	0	0	-	-	0	0	0	-
• Log bins	Land	H	10	20	40	Avg	H	10	20	40	Avg
• Log booming area foot traffic	Water	F	5	10	20	Avg	F	5	10	20	Avg
• Log grading	Water or land	K	25	50	100	Avg	K	25	50	100	Avg
• Log loading and unloading		K	25	50	100	Avg	K	25	50	100	Avg
• Log stowing	Water	D	3	6	12	Avg	D	3	6	12	Avg
• Yarding		I	15	30	60	Avg	I	15	30	60	Avg
LUMBER YARDS	Outdoor										
• LZ4[i]		F	5	10	20	Avg	F	5	10	20	Avg
• LZ3[i] (and LZ4 curfew)		F	5	10	20	Avg	F	5	10	20	Avg
• LZ2[i] (and LZ3 curfew)		D	3	6	12	Avg	D	3	6	12	Avg
• LZ1[i] (and LZ2 curfew)		C	2	4	8	Avg	C	2	4	8	Avg
• LZ0[i] (and LZ1 curfew)		-	0	0	0	-	-	0	0	0	-

Table 30.2 | Industrial Illuminance Recommendations continued next page

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Max:Avg	Avg:Min	Max:Min	Task Proper or Task Area	Room or Designated Area
		3:1		
		3:1		
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		3:1		
		3:1		
		3:1		
		10:1		
		10:1		
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e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or polished metalic surfaces, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

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		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
MEAT PACKING											
• Cleaning, cooking, grindir		P	150	300	600	Avg	P	150	300	600	Avg
• Slaughtering		P	150	300	600	Avg	P	150	300	600	Avg
NUCLEAR POWER PLANTS	See also Electric Generating Stations										
• Auxiliary building, uncontrolled access areas		N	75	150	300	Avg	N	75	150	300	Avg
• Controlled acccess areas											
• Count room		S	375	750	1500	Avg	O	100	200	400	Avg
• Diesel generator building		P	150	300	600	Avg	L	37.5	75	150	Avg
• Engineering safety equipment		P	150	300	600	Avg	P	150	300	600	Avg
• Fuel handling building											
• Below operating floor		N	75	150	300	Avg	J	20	40	80	Avg
• Operating floor		P	150	300	600	Avg	L	37.5	75	150	Avg
• Health physics office	See 27 | LIGHTING FOR HEALTH CARE										
• Hot laundry		P	150	300	600	Avg	P	150	300	600	Avg
• Medical aid room		U	750	1500	3000	Avg	Q	200	400	800	Avg
• Off gas building		N	75	150	300	Avg	N	75	150	300	Avg
• Radwaste building		P	150	300	600	Avg	P	150	300	600	Avg
• Reactor building											
• Below operating floor		N	75	150	300	Avg	J	20	40	80	Avg
• Operating floor		P	150	300	600	Avg	L	37.5	75	150	Avg
• Storage room		N	75	150	300	Avg	J	20	40	80	Avg
PAINT MANUFACTURING											
• Mix comparison		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Processing		P	150	300	600	Avg	P	150	300	600	Avg
PAPER-BOX MANUFACTURING		S	375	750	1500	Avg	S	375	750	1500	Avg
PARKING AREAS	See 26 | LIGHTING FOR EXTERIORS										

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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
PETROLEUM, CHEMICAL, PETROCHEMICAL PLANTS											
• Building											
• Clock house, entrance											
• Entrance gate, inspection		N	75	150	300	Avg	J	20	40	80	Avg
• General		I	15	30	60	Avg	E	4	8	16	Avg
• Garage and firehouse											
• Storage and minor repairs		P	150	300	600	Avg	L	37.5	75	150	Avg
• First aid room		R	250	500	1000	Avg	N	75	150	300	Avg
• Nonprocess areas											
• Aircraft obstruction lighting	Refer to FAA regulations										
• Cooling water pump houses											
• Pump area		K	25	50	100	Avg	K	25	50	100	Avg
• General control area		N	75	150	300	Avg	N	75	150	300	Avg
• Control panel		O	100	200	400	Avg	O	100	200	400	Avg
• Boiler and compressor plants											
• Indoor equipment		O	100	200	400	Avg	O	100	200	400	Avg
• Outdoor equipment		K	25	50	100	Avg	K	25	50	100	Avg
• Electrical substation											
• Outdoor switch yards		H	10	20	40	Avg	D	3	6	12	Avg
• General substation-outdoor		H	10	20	40	Avg	D	3	6	12	Avg
• Substation operating aisles		N	75	150	300	Avg	J	20	40	80	Avg
• General substation-indoor		K	25	50	100	Avg	G	7.5	15	30	Avg
• Switch racks		K	25	50	100	Avg	K	25	50	100	Avg
• Loading racks											
• General area		K	25	50	100	Avg	G	7.5	15	30	Avg
• Tank car		M	50	100	200	Avg	I	15	30	60	Avg
• Tank trucks, loading point		M	50	100	200	Avg	I	15	30	60	Avg
• Loading and unloading											
• Plant road lighting	Where lighting is required										
• Frequent use	Trucking	C	2	4	8	Avg	A	0.5	1	2	Avg
• Infrequent use		B	1	2	4	Avg	A	0.5	1	2	Avg
• Plant parking lots	See 26 | LIGHTING FOR EXTERIORS										
• Tanker dock facilities	Consult authority having jurisdiction										
• Tank fields	Where lighting is required										
• Ladders and stairs		D	3	6	12	Avg	D	3	6	12	Avg
• Gaging area		F	5	10	20	Avg	F	5	10	20	Avg
• Manifold area		D	3	6	12	Avg	D	3	6	12	Avg
• Process areas											
• General process units											
• Compressor houses		O	100	200	400	Avg	K	25	50	100	Avg
• Cooling towers	Equipment areas	K	25	50	100	Avg	K	25	50	100	Avg
• Furnaces		I	15	30	60	Avg	I	15	30	60	Avg

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		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
PETROLEUM, CHEMICAL, PETROCHEMICAL PLANTS	(Process areas/General process units continued)										
• Gage glasses		K	25	50	100	Avg	K	25	50	100	Avg
• General area		F	5	10	20	Avg	B	1	2	4	Avg
• Hat exchangers		I	15	30	60	Avg	I	15	30	60	Avg
• Instruments	On process units	K	25	50	100	Avg	K	25	50	100	Avg
• Ladders and stairs											
• Active		K	25	50	100	Avg	G	7.5	15	30	Avg
• Inactive		F	5	10	20	Avg	B	1	2	4	Avg
• Maintenance platforms		F	5	10	20	Avg	F	5	10	20	Avg
• Operating platforms		K	25	50	100	Avg	K	25	50	100	Avg
• Pump rows, valves, manifolds		K	25	50	100	Avg	K	25	50	100	Avg
• Separators		K	25	50	100	Avg	K	25	50	100	Avg
• Control rooms and houses											
• Central cotrol house		R	250	500	1000	Avg	N	75	150	300	Avg
• Console		R	250	500	1000	Avg	R	250	500	1000	Avg
• Back of panel		M	50	100	200	Avg	M	50	100	200	Avg
• Instrument panel		R	250	500	1000	Avg	R	250	500	1000	Avg
• Ordinary control house		P	150	300	600	Avg	L	37.5	75	150	Avg
• Console		P	150	300	600	Avg	P	150	300	600	Avg
• Back of panel		M	50	100	200	Avg	M	50	100	200	Avg
• Instrument panel		P	150	300	600	Avg	P	150	300	600	Avg
• Specialty process units											
• Conveyor transfer points		K	25	50	100	Avg	K	25	50	100	Avg
• Conveyors		H	10	20	40	Avg	H	10	20	40	Avg
• Electorlytic cell room		K	25	50	100	Avg	K	25	50	100	Avg
• Electric furnace		K	25	50	100	Avg	K	25	50	100	Avg
• Extruders and mixers		O	100	200	400	Avg	O	100	200	400	Avg
• Kilns	Operating area	K	25	50	100	Avg	K	25	50	100	Avg
PLATING		P	150	300	600	Avg	P	150	300	600	Avg
POWER PLANTS	See Electric Generating Stations										
POULTRY INDUSTRY	See also Farms/Dairy										
• Brooding, production, and laying houses											
• Charts and records		P	150	300	600	Avg	P	150	300	600	Avg
• Feeding, inspection, cleaning		N	75	150	300	Avg	N	75	150	300	Avg
• Instrumentation	Thermometers, time clocks	P	150	300	600	Avg	P	150	300	600	Avg
• Egg handling, packing, shipping											
• Egg quality inspection		S	375	750	1500	Avg	S	375	750	1500	Avg
• Egg storage area		N	75	150	300	Avg	J	20	40	80	Avg
• General lighting		S	375	750	1500	Avg	O	100	200	400	Avg
• Loading platform		N	75	150	300	Avg	J	20	40	80	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
		5:1				
		10:1				
		10:1				
		5:1				
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		10:1				
		5:1				
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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
POULTRY INDUSTRY	(continued)										
• Egg processing											
• General lighting		S	375	750	1500	Avg	O	100	200	400	Avg
• Fowl processing plant											
• General	Excluding killing, unloading	S	375	750	1500	Avg	O	100	200	400	Avg
• Government inspection station and grading stations		S	375	750	1500	Avg	S	375	750	1500	Avg
• Unloading and killing area		N	75	150	300	Avg	N	75	150	300	Avg
• Feed storage											
• Charts and records		P	150	300	600	Avg	P	150	300	600	Avg
• Grain, feed rations		N	75	150	300	Avg	N	75	150	300	Avg
• Processing		N	75	150	300	Avg	N	75	150	300	Avg
• Hatcheries											
• Dubbing station		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• General area, loading platform		N	75	150	300	Avg	N	75	150	300	Avg
• Inside incubators		P	150	300	600	Avg	P	150	300	600	Avg
• Sexing		X	2500	5000	10000	Avg	X	2500	5000	10000	Avg
• Machine storage area	Garage and machine shed	L	37.5	75	150	Avg	L	37.5	75	150	Avg
PRINT INDUSTRIES											
• Type foundries											
• Casting		S	375	750	1500	Avg	S	375	750	1500	Avg
• Font assembly-sorting		P	150	300	600	Avg	P	150	300	600	Avg
• Matrix making, dressing type		S	375	750	1500	Avg	S	375	750	1500	Avg
• Printing plants											
• Color inspection and appraisal		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Composing room		S	375	750	1500	Avg	O	100	200	400	Avg
• Imposing stones		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Machine composition		S	375	750	1500	Avg	S	375	750	1500	Avg
• Presses		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Proofreading		U	750	1500	3000	Avg	U	750	1500	3000	Avg
PULP AND PAPER INDUSTRY											
• Maintenance shops and stores											
• Benchboard		R	250	500	1000	Avg	R	250	500	1000	Avg
• Medium		R	250	500	1000	Avg	R	250	500	1000	Avg
• Fine		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Machine work											
• Medium		R	250	500	1000	Avg	R	250	500	1000	Avg
• Fine		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Instrument repair		S	375	750	1500	Avg	S	375	750	1500	Avg
• Electrical rooms		P	150	300	600	Avg	P	150	300	600	Avg
• Heating and ventilating rooms		P	150	300	600	Avg	P	150	300	600	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
PULP AND PAPER INDUSTRY	(continued)										
• Paper mill	Finishing, inspection, shipping										
• Coater and supercalender		S	375	750	1500	Avg	S	375	750	1500	Avg
• Finished rool storage		P	150	300	600	Avg	L	37.5	75	150	Avg
• Cutting and sorting		S	375	750	1500	Avg	S	375	750	1500	Avg
• Trimming		S	375	750	1500	Avg	S	375	750	1500	Avg
• Shipping railroad shed		O	100	200	400	Avg	K	25	50	100	Avg
• Shipping truck shed		O	100	200	400	Avg	K	25	50	100	Avg
• Paper mill machine room											
• Paper machine room basement		P	150	300	600	Avg	L	37.5	75	150	Avg
• Headbox, slice, wire, and press		S	375	750	1500	Avg	S	375	750	1500	Avg
• Working aisle		S	375	750	1500	Avg	O	100	200	400	Avg
• Roll dryer		R	250	500	1000	Avg	R	250	500	1000	Avg
• Calender, reel, winder		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Rewinder		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Mezzanines		P	150	300	600	Avg	L	37.5	75	150	Avg
• Paper mill - preparation											
• Groundwood mill grinder room		S	375	750	1500	Avg	O	100	200	400	Avg
• Beater room		P	150	300	600	Avg	L	37.5	75	150	Avg
• Brown stock washers		R	250	500	1000	Avg	R	250	500	1000	Avg
• SW and HW Kraft bleaching		R	250	500	1000	Avg	R	250	500	1000	Avg
• Basement		P	150	300	600	Avg	P	150	300	600	Avg
• Operating Floor		R	250	500	1000	Avg	R	250	500	1000	Avg
• Lime kiln		P	150	300	600	Avg	P	150	300	600	Avg
• Color plant		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Digester operating floors		P	150	300	600	Avg	L	37.5	75	150	Avg
• Digester inactive floors		O	100	200	400	Avg	K	25	50	100	Avg
• Power plant - interior	Power boiler and recovery boiler										
• Air conditioning equipment		M	50	100	200	Avg	M	50	100	200	Avg
• Air preheater and fan floor		M	50	100	200	Avg	M	50	100	200	Avg
• Ash sluicing		M	50	100	200	Avg	M	50	100	200	Avg
• Auxiliaries	Pumps, tanks, compressors, gauge areas	O	100	200	400	Avg	O	100	200	400	Avg
• Battery rooms		P	150	300	600	Avg	P	150	300	600	Avg
• Boiler platforms		O	100	200	400	Avg	O	100	200	400	Avg
• Burner platforms		P	150	300	600	Avg	P	150	300	600	Avg
• Cable room		M	50	100	200	Avg	M	50	100	200	Avg
• Coal handling systems		M	50	100	200	Avg	M	50	100	200	Avg
• Coal pulverizer		O	100	200	400	Avg	O	100	200	400	Avg
• Control rooms:											
• Main control boards		R	250	500	1000	Avg	N	75	150	300	Avg
• Auxiliary control panels		R	250	500	1000	Avg	R	250	500	1000	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
PULP AND PAPER INDUSTRY	(Power plant/control room, continued)										
• Operator's station		T	500	1000	2000	Avg	P	150	300	600	Avg
• Maintenance and wiring areas		P	150	300	600	Avg	L	37.5	75	150	Avg
• Emergency operating lighting		I	15	30	60	Avg	I	15	30	60	Avg
• Gauge reading		P	150	300	600	Avg	P	150	300	600	Avg
• Floors	Condensers, deaerator, evaporator, heaters	M	50	100	200	Avg	I	15	30	60	Avg
• Hydrogen and CO_2 manifold area		O	100	200	400	Avg	O	100	200	400	Avg
• Precipitators		M	50	100	200	Avg	M	50	100	200	Avg
• Screen house		O	100	200	400	Avg	O	100	200	400	Avg
• Soot or slay blower platform		N	75	150	300	Avg	N	75	150	300	Avg
• Steam headers and trottles		M	50	100	200	Avg	M	50	100	200	Avg
• Switchgear, motor control centers		P	150	300	600	Avg	P	150	300	600	Avg
• Telecom equipment rooms		O	100	200	400	Avg	O	100	200	400	Avg
• Tunnels or galleries	Piping and electrical	M	50	100	200	Avg	M	50	100	200	Avg
• Turbine building:											
• Operating floor		R	250	500	1000	Avg	R	250	500	1000	Avg
• Below operating floor		O	100	200	400	Avg	O	100	200	400	Avg
• Visitors' gallery		O	100	200	400	Avg	O	100	200	400	Avg
• Water treatment area		P	150	300	600	Avg	P	150	300	600	Avg
• Roadways											
• Conveyors		H	10	20	40	Avg	H	10	20	40	Avg
• Log unloading		K	25	50	100	Avg	K	25	50	100	Avg
• Log pile-active		I	15	30	60	Avg	I	15	30	60	Avg
• Log pile-storage		D	3	6	12	Avg	D	3	6	12	Avg
• Parking lots	See 26 | LIGHTING FOR EXTERIORS										
QUARRIES											
• LZ4i		K	25	50	100	Avg	K	25	50	100	Avg
• LZ3[i] (and LZ4 curfew)		K	25	50	100	Avg	K	25	50	100	Avg
• LZ2[i] (and LZ3 curfew)		J	20	40	80	Avg	J	20	40	80	Avg
• LZ1[i] (and LZ2 curfew)		I	15	30	60	Avg	I	15	30	60	Avg
• LZ0[i] (and LZ1 curfew)		-	0	0	0	-	-	0	0	0	-
RAILROAD YARDS	Outdoor										
• Body		F	5	10	20	Avg	F	5	10	20	Avg
• Container-on-flatcars		I	15	30	60	Avg	I	15	30	60	Avg
• Control tower and retarder area	Vertical illuminance						M	50	100	200	Avg
• Head end		K	25	50	100	Avg	K	25	50	100	Avg
• Hump area	Vertical illuminance						O	100	200	400	Avg
• Dispatch or forwarding yard		F	5	10	20	Avg	F	5	10	20	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
		3:1				
		3:1				
		10:1				
		3:1				
		5:1				
		5:1				
		5:1				
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		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
RAILROAD YARDS	(continued)										
• Flat switching yard											
• Side of cars (vertical)							K	25	50	100	Avg
• Switch points		H	10	20	40	Avg	H	10	20	40	Avg
• Hump and car rider classification yard											
• Hump area		K	25	50	100	Avg	K	25	50	100	Avg
• Pull-out end		H	10	20	40	Avg	H	10	20	40	Avg
• Retarder classification yards											
• Receiving yard											
• Switch points		H	10	20	40	Avg	H	10	20	40	Avg
• Body of yard		F	5	10	20	Avg	F	5	10	20	Avg
• Trailer-on-flatcars											
• Horizontal surface of flatcar		K	25	50	100	Avg					
• Hold-down points	Vertical illuminance						K	25	50	100	Avg
RUBBER GOODS - MECHANICAL											
• Extruded products		R	250	500	1000	Avg	R	250	500	1000	Avg
• Fabric preparation, stock cutting		R	250	500	1000	Avg	R	250	500	1000	Avg
• Hose looms		R	250	500	1000	Avg	R	250	500	1000	Avg
• Inspection		V	1000	2000	4000	Avg	V	1000	2000	4000	Avg
• Molded products and curing		R	250	500	1000	Avg	R	250	500	1000	Avg
• Stock preparation											
• Plasticating, miling, Banbury		P	150	300	600	Avg	P	150	300	600	Avg
• Calendering		R	250	500	1000	Avg	R	250	500	1000	Avg
RUBBER TIRE MANUFACTURING											
• Banbury		P	150	300	600	Avg	P	150	300	600	Avg
• Bead building		R	250	500	1000	Avg	N	75	150	300	Avg
• Calendering											
• General		P	150	300	600	Avg	P	150	300	600	Avg
• Letoff and windup		R	250	500	1000	Avg	R	250	500	1000	Avg
• In-process stock											
• At tires		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Curing											
• At molds		S	375	750	1500	Avg	S	375	750	1500	Avg
• General		P	150	300	600	Avg	P	150	300	600	Avg
• Inspection											
• General		T	500	1000	2000	Avg	P	150	300	600	Avg
• Storage		O	100	200	400	Avg	O	100	200	400	Avg
• Stock cutting											
• Cutters and splicers		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• General		P	150	300	600	Avg	P	150	300	600	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
RUBBER TIRE MANUFACTURING	(continued)										
• Tire building											
• At machines		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• General		R	250	500	1000	Avg	N	75	150	300	Avg
• Tread stock											
• Booking and inspection		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Check weighing		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Extruder		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• General		R	250	500	1000	Avg	N	75	150	300	Avg
• Width measuring		T	500	1000	2000	Avg	T	500	1000	2000	Avg
SAFETY	See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY										
SAWMILLS											
• Basement areas											
• Active		I	15	30	60	Avg	E	4	8	16	Avg
• Inactive		I	15	30	60	Avg	E	4	8	16	Avg
• Chipper infeed		L	37.5	75	150	Avg	L	37.5	75	150	Avg
• Dry kiln coiling shed		L	37.5	75	150	Avg	H	10	20	40	Avg
• Dry lumber warehouse	Planer	N	75	150	300	Avg	J	20	40	80	Avg
• Finished lumber grading		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Head saw	Cutting area viewed by saw	S	375	750	1500	Avg	S	375	750	1500	Avg
• Head saw cutfeed	Bull edger, resaws, edgers, trim, hula saws, planers	L	37.5	75	150	Avg	L	37.5	75	150	Avg
• Machine in-feeds		L	37.5	75	150	Avg	L	37.5	75	150	Avg
• Main mill floor	Ambient lighting	I	15	30	60	Avg	E	4	8	16	Avg
• Rough lumber grading		P	150	300	600	Avg	P	150	300	600	Avg
• Secondary log deck		L	37.5	75	150	Avg	L	37.5	75	150	Avg
• Sorting tables		P	150	300	600	Avg	L	37.5	75	150	Avg
• Filing room	Work areas	S	375	750	1500	Avg	O	100	200	400	Avg
SAWMILLS - OUTDOOR	See also Logging										
• Barker in-feed		P	150	300	600	Avg	P	150	300	600	Avg
• Cut-off saw		M	50	100	200	Avg	M	50	100	200	Avg
• Green chain		P	150	300	600	Avg	P	150	300	600	Avg
• Log haul		H	10	20	40	Avg	H	10	20	40	Avg
• Log hoist	Side lift	H	10	20	40	Avg	H	10	20	40	Avg
• Lumber handling area											
• LZ4[i]		H	10	20	40	Avg	H	10	20	40	Avg
• LZ3[i] (and LZ4 curfew)		H	10	20	40	Avg	H	10	20	40	Avg
• LZ2[i] (and LZ3 curfew)		G	7.5	15	30	Avg	G	7.5	15	30	Avg

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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
SAWMILLS - OUTDOOR	(continued)										
• Lumber loading areas											
• LZ4[i]		K	25	50	100	Avg	K	25	50	100	Avg
• LZ3[i] (and LZ4 curfew)		K	25	50	100	Avg	K	25	50	100	Avg
• LZ2[i] (and LZ3 curfew)		J	20	40	20	Avg	J	20	40	20	Avg
• LZ1[i] (and LZ2 curfew)		I	15	30	60	Avg	I	15	30	60	Avg
• Lumber strapping		O	100	200	400	Avg	O	100	200	400	Avg
• Primary log deck		M	50	100	200	Avg	M	50	100	200	Avg
• Wood chip storage areas		D	3	6	12	Avg	D	3	6	12	Avg
SEWN PRODUCTS											
• Cloth inspection and perching		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Computerized designing	Pattern making and grading, digitizing, marker making, and plotting	L	37.5	75	150	Avg	L	37.5	75	150	Avg
• Designing	Pattern drafting and grading, marker making	U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Finished good storage, packing		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Fitting		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Hat manufacture	See Hat Manufacture										
• In-process and final inspection		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Knitting		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Leather working	See Leather Working										
• Machine repair shops		W	1500	3000	6000	Avg	S	375	750	1500	Avg
• Measuring		S	375	750	1500	Avg	S	375	750	1500	Avg
• Opening, raw goods storage		S	375	750	1500	Avg	S	375	750	1500	Avg
• Pressing		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Receiving, packing, shipping		S	375	750	1500	Avg	S	375	750	1500	Avg
• Sewing		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Shading		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Shoe manufacturing	See Shoe Manufacturing										
• Sorting and bluding		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Sponging, decating, rewinding		S	375	750	1500	Avg	S	375	750	1500	Avg
• Spreading and cutting	Includes computerized cutting	U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Stitch marking		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Trim preparation, piping, canvas and pads		U	750	1500	3000	Avg	U	750	1500	3000	Avg

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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
SHEET METAL WORKS											
• Medium bench work		S	375	750	1500	Avg	O	100	200	400	Avg
• Miscellaneous machines		S	375	750	1500	Avg	S	375	750	1500	Avg
• Ordinary bench work		S	375	750	1500	Avg	O	100	200	400	Avg
• Presses, shears, stamps, spinning		S	375	750	1500	Avg	S	375	750	1500	Avg
• Punches		S	375	750	1500	Avg	S	375	750	1500	Avg
• Scribing		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Tin plate inspection, galvanizing		U	750	1500	3000	Avg	U	750	1500	3000	Avg
SHIP YARDS											
• Fabrication area		P	150	300	600	Avg	P	150	300	600	Avg
• General		K	25	50	100	Avg	G	7.5	15	30	Avg
• Ways		M	50	100	200	Avg	M	50	100	200	Avg
SHOE MANUFACTURING - LEATHER											
• Buttonholding		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Buffing, polishing, embossing		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Cleaning, spraying		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Counting		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Cutting and stitching											
• Cutting tables		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Making and finishing		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Marking		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Nailers, sole layers, trimmers, lasters, edge setters		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Skiving		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Sorting		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Stitching dark materials		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
• Vamping		W	1500	3000	6000	Avg	W	1500	3000	6000	Avg
SHOE MANUFACTURING - RUBBER											
• Lining		S	375	750	1500	Avg	S	375	750	1500	Avg
• Making and finishing process		S	375	750	1500	Avg	S	375	750	1500	Avg
• Sole rolling		S	375	750	1500	Avg	S	375	750	1500	Avg
• Upper and sole cutting		P	150	300	600	Avg	P	150	300	600	Avg
• Varnishing		P	150	300	600	Avg	P	150	300	600	Avg
• Vulcanizing		P	150	300	600	Avg	P	150	300	600	Avg
• Washing, coating		P	150	300	600	Avg	P	150	300	600	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
		3:1				
		3:1				
		3:1				
		3:1				
		3:1				
		3:1				
		3:1				
		3:1				
		5:1				
		5:1				
		3:1				
		3:1				
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d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or polished metalic surfaces, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

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Table 30.2 | Industrial Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
SOAP MANUFACTURING											
• Cutting		P	150	300	600	Avg	P	150	300	600	Avg
• Filing and packing soap powder		P	150	300	600	Avg	P	150	300	600	Avg
• Kettle houses		P	150	300	600	Avg	P	150	300	600	Avg
• Soap chip and powder		P	150	300	600	Avg	P	150	300	600	Avg
• Stamping, wrapping and packing		P	150	300	600	Avg	P	150	300	600	Avg
STEEL	See Iron and Steel										
STORAGE BATTERY MANUFACTURING		P	150	300	600	Avg	P	150	300	600	Avg
STORAGE YARDS											
• Active		K	25	50	100	Avg	G	7.5	15	30	Avg
• Inactive		F	5	10	20	Avg	B	1	2	4	Avg
STRUCTURAL STEEL FABRICATION		S	375	750	1500	Avg	S	375	750	1500	Avg
SUGAR REFINING											
• Color inspection		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Grading		S	375	750	1500	Avg	S	375	750	1500	Avg
TESTING											
• General		P	150	300	600	Avg	P	150	300	600	Avg
• Exacting tests	Extra-fine instruments, scales	U	750	1500	3000	Avg	U	750	1500	3000	Avg
TEXTILE MILLS											
• Finishing											
• Fabric dyeing	Printing	P	150	300	600	Avg	P	150	300	600	Avg
• Fabric preparation	Desizing, scouring, bleaching, singeing, and mercerization	P	150	300	600	Avg	P	150	300	600	Avg
• Staple fiber preparation											
• Sorting and grading	Wool and cotton	S	375	750	1500	Avg	S	375	750	1500	Avg
• Stock dyeing, tinting		P	150	300	600	Avg	P	150	300	600	Avg

Table 30.2 | Industrial Illuminance Recommendations continued next page

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
		3:1			■	
		3:1			■	
		3:1				■
		3:1			■	
		3:1			■	
		3:1			■	
		5:1				■
		10:1				■
		3:1				■
		3:1			■	
		3:1			■	
		3:1			■	
		3:1		■	■	
		3:1			■	
		3:1			■	
		3:1			■	
		3:1			■	

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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
TEXTILE MILLS	(continued)										
• Yarn manufacturing											
• Carding	Non-woven web formation	P	150	300	600	Avg	P	150	300	600	Avg
• Combing		P	150	300	600	Avg	P	150	300	600	Avg
• Drawing	Gilling, pin drafting	P	150	300	600	Avg	P	150	300	600	Avg
• Opening and picking	Chute feed	P	150	300	600	Avg	P	150	300	600	Avg
• Roving	Slubbing, fly flame	S	375	750	1500	Avg	S	375	750	1500	Avg
• Spinning	Cap spinning, twisting, texturing	S	375	750	1500	Avg	S	375	750	1500	Avg
• Yarn preparation		S	375	750	1500	Avg	S	375	750	1500	Avg
• Warp tie-in or drawing-in	Automatic	S	375	750	1500	Avg	S	375	750	1500	Avg
• Warping	Beaming, sizing	U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Winding, quilling, twisting		S	375	750	1500	Avg	S	375	750	1500	Avg
TOBACCO PRODUCTS											
• Drying, stripping		P	150	300	600	Avg	P	150	300	600	Avg
• Grading and sorting		U	750	1500	3000	Avg	U	750	1500	3000	Avg
UPHOLSTERING		U	750	1500	3000	Avg	U	750	1500	3000	Avg

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Max:Avg	Avg:Min	Max:Min	Task Proper or Task Area	Room or Designated Area
		3:1		
		3:1		
		3:1		
		3:1		
		3:1		
		3:1		
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Figure 30.2 | Cleanrooms
Special luminaires are usually required in cleanrooms. Power supply and mounting requirements may be unique. Special seals to achieve specific IP ratings may be necessary. Depending on the production processes involved, spectral filtering is used to eliminate optical radiation interference.
» Image ©Chris Close/The Image Bank/Getty

Abnormally low ambient temperatures are usually found in commercial food processing and distribution facilities. Temperatures become an issue if they are below 10° C (50°F) for fluorescent lamps, and -29° C (-20° F) for HID lamps. Fluorescent systems generally require a ballast for low temperature starting if the ambient temperature is lower than 10° C (50° F) for standard lamps and -18° C (0° F) for 800 ma and 1500 ma lamps. At temperatures less than 20° C (68° F) fluorescent lamps stabilize at rated watts but at less than rated lumens. Enclosing the bulb-wall, either with a plastic sleeve or an enclosed optical area, will improve the lumen output. Depending on the type of enclosure and the ambient conditions, the lamp or lamps may heat up the enclosure to normal operating temperature to produce rated lamp lumens.

Most ignitor-start HID ballasts are rated to start a lamp (pulse-start metal halide or high pressure sodium) in temperatures to -40° C (-40°F). Temperatures below this require auxiliary incandescent sources, which warm up the interior of the luminaire until the HID lamp starts. These are usually coupled with a relay, which turns off the incandescent source when the HID lamp starts.

30.2.3 Classified Areas

Classified Areas are where flammable gas or vapors or combustible dust or easily ignitable flyings or fibers are or can be present. These are defined in the National Electric Code (NEC) in the United States in terms of Classes (gas, dust) and Divisions, which define the conditions and manner in which the material is present. The National Fire Protection Association (NFPA) defines the hazardous nature of the space and the requirements for luminaries suitable for application in classified areas. The designer should check with the insurance carrier for the industrial site to determine the exact Class and Division for individual areas. Luminaires that have undergone special testing and subsequently rated for use in these special areas must be used. These involve special gasketing, exterior surfaces, limited maximum operating temperatures, and lamp power.

30.2.4 Cleanrooms

Clean room lighting uses entirely different luminaries than other industrial environments. Clean rooms are sealed, controlled environments designed to eliminate microscopic particles of a specified size. The particle may be dirt, which at a certain size (usually measured in microns) causes quality problems of the manufactured product, such as a silicon chip. The particle could also be an organism, such as a microbe that must be eliminated from an operating room. The Institute of Environmental Sciences (IES) categorizes generic clean rooms by a series of classifications based upon the number of micron particles found in a cubic foot of air inside the room. The categories start at 100,000 parts per cubic foot and get cleaner by factors of ten. Class 10,000, class 1,000, class 100 and class 10 Clean Rooms are all defined by this organization. Quite often, class 100 clean rooms are found inside class 1,000 clean rooms. See Figure 30.2.

Clean room structure usually includes t-grid ceilings of a type not found outside this application. The t-grid is of a larger cross-section, such as 1" or 2" wide and is always gasketed in some fashion. Many of these ceilings are made for walking upon so that the fixtures and High Efficiency Particulate Air (HEPA) filters can be serviced from above.

There are four main types of luminaries used in clean-rooms:

1. Gasketed recessed (troffer) fluorescent
2. Tear-drop surface fluorescent Flow-thru
3. Recessed fluorescent Recessed T5
4. Fluorescent integral to the T-grid

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Gasketed recessed fluorescent luminaries are usually used in the class 100,000 and class 10,000 spaces, and the other three types are used as more and more of the grid-spaces are taken up with filters and cannot be occupied with luminaries.

In most of these construction styles, the important issues are that gasketing seals the room from the outside environment and that the outside surfaces are smooth and cleanable. Prismatic lenses, for example normally are installed "prisms-up" to present a smooth surface to the space.

30.2.5 Components Sub- and Final Assembly

This phase of manufacturing has special requirements not usually found in other industrial operations. Modern industrial requirements have necessitated the construction of buildings with clear bay areas, which may exceed 26,000 m^2 (300,000 ft^2) and truss heights of more than 24 m (80 ft) from floor level. The lighting problems in buildings of this size are not confined to the engineering and design concepts but include the task of maintenance and lamp replacement The use of either a system of catwalks or traveling-bridge cranes may be appropriate to allow access to the lighting units. In some cases, mobile telescoping cranes can be used to reach luminaries from the floor, but the heights involved and obstructions on the floor may make this method of maintenance impractical. Where access is available from the floor, disconnecting hangers and lowering chains can be an effective method for maintaining luminaries in high-bay areas.

One special problem in lighting certain assembly tasks, is that the lighting is usually designed to specific task levels with the assumption that the areas will be completely open, whereas in reality that is seldom so. The lighting from overhead systems is often reduced by the presence of large assemblies or large production equipment. A knowledge of the size and placement of such obstructions is necessary in order for design calculations to accurately predict how a proposed lighting system will perform. See 10 | CALCULATION OF LIGHT AND ITS EFFECTS.

Typical of the types of assemblies found in these facilities are aircraft and automobile subassemblies and the installation of sub-systems in these assemblies for which supplementary lighting is often required.

Assembly of large aircraft sections, for instance, can present special lighting problems. Exterior lighting for joining together these sections requires both horizontal and vertical illuminance as well as lighting installed in such a manner that it will light the underside of the body and wings. Use of floodlights can give both components of light on the exterior body and also provide light to the undersides of the body and wings. Specially mounted luminaries or portable lighting are required to light areas such as landing-gear pockets. High reflectance floor finishes will aid in lighting the underside of assemblies but supplementary lighting is still usually required.

30.2.6 Control Rooms

The control room is the nerve center of facilities such as electric generating plants, electric-dispatch facilities, steam or hot water generating plants, and chemical plants, and it must be continuously monitored. Lighting must be designed with special attention on the comfort of the operator; direct and reflected glare and veiling reflections must be minimized, and luminance ratios must be low. Along with ordinary office-type seeing tasks, the operator has to read gauges, meters and other monitoring devices, often at distances of 3-4.5 m (10-15 ft) away. Reflected glare and veiling reflections must be eliminated from these indicating devices, including those with curved glass faces.

While the practice is not standardized, most control-room lighting involves one of two general categories: diffuse lighting or directional lighting. Diffuse lighting may be from low-luminance, indirect lighting equipment, solid luminous plastic ceilings or louvered

Table 30.3 | SI Dimensional Conversions

US Customary	SI
General	**Hard Conversion**
inches	mm [inches × 25.40]
feet	m [feet × 0.30]
Specific	**Convenient Conversions[a]**
2'	610 mm or 0.6 m
2' 6"	760 mm or 0.75 m
3'	915 mm or 0.9 m
3' 6"	1065 mm or 1.1 m
4'	1220 mm or 1.2 m
5'	1525 mm or 1.5 m

a. Hard conversions rounded for reporting convenience. Not to be confused with metric-sized luminaires or other building materials. Not for precision construction.

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Figure 30.3 | Inspection with General Lighting
Many inspection tasks involve viewing moving items, recognizing defects, and removing the items. The moving items are visually tracked by move the head. General lighting, such as provided by the Low-Bay luminaires used here, is often sufficient.
» Image ©Jim Richardson/CORBIS

ceilings. Directional lighting may be from recessed troffers, which follow the general contour of the control board. (These luminaries must be accurately located to keep reflected light out of the glare zone.) Lighting for the rest of the room may be from any type of low-luminance general lighting equipment.

As control room data displays are more and more digital, the problems concerning lighting and VDTs are more in evidence. Many operators like to have black or dark colored backgrounds on their VDTs in order to increase the contrast between pixel derived data and its background. In this instance the veiling reflection problems are increased over those with light background panel meters. Under these conditions light surfaced walls behind the operator, walls and lighting outside of glass partitions, floors and even light reflecting off the operator's clothing and the table surfaces next to the operator can show up as a veiling reflection in the VDT.

Often, the orientation and tilt angle of the VDT may not be easily adjusted to reduce objectionable screen reflections. In these cases, control of sources of direct and reflected light relative to the screens and operators is even more critical.

30.2.7 Emergency, Safety, and Security Lighting

See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

30.2.8 Food and Drug Processing

Food and drug processing areas generally have additional requirements for construction and materials used in the luminaire. The requirements are documented by sanitation-regulating entities, such as the National Sanitary Foundation (NSF) or the US Department of Agriculture (USDA), and can classify different sections of the food processing area by the proximity of the luminaire to the food. Some classifications call for smooth exterior surfaces to eliminate areas for particle accumulation or bacterial growth. One constant is that glass cannot be exposed. This means that open-lamp and glass-enclosed luminaries are not suitable. In many food processing areas, scheduled pressure washing is required and therefore luminaries must be gasketed to withstand washing. Each facility's pressure washing equipment is different, producing different pressure and flow rates. This information should be obtained from the plant engineering office and luminaire capabilities matched to it. Paint is required to be non-toxic and environmentally neutral, in case it chips or flakes off. Unfinished stainless steel luminaries are popular in the extremes of this type of application. Figure 30.3 illustrates an example of a food processing task.

The color rendering properties of light sources used in food inspection areas are important when examination is based on color appearance.

30.2.9 Inspection

The color of light can be used to increase contrast by either intensifying or subduing certain colors inherent in the seeing task. To intensify a color, the light source should be strong in that color; to subdue a color the source should have relatively low spectral power in that color. For example, it has been found that using a bluish light such as a daylight fluorescent lamp can emphasize imperfections in chromium plating over nickel plating.

Three-dimensional objects are seen in their apparent shapes because of the shadows and highlights resulting from a strong directional component in the incident light. This directional effect is particularly useful in emphasizing texture and defects on uneven surfaces.

Silhouette is an effective means of checking contour with a standard template. Illumination behind the template will show brightness where there is a difference between the contour of the standard and the object to be checked.

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Fluorescence under ultraviolet radiation is often useful in creating contrast. Surface flaws in metal and nonporous plastic and ceramic parts can be detected by the use of fluorescent materials.

The detection of internal strains in glass, lenses, lamp bulbs and transparent plastics may be facilitated by transmitted polarized light. The nonuniform spectral transmittance of strained areas causes the formation of color fringes that are visible to an inspector. With transparent models of structures and machine parts, it is possible to analyze strains under operating conditions.

Successful inspection of very small objects is greatly improved by viewing them through lenses and providing suffiicient illuminance. See Figure 30.4. For production work, the magnified image may be projected on a screen. Because the projected silhouette is many times the actual size of the object, any irregular shapes or improper spacings can be detected readily. Similar devices are employed for the inspection of machine parts where accurate dimensions and contours are essential. One typical device now in common use projects an enlarged silhouette of gear teeth on a profile chart. The meshing of these production gears with a perfectly cut standard is examined on the chart.

There are occasions when moving parts must be inspected or studied while they are operating. Stroboscopic illumination can be effective in this process by adjusting the rate of "strobe" to stop or slow the apparent motion of constant-speed rotating or reciprocating machinery. Stroboscopic lamps give flashes of light at controllable intervals (frequencies). The flashing can be so timed that when the flash occurs, an object with rotating or reciprocating motion is always in exactly the same position and appears to remain stationary. This technique can be very effective in allowing inspection of rotating parts without the necessity of stopping the process.

Some inspection tasks involve large surface areas and the detection of irregularities and finish imperfections. Reflected images of linear light sources can be used to reveal such irregularities and imperfections. See Figure 30.5.

There is a potentially dangerous stroboscopic effect unintentionally produced by fluorescent and HID lamps and other sources operated on magnetic ballasts when flicker occurs on rotating equipment such as drilling, milling and lathe machines. At some rotational speeds, these parts can appear to be stopped when, in fact, they are rotating at a dangerous speed. The use of electronic ballasts to operate lamps at high frequency can virtually eliminate flicker and strobe effects.

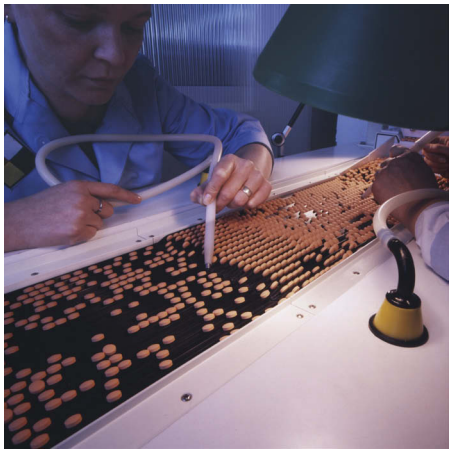


Figure 30.4 | Inspection with Localized Lighting
Some inspection tasks involve not only motion but small items and hand-manipulated instrments. The illuminance levels required are best achieve with local lighting placed close to the task.
» Image ©doc-stock/Corbis

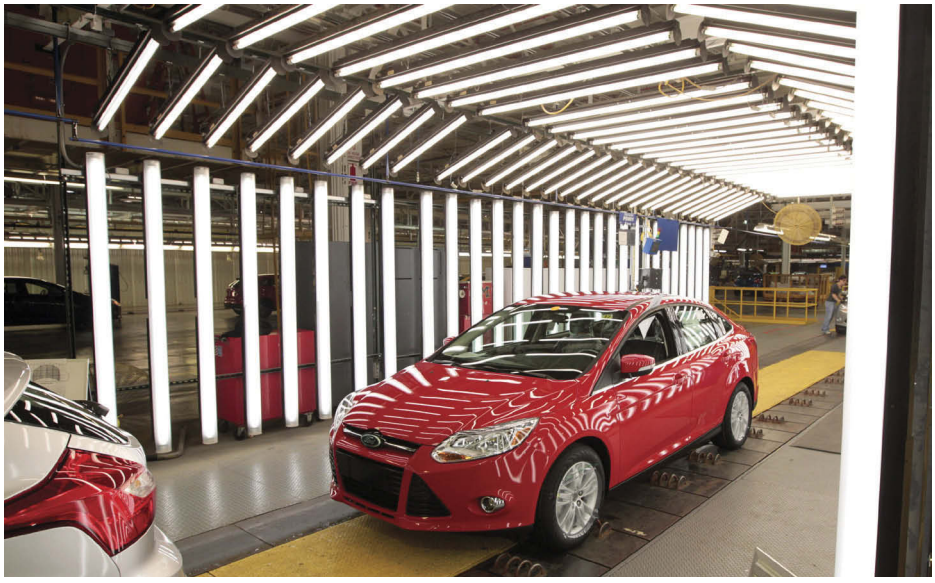


Figure 30.5 | Inspection Using Source Images
Some inspection tasks involve detecting imperfections in surface finishes. This is often best accomplished with multiple sources that are small in at least one dimension, such as the multiple fluorescent strip luminaires used here. Distinct, multiple incident directions of light help model and reveal imperfections. The regular geometric pattern of the reflected source images also help show surface irregularities.
» Image ©2011 Bloomberg via Getty

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30.2.10 Machining and Working with Materials

While computer numerically controlled (CNC) machines do most precision work, there is still considerable hand work, especially as pertaining to set-up work. Machining of metal parts consists of the preparation and operation of machines such as lathes, grinders (internal, external and surface), millers (universal and vertical), shapers and drill presses, bench work, and inspection of metal surfaces. The precision of such machine operations usually depends upon the accuracy of the setup and the careful use of the graduated feed-indicating dials rather than the observation of the cutting tool or its path. The work is usually checked by portable measuring instruments, and only in rare cases is a precision cut made to a scribed line. The fundamental visual task is to discriminate detail on planar or curved metallic surfaces.

Most of the visual tasks in the machining of metal parts are best lighted by large-area low-luminance sources. The ideal general lighting system would have a large indirect component. While both fluorescent and high-intensity discharge sources can be used for general lighting, fluorescent luminaries, particularly in a grid pattern, are sometimes preferred for low mounting heights. High-reflectance room surfaces improve illumination and visual performance. Luminaire placement is often constrained by the location and size of building structure and other occluding elements, as well as the size and position of the equipment that needs to be lighted. These constraints often help define the required optics and intensity distribution of the luminaires to be used. See Figure 30.6.

Workers often refer to information on a VDT or other digital display, so the potential for veiling reflections produced by luminaries, light surfaced walls, and windows must anticipated.

Industrial visual task often involve surfaces (metallic or otherwise) that are shaped and exhibit nondiffuse reflectance. These characteristics are important considerations in choosing and placing lighting equipment.

Convex Surfaces
Discriminating detail on a convex surface, as in reading a convex scale on a micrometer caliper, is a typical seeing task. The reflected image of a large-area low-luminance source on the scale provides excellent contrast between the dark figures and divisions and the bright background without producing reflected glare. The use of a near-point source for such applications results in a narrow, brilliant band that obscures the remainder of the scale because of the harsh specular reflection and loss of contrast between the figures or divisions and the background.

Flat Surfaces
In viewing a flat surface, such as a flat scale, the seeing task is similar to that in reading a convex scale. With a flat scale, however, it is possible, depending on the size, location and shape of the source, to reflect the image of the source either on the entire scale, or only on a small part of it. If the reflected image of the source is restricted to too small a part of the scale, the reflection is likely to be glaring.

Scribe Marks
The visibility of scribed marks depends upon the characteristics of the surface, the orientation of the scribed mark and the nature of the light source. Directional light produces good visibility of scribed marks on untreated cold-rolled steel if the marks are oriented for maximum visibility, so that the luminance of the source is reflected from the side of the scribed mark to the observer's eye. Unfortunately, this technique reduces the visibility of other scribed marks. Better results are obtained with a large-area low-luminance source. If the surface to be scribed is treated with a low-reflectance dye, the process of scribing will remove the dye and expose the surface of the metal. Such scribing appears bright against a dark background. The same technique is appropriate for lighting specular or diffuse aluminum. In this case, the scribed marks will appear dark against a bright background.

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Figure 30.6 | Machining
Luminaires carfully located with respect to overhead obstructions and machines can provide the general lighting needed in many industrial areas. The fluorescent wrap-around luminaires used here, along with the high reflectance ceiling provide efficient horiztonal and vertical illuminances at all task locations.
» Image ©moodboard/Corbis

Center-Punch Marks
A visual task quite similar to scribing is that of seeing center-punch marks. Maximum visibility is obtained when the side of the punch opposite the observer reflects the luminance of a light source. A directional source located between the observer and the task provides excellent results when the light is at an angle of about 45° with the horizontal.

Concave Specular Surfaces
The inspection of concave specular surfaces is difficult because of reflections from surrounding light sources. Large-area, low-luminance sources provide the best visibility. In the machining of small metal parts, a low-luminance source of approximately 1700 cd/rn^2 is desirable. The size of the source depends on the shape of the machined surface and the area from which it is desired to reflect the brightness. The techniques applicable to specular reflections can also be applied to semispecular surfaces.

30.2.11 Outdoor Area Lighting

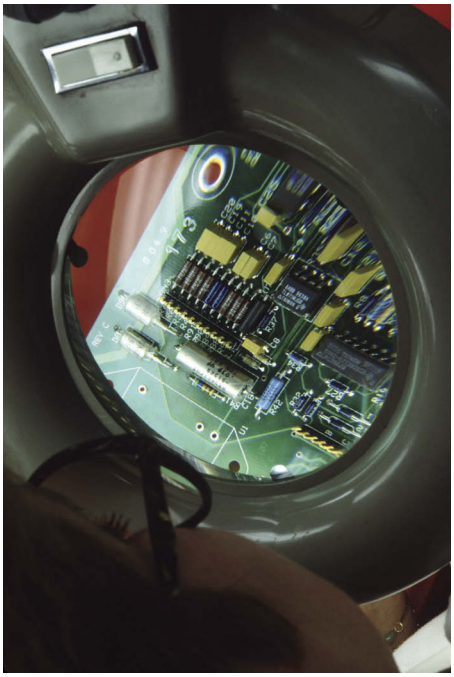
Two different systems of lighting are commonly used to illuminate large, outdoor areas of industrial facilities: projected (long-throw) lighting and distributed lighting. Each has its advantages under specific situations.

Projected Lighting Systems
The function of this system is to provide illumination from a minimum of locations throughout the various outdoor work areas. This is usually accomplished by use of aimmable floodlighting luminaries.

Projected outdoor area lighting has the fewest locations and thus requires the least amount of aerial structure. Structures are usually the most expensive part of the lighting system.

Distributed Lighting Systems
In distributed lighting systems luminaries are installed at many locations. Wall mounted equipment is often used at personnel and loading dock doors. Wall mounted equipment, however, should rarely be used to cover a transverse dimension greater than two mounting heights and a longitudinal (horizontal, to the side) area more than 4 mounting heights. This would place continuous area lighting equipment on 4 mounting height spacing along a wall.

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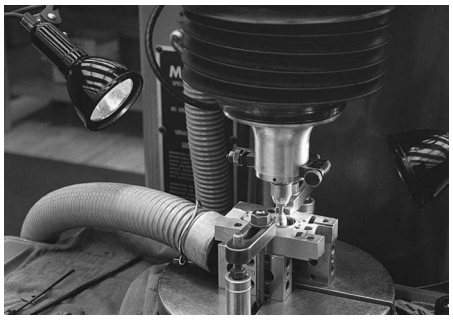


Figure 30.7 | Supplementary Task Lighting
Top Image. Some tasks are sufficiently small to require supplementary lighting as well as manifcation. Here, a circular fluorescent lamps is used around the magnifiying lens in a single supplementary task lighting luminaire.

Bottom Image. Some machining tasks are performed on equipment that is so large that only supplementary lighting can provide the necessary illuminance. Here a small adjustable, high intensity luminaire, can be moved with work and/or machine

» Top image ©Robert Essel NYC/Corbis

Distributed outdoor area lighting systems have the least amount of glare because mounting heights can be lower. When floodlights are used, aiming angles can be less oblique, thus permitting glare control media such as louvers and visors to work. Care should be taken to keep aiming angles below 65 degrees above nadir.

See also 26 | LIGHTING FOR EXTERIORS.

30.2.12 Supplementary Task Lighting

Difficult visual tasks, such as inspection, often require a specific quality and quantity of light that cannot readily be obtained by general lighting methods. Supplementary luminaries are often used to:

- Provide higher illuminances
- Direct attention on small or restricted areas
- Achieve a certain luminance
- Provide a specific color rendition
- Permit special aiming or positioning of light sources to produce/avoid highlights or shadows
- Reveal the details of the visual task.

The specific requirement of each visual task need to be evaluated before supplementary task lighting can be specified. Simply adding lighting at the task with no consideration for the light reflecting or transmitting characteristics of the object(s) observed will be ineffective. An improvement in the visibility of the task will depend upon improvement of one or more of the four fundamental visibility factors - luminance, contrast (chromatic or achromatic), size and time.

The planning of supplementary task lighting also requires consideration of the visual comfort of workers performing the task and other workers in the immediate area. Supplementary equipment must be carefully shielded to prevent glare for the user and neighboring workers. Luminance ratios should be carefully controlled.

Wherever possible, supplementary luminaries should be permanently mounted in the location where they can produce the best lighting effect and maintenance after assembly. Portable equipment, however, can be used to good advantage where it must be moved in and around movable machines or objects, as in airplane assembly, or in maintenance operations where internal surfaces must be viewed. The luminaries must be mechanically and electrically rugged to withstand possible rough handling. Lamps should be guarded and of the rough-service type. Guards or other means should protect the user from excessive heat. Precautions, such as the use of ground fault circuit interrupters for personnel protection, should be taken to prevent electrical shock, and electrical connections must be suitable for the service to which they will be subjected. See Figure 30.7.

30.2.13 Visibility of Objects

The visibility of objects in industrial facilities is necessary not only for the correct and efficient performance of visual work, but the safety of workers as well. In addition to the recommended illuminances shown in Table 30.2, task visibility in an industrial environment often requires particular attention to contrast, flicker, modeling, source geometry, and shadowing as fundamental components of task visibility.

Contrast
Luminance and color contrast can be enhanced with appropriate choices of materials and sources. Color contrast and color rendering may be the most important aspect of a tasks visibility. See 6 | COLOR.

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Flicker

Flicker is the rapid variation in light source intensity, usually most noticeable in peripheral vision. The output of lighting systems that operate on alternating current power varies in output at a rate that is twice the cyclic frequency of the input power. Sometimes this "strobe effect" appears to slow or even stop the movement of objects. This can be annoying or dangerous for operators of rotating or other rapidly cycling equipment.

The "flicker index" has been established as a reliable relative measure of the cyclic variation in output of various light sources at a given power frequency and takes into account the waveform of the light output as well as its amplitude. The flicker index assumes values from 0 to 1.0 with zero for steady light output. Higher values indicate increased possibility of noticeable stroboscopic effect as well as lamp flicker.

Most fluorescent lamps have low flicker indices, and typically do not cause problems when operating on a 60-Hz power supply. Their visible flicker is virtually eliminated when operated at high frequency on electronic ballasts. Sensitivity to flicker varies among individuals, varies across the visual field and often will be unnoticed. Designers are cautioned to consult with a lamp manufacturer about the flicker index of a particular fluorescent lamp/ballast combination before it is used in an area where flicker or strobe could be a problem.

The flicker in HID lamps depends on the lamp type and the ballast circuit. The flicker index is considerably higher in 50-Hz power systems. Using electronic ballasts having high-frequency or rectangular wave characteristics can be effective in reducing the flicker effect. Operating fluorescent or HID lamps on alternate phases of a three-phase power supply will reduce observed flicker when the light from luminaries connected to all three phases is well mixed before it reaches the workplane. This is accomplished by using luminaries with a wider spacing criterion, designing for 50 percent light pat tem overlap, and powering adjacent luminaries from alternate phases.

Modeling

Lighting will reveal the depth, shape and texture of an object. In industrial applications, modeling of the visual task can be critical to assessing quality of raw materials, quality of finished goods and degree of consistency in manufacturing processes. Appropriate direction and distribution of light may vary depending on material and task. Diffuse ambient lighting is often inadequate for assessing fine texture; task lighting may be used to provide the required direction, distribution and intensity of light. See Figure 30.8.

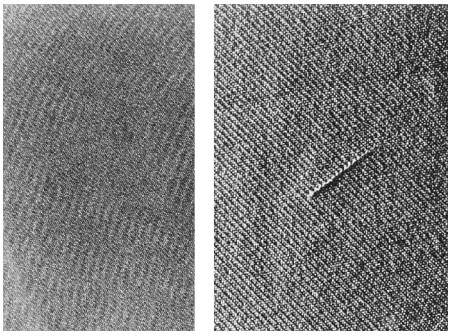


Figure 30.8 | Modeling
Diffuse lighting (left) does not show pulled thread but grazing or directional lighting (right) reveals a pulled thread by generating its shadow.

Source-Eye Geometry

The angular relationships between the viewer, the task and the luminaire are frequently critical to task visibility. Industrial tasks are often three-dimensional, and they often move. Because viewing angles are dynamic, the source/task/eye geometric relationships must be understood for individual work areas. The geometry can enhance contrast (such as scribed marks on a micrometer) or reduce it (such as viewing a meter dial through glass).

Shadows

Shadows can interfere with task visibility by placing detail in darkness (for example, a body shadow on a machine task), or they can enhance definition of three-dimensional details (such as imperfections in textiles). Point sources (such as incandescent or high intensity discharge lamps) create more defined shadows than fluorescent lamps, which produce diffuse shadows.

Generally, a large area of shadow, covering the whole task area, will simply lower the task illuminance. Shadows cast by the structure of the task may reveal detail, or may mask what needs to be seen. High reflectance surroundings help fill in and modify shadows, as do luminaries with 10 percent or more uplight when the ceiling cavity reflectance is over

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Figure 30.9 | Warehouse Lighting
The tall narrow aisles established by warehouse shelving and stock require relatively uniform vertical illuminances. Here, HID high bay luminaires with an intensity distribution appropriate to the aisle width and stack height illuminate the vertical surfaces.
» Image ©moodboard/Corbis

50 percent. A combination of supplementary task lighting and general illumination is often the best approach, if care is taken to minimize glare.

The presence of shadows may be desirable, and the interplay of highlight and shadow helps to define the form of many visual tasks. Lighting vertical surfaces to at least half the horizontal illuminance level often brings the ratio of highlight to shadow into a tolerable range for three-dimensional tasks. Some shadow will still be present, which helps to model the task and reveal form. Since each visual task has an optimum range of modeling, a careful evaluation of critical visual tasks should be made to determine the effects of various ratios of horizontal vs. vertical illuminance on visibility.

Obstructions below the luminaire mounting plane, such as pipes and ducts, and the location and orientation of the task, affect the availability of vertical illuminance. Obstructions can also produce shadows, as can an operator positioned between the task and the luminaries. When a task is close to a wall, and the operator is facing the wall, relatively few luminaries are likely to contribute to task illuminance. In these cases, high wall reflectances (greater than 60 percent) can improve task visibility

30.2.14 Warehouses

Placing items in storage, accounting for them and later retrieving them are some of the most widespread activities requiring electric lighting in industrial facilities. Storage activities are found in business operations of every type, ranging from small local operations to multinational corporations.

Since rapid changes are taking place, the traditional concept of the warehouse must be expanded to encompass new techniques, including automation, high-rise storage, bar coding, cold storage, and shrink-wrap packaging. Warehouses may contain any of the following areas and activities.

Storage Systems
A variety of warehouse areas and storage systems requiring specific tasks may occur in warehouse usage. In each case the nature of the storage area determines the task plane and the nature of objects that can produce unwanted shadowing.

- Open Storage. Areas of material stored without the use of rack systems. This includes storage on the floor and on pallets, which may be stacked on each other.

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Figure 30.10 | Warehouse Lighting
Here, fluorescent high bay luminaires illuminate vertical warehouse stock surfaces. Sensor and controls systems can be used to dim the luminaires and take advantage of the daylight available from skylights.
» Image ©Ian Lishman/Juice Images/Corbis

- High Rise. Areas generally automated, where storage bins may be rotated so that unused bins are kept high up, and with storage levels rising to over 30.5 m (100 ft).
- Fixed Racking. Areas with fixed racking may range from 1-4 m (3-12 ft) wide and from 2.5-9 m (8 to 30 ft) high. Items may be in bins, on racks, or in various types of containers. Labeling of the racks, containers or bins can vary from large black-on-white lettering to small, hard-to-read hand written labels.
- Mobile Racking. A storage system now widely used in North America. Entire blocks of racking move on floor-mounted rails to open and close aisles as needed. In order to obtain maximum use from any lighting provided, the definition of the actual seeing task should be considered.
- Stockroom Area. Identification marks on the sides of bulky materials, rolls of paper, and crates or boxes require vertical illumination. Additional lighting should be provided over the aisles where high piles of stock interfere with general lighting.
- Cold Storage. Areas that warehouse normally perishable food items and require low (sometimes below freezing) temperatures. See 30.2.2 Areas with Extreme Humidity or Temperatures, or with Corrosive Atmospheres.

Figures 30.9 and 30.10 illustrate HID and fluorescent warehouse lighting approaches.

Hazardous Materials
Areas where hazardous gases, vapors, or dust are or could be present require specific methods of storage. Local building code requirements should be checked as to permissible luminaries for lighting areas where hazardous materials are stored or used. See 30.2.3 Classified Areas

Shipping and Receiving
Areas where materials are received into the warehouse for sorting and placement in storage areas. Areas that serve as staging areas for coordination of products to be sorted and placed on trucks or trains to be shipped. One of the most difficult visual tasks is reading markings on shipments, labels and bills of lading. General illumination may provide sufficient light for these tasks and for the operation of manual or powered forklift trucks, as well as for general traffic in the area.

Supplementary lighting may be necessary for the interior of transport carriers bringing material to the plant. Angle or projector-type luminaries may be utilized, but care must

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be taken to avoid glare from these sources. If the conveyances are deep, reel-type or other portable lighting equipment may be necessary. Yard or loading-dock lighting should be installed for night operation.

Loading Docks and Staging
Areas, generally just outside the shipping area, that may be outdoors but are often covered and that are used to place items on and off trucks and railroad cars and to assemble goods.

Maintenance
This includes maintenance shops, fork lift recharging areas and refrigeration equipment rooms. Locations where general plant housekeeping activities occur. Separate areas or rooms are generally set aside for these purposes.

Daylighting
While daylight can be used to help light warehouses, care should be taken to control the quantity and distribution of the light. Daylighting is most effective for many interior warehouse spaces when used as ambient illuminance, but if energy is to be save and its variability managed, an electric lighting system under daylight control is required. See also 14 | DESIGNING DAYLIGHTING.

30.3 Illuminance Criteria

Illuminance criteria, when fully deployed, are a robust set of quantitative values that influence visibility, visual performance, and visual comfort and attention. Short-circuiting the criteria selection or designing to a single criterion value, such as horizontal illuminance over a large area housing machines, is unlikely to satisfy the requirements for the varied tasks being performed. It is unlikely that this will get the most from the energy expended or, worse, will waste energy. Following are notes related to various topics outlined in Table 30.2.

30.3.1 Applications and Tasks

Applications and tasks encountered on any given project may be different from those identified in Table 30.2 and may warrant different illuminance criteria. Cross-referencing closely-associated applications or tasks is appropriate. This is based on similarities of visual size, reflecting properties, difficulty, and importance. Reviewing the list in Table 30.2 may be in order to determine if any applications or tasks exhibit a similar visual-component to the unique applications or tasks. Otherwise, reviewing 4.12 An Illuminance Determination System and Table 4.1 is necessary to establish a task category based on the task characteristics or visual performance descriptions most closely associated with the unique applications or tasks. These exercises as well as any deviations from recommendations the designer intends to make should be carefully documented for the record.

30.3.2 Notes

The notes in Table 30.2 may refer to other task headings in the table or to other handbook chapters as appropriate. Where some degree of clarification is warranted, notes are made.

30.3.3 Recommended Maintained Illuminance Targets

Values cited are maintained on the area of coverage for the task under consideration. Illuminance is additive. Where practical and without negatively affecting the intended application of light, target values are achieved with any combination of daylighting and/or electric lighting in whatever mix of ambient, task, and supplemental lighting is deemed appropriate to meet these and the other lighting goals established during design. See 12 | COMPONENTS OF LIGHTING DESIGN and see 10.7.1 Light Loss Factors.

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With respect to light loss factors, account for anticipated losses through the point in time at which group relamping and cleaning should occur. Group relamping and cleaning should be standard practice and for purposes of sustainability can no longer be presumed to be infrequent or unlikely. Maintenance procedures must be part of the design discussions with the client. See the IES document IESNA/NALMCO RP-36 Recommended Practice for Planned Indoor Lighting Maintenance for additional information. Where maintenance is deferred or practiced poorly or not at all, the actual illuminance values will fall below criteria targets. This is inefficient, unsustainable, and may be unsafe while adversely affecting users' quality of life or work. Ratcheting initial illuminances higher is poor practice and not recommended. Maintenance procedures may be especially problematic with LEDs where promises of extraordinarily long life may be offered, but usually with the caveat that lamp lumen depreciation (LLD) at that rated life is 70% or perhaps even as low as 50% of initial rating. If replacement cycles are presumed to be rated life, then LLD alone must be 0.7 or 0.5 or whatever lumen rating is certified by the LED vendor. See 13.3 Life and Lumen Maintenance.

Targets cited are consensus and recommended for respective functional activity. For some applications, IES recommendations are within 10% of code requirements. This apparently is an artifact of metrication. Footcandle conversions of any values cited in Table 30.2 should be made at 1 fc to 10 lx. This soft conversion avoids a redundant diminishing of illuminance values after multiple citations and conversions over time. This also eliminates a false sense of accuracy advanced by an ever-increasing number of decimal places and a false sense of urgency advanced by eccentric fractional values introduced by hard conversions. Nevertheless, a lighting design must meet code and the mechanics of which must be coordinated amongst the design team. The IES recommendations should not, do not, and cannot reflect all of the various code requirements in force in all jurisdictions at any given time.

Targets are intended to apply to the dominant plane of the task. For industrial environments, this is typically, but not always, horizontal or vertical.

30.3.3.1 Target Planes

Many, though certainly not all, tasks are performed with the task in roughly a horizontal orientation or vertical orientation. A dominant orientation must be assigned and the illuminance target determined accordingly. There may be situations where the IES recommended target relating to the typical planar mode of a task must be applied to a different plane. The task may be three-dimensional and no particular plane is more important than another and it may be necessary to provide the required illuminance on several planes at the task position.

Nearly all tasks are expected to have both a horizontal illuminance component (E_h) and a vertical illuminance component (E_v). This allows some degree of task flexibility for off-plane viewing and accommodates various aspects of the task.

Where illuminance targets are intended at differing planar elevations, this is indicated under "Notes." Note the implication for observers' visual ages. Establishing and tracking task orientations and addressing both horizontal and vertical illuminance is necessary. If orientations in the project under consideration are programmed to be flipped from what might be considered normal-viewing, then criteria must be adjusted accordingly. If a task is scheduled to be oriented on some plane off axis from horizontal or vertical by more than 10°, say, then the illuminance criteria must be applied to that off-axis orientation. This is an important distinction for luminaire optical selection and aiming capabilities and for layout, calculations, and field measurements.

For planes related to vertical illuminance targets, some guidance is indicated under "Notes." However, the designer may elect to use alternate or multiple vertical planes. In some situations the vertical planes could be oriented in a number of directions and the

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designer must determine which are most appropriate for the situation. Understanding the machinery and its operation, the process involved, and the position of the machine operator, is necessary.

30.3.3.2 Visual Ages of Observers

Illuminance criteria are based on the visual ages of more than half the intended observers. This aspect should be resolved during programming with the client. It may be determined that illuminance criteria for an age group other than that representing the majority of the intended observers is appropriate. However, this may result in overlighting, underlighting, harsh lighting, visual displeasure, or visual discomfort for many of the observers. See 12.5.5 Illuminance and 4.12 An Illuminance Determination System for additional information and guidance. In some situations, such as video conferencing, lighting must meet the requirements of the camera technology and, therefore, is not tied to ages of observers.

30.3.3.3 Illuminance Categories

Illuminance categories are designated by letters A through Y. These are shown in Table 30.2 for more convenient reference to Table 4.1 | Recommended Illuminance Targets should the designer wish to explore other criteria targets or if applications or tasks on a specific project are not readily correlated to the table citations.

30.3.3.4 Gauge

The common gauge for determining illuminance target compliance is cited for each application. All gauges presume that point-by-point techniques are used for predictive calculations and presume that uniformity criteria are closely monitored. Where an average illuminance value over the area of coverage can satisfy target compliance, “Avg” is cited. In applications or tasks where a minimum or maximum target is necessary, the gauge for compliance is “Min” or “Max” respectively.

The designer may elect to use other methods to evaluate target compliance, such as criterion rating (CR) or coefficient of variation (C_v). See 4.12.4.5 Tasks at Uncertain Locations Over a Large Area.

In any event, once illuminance targets and uniformities are established, then any calculated deviation from them should be limited. Standard engineering allowance of ±10% might be acceptable for targets gauged as average unless contractual or code obligations demand otherwise. Minima and maxima must be achieved as intended.

Designs should be adjusted until predictions are within allowance for averages and meet minima and maxima. For additional information, see 4.12.4.1 Recommended Illuminances at Design Time, 4.12.5 Illuminance Ratios, 9.15.1.1 Average Illuminance, and 10.8 Assessing Computed Results.

30.3.4 Uniformity Targets

Illuminance uniformity targets work in conjunction with luminance uniformities and surface reflectances all of which must be addressed as part of the design to avoid visual discomfort, glare, and strain. Uniformity ratios are targets that define the widest recommended ranges. In many situations, uniformity ratio criteria are those between average values of an array of points and the minimum value in the same array of points. Uniformity targets apply to both horizontal and vertical illuminances over the area of coverage. Where horizontal uniformity criterion is different from vertical uniformity criterion, two ratios are reported with the first value for horizontal illuminance (E_h). In some situations, notably those with regard to exterior illuminances, two uniformity values are cited. The first value addresses the primary cited application or task. The parenthetical value references the parenthetical application or task, such as a curfew situation associated with nighttime outdoor lighting.

Generally the more important speed and accuracy and the more demanding the visual task, the tighter the ratio.

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30.3.4.1 Maximum-to-average

This is the recommended ratio of maximum illuminance to the average illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations sensitive to even a relatively small degree of overlighting.

30.3.4.2 Average-to-minimum

This is the recommended ratio of average illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where illuminance too far below average conditions is noticeable and detrimental to task performance or inconsistent with normal expectations.

30.3.4.3 Maximum-to-minimum

This is the recommended ratio of maximum illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where too much variation in illuminance is considered undesirable and untenable from a performance or safety perspective.

30.3.5 Daylighting Advancement

Generally, design strategies should embrace any combination of daylighting and electric lighting to achieve target values during daylight hours. The preference is for daylighting to provide all or most of the recommended illuminance presuming that all aspects of daylighting are properly addressed. A sunburst icon depicts those applications and tasks where daylighting is considered a strategic candidate. Use photocells and stepped-dimming or continuous dimming to reduce or eliminate electric lighting during daylight hours. See 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Even for those applications where daylighting is not traditionally a strategic candidate, it may be determined that very careful and coordinated design will offer great sustainability opportunities along with positive influences associated with daylight and views.

30.3.6 Veiling Reflections

Some industrial tasks, like computers with CSA/ISO Type III screens, printed tasks with glossy ink or glossy paper, and many objects made of metals and plastics are prone to specular reflections. In some cases these reflections can help (such as seeing scratches in an otherwise smooth finish), but it others they reduce visibility by causing veiling reflections. The likelihood of particular applications and tasks predisposed to specular reflections is indicated by a "reflected light" icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood. Veiling reflections are minimized by controlling the overall amount and direction of light with respect to the task locations and orientations. Alternatively, tasks sensitive to veiling reflections can be screened or isolated. Effective strategies include employing indirect soft, diffuse electric lighting or direct electric lighting with multiple low-output luminaires, or positioning tasks and luminaires and luminance patterns to avoid harsh reflections from tasks. Addressing luminance recommendations (see Table 12.4 | Default Luminance and Luminaire Intensity Recommendations for VDT Applications) minimizes veiling reflections. Changing the task will reduce or eliminate veiling reflections, such as use of CSA/ISO Type I or II computer screens and matte paper versus their specular counterparts.

30.3.7 Defining Areas of Coverage

In addition to establishing planes of task orientation, the areas of coverage to which targets apply must be determined. Typical areas of task illuminance coverage are identified here, but these may not be appropriate to specific project situations. One area of coverage is "task proper or task area." Here, the illuminance criteria are applied to the task itself or to a relatively small area to which the task is confined. See 12.5.5.1 Applications and Tasks and Figure 12.22 | Task Coverage Example. In some situations, such as accenting, the "task"

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area may consist of the entire wall when "feature wall" or "perimeter" accenting is desired. It is important to remember that illuminance is additive, that is, task illuminance can be achieved with some combination of ambient lighting, task lighting, and/or accent lighting, providing that the total illuminance on the task proper or task area meets the illuminance criteria outlined in Table 30.2.

Another area of coverage is "room or designated area." In this situation, illuminance criteria are applied to the room or an area of fairly substantive size representing the zone in which the applications and tasks are expected to occur. The designated area is typically established by the furniture layout, for example, or might be established by the design team or client. The area-of-coverage citations in Table 30.2 are based on traditional notions. So, for example, it may be determined that a "task proper or task area" coverage would result in some amount of LPD reduction when compared to "room or designated area" coverage. If the task can be confined to one area rather then multiple areas, if the room or area in which the task is located is itself relatively small, such as a single-occupant office, and if the other design goals and criteria outlined in 12 | COMPONENTS OF LIGHTING DESIGN are addressed, then this strategy of redefining area of coverage has merit.

An assessment and determination must be made on which area of coverage best satisfies the lighting goals on a particular project.

30.4 Designing

Information provided here is specific to manufacturing facilities and should be used as part of the design and documentation processes outlined in Chapters 12, 15, and 20. Equipment selection and location strategies may need to address the possibility of lighting equipment abuse. For outdoor applications, lamps and ballasts, transformers, and drivers must be selected for ambient temperature conditions, some of which are extremely hot and others extremely cold. Dimming response to daylight may be impractical. See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY for additional information on respective aspects. Addressing all code requirements is a must. Energy efficient and sustainable practices are an integral part of all IES recommendations. Key design tenets include, but are not limited to:

- designing for the safety and productivity of the workers intended to use the project
- using baseline reflectances of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively) in interior production, holding, and work-oriented spaces
- using daylighting that meets luminance and illuminance criteria
- using highest-efficacy lamps that meet color, optical and electrical control, and output criteria
- using highest-efficiency luminaires that meet aesthetic, abuse, and luminance criteria
- using accenting to provide luminance balancing
- using controls liberally, preferably automated varieties such as presets, occupancy and vacancy sensors, astronomical timeclocks, and photocells
- establishing IES-recommended illuminance criteria to meet programmed tasks
- establishing layouts that just meet IES-recommended illuminance criteria
- addressing outdoor environmental needs
- using calculations, photometrically-realistic renderings, and operational samples and mockups to prove concepts
- identifying and designing to code-specific requirements, if any, for ambient, task, and accent lighting

IESH/10e Economics Resources

> 15.3.3 Budgets
- for more on budgets and value engineering

> 18 | ECONOMICS
- for more on estimating costs
- for more on life cycle costs
- for more on paybacks and rates of return

IESH/10e Energy Efficiency Resources

> 17.2 New Construction
- for more on designing for daylighting
- for more on electric lighting equipment
- for more on lighting controls

> 17.4 Lighting Codes, Regulations and Standards
- for more on application standards
- for more on equipment regulations

IESH/10e Lighting Exteriors Resources

> 12.5.5.6 Nighttime Outdoor Illuminances
- for more on lamp efficacies under mesopic adaptation

> 26 | LIGHTING FOR EXTERIORS
- for more on criteria

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- documenting all code-, energy-, sustainability-, and IES-criteria compliance
- documenting criteria and design deviations and rationale and subsequent disposition by team, client, or AHJ
- documenting clearly the layouts, controls, and luminaire and lamp selections

Designing for the safety and productivity of the workers is the paramount design tenet and must be kept in perspective during all aspects of design. If the workers' expectations are not fulfilled, then how much energy could be saved is moot, as is how many fewer earth resources were spared, as is how much the whole affair cost or how much value engineering saved or the photogenic qualities of the project. See sidebar references for additional guidance on the key tenets. The design effort must be undertaken with coordinated and realistic expectations by all involved on initial and life cycle costs. Budgeting should include designer input and dialogue with the team and client at project commencement and design milestones. In other words, and paraphrasing Thomas Edison, genius is, indeed, just 1% inspiration and 99% perspiration.

IESH/10e Sustainability Resources

> 13.11 Sustainability
- for more on lamps

> 19 | SUSTAINABILITY
- for more on controls
- for more on earth resources
- for more on energy
- for more on life cycle analyses
- for more on lighting design
- for more on recycling

30.5 References

[1] Mark S. Rea, ed. The IESNA Lighting Handbook: Reference and Application, Ninth Edition (New York: Illuminating Engineering Society of North America, 2000), Chapters 5, 10, and 13.

[2] ANSI/IESNA American National Standards Institute, Illuminating Engineering Society of North America. 2001. RP-7-01, American National Standard Recommended Practice for Lighting Industrial Facilities. New York: IESNA. 75p.

[3] Peter Boyce, Human Factors in Lighting, Second Edition (London: Taylor & Francis, 2003), pp. 425-427.

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31 | LIGHTING FOR MISCELLANEOUS APPLICATIONS

Science is organized knowledge. Wisdom is organized life.
Immanuel Kant, 18th Century German Philosopher [1]

Contents

31.1 Project Type and Status. . . 31.2
31.2 Application Types 31.2
31.3 Illuminance Criteria 31.25
31.4 Designing. 31.29
31.5 References 31.30

There are several sets of applications and tasks that are not conveniently categorized with those of other chapters. They are collected here in the format similar to other application chapters in this handbook, though their only relationship to one another is that they arguably qualify as institutional facilities. Certainly all are important applications with demanding tasks supporting commerce, liberties, safety, and security. Lighting addresses the visual needs of users, ranging from 911-call-center tasks to facilitating public forums in council chambers. The applications that are consolidated here are:

- Financial Facilities
- Municipal Facilities
- Post Offices

Financial facilities include banking and trading. Municipal facilities include city halls and fire and police stations. Post offices include consumer services and sorting.

Comprehensive design efforts involve the information in this chapter combined with material in 12 | COMPONENTS OF LIGHTING DESIGN, 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS, 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Design tenets deemed appropriate from those chapters must be identified and lighting goals and strategies developed accordingly. This chapter primarily addresses illuminance criteria for miscellaneous facilities which should influence luminaire optical selections, lampings, and final layouts based on design thought-starters (see 15.2 A Lighting Scheme). Use of the material in this chapter to the exclusion of material in Chapters 12, 13, 14, and 15 will likely lead to unsatisfactory results. Previous IES related documents serve as archival reference sources [2].

Deliberate thought must be given to details beyond the recommended illuminances in this chapter. For example, with MUNICIPAL FACILITIES/Fire Stations/Apparatus Bays/General in Table 31.2, the illuminance citations are intended to apply to the general room in which the emergency vehicles will be secured. This allows for equipment inspection and cleaning on rigs and for basic service and maintenance activities on components in empty bays. However, it is not uncommon for fire stations to serve various civic functions, such as election polling. Should such a situation be programmed, the designer must review the likely voting tasks and determine if the general illuminance for apparatus bays will suffice. The design must know what, if any, additional tasks must be accommodated. A task survey, such as that exemplified in Table 12.3 | Sample Visual Task Survey, should be undertaken. Such details are not enumerated for tasks. Table 31.1 offers a checklist of IES lighting topics and criteria. The design team is responsible for determining and addressing indoor and outdoor lighting and energy criteria set forth by authorities having jurisdiction (AHJ) which may be different from and supersede IES criteria. See also 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

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Table 31.1 | Miscellaneous Applications Lighting Checklist

Topics
✔ **Criteria and Design Resources**
Accenting
15.1.1.3 Accent Lighting
Table 12.2 | Subjective Impressions
Table 15.2 | Accent Illuminance Ratios
Table 22.2 | Common Applications Illuminance Recommendations
Appearance
12.2 Spatial Factors
Color
12.5.6 Color Considerations
Controls
16 | LIGHTING CONTROLS
Daylighting
14 | DESIGNING DAYLIGHTING
Electric Lighting
15 | DESIGNING ELECTRIC LIGHTING
Flicker
4.6 Flicker and Temporal Contrast Sensitivity
Glare
4.10.1 Discomfort Glare
4.10.2 Disability Glare
Illuminance
This Chapter: Table 31.2
12.5.5.1 Applications and Tasks
Table 12.6 | Default Illuminance Ratio Recommendations
Figure 12.22 | Task Coverage Example
Light Distribution
12.3.2 Subjective Impressions
Luminances
12.5.2 Luminance
Table 12.5 | Default Luminance Ratio Recommendations
Maintenance
15.4.4 Installation and Maintenance
Nighttime Outdoor Environment
Table 15.6 | Nighttime Operational Strategies for Improved Outdoor Environmental Regard
Systems Integration
12.6 Systems Factors
Veiling Reflections
This Chapter: Section 31.3.6
12.5.4 Veiling Reflections
Visual Tasks
This Chapter: Section 31.2
This Chapter: Table 31.2
Table 11.2 | Programming: Inventory Scope and Specific Examples
12.5.1 Visual Tasks
Table 12.3 | Sample Visual Task Survey

31.1 Project Type and Status

Before any design work, an understanding of the project type and scope is necessary. This will establish the extent to which daylighting can address most or many or some of the lighting goals. New, renovation, and restoration projects each offer varying opportunities. See 11.2 Planning, 11.3.1 Pre-design, and 11.3.2 Schematic Design. At every opportunity the lighting designer should give every consideration to daylighting as a light source. For some applications and tasks, daylighting can be the primary light source. Critically, this means addressing the host of lighting design factors identified in 12 | COMPONENTS OF LIGHTING DESIGN. Daylight demands attention to moderate or eliminate glare and balance visible and thermal energy.

31.2 Application Types

To develop lighting solutions that meet quality, quantity, and operational criteria, an inventory is made of the miscellaneous facilities space types under consideration and the anticipated occupants, functions, and tasks (see Table 11.2 | Programming: Inventory Scope and Specific Examples and Table 12.3 | Sample Visual Task Survey). Otherwise, lighting cannot be best targeted to the users, their expectations, functions and tasks.

Space type definitions are required early in the project design in order to track design efforts that include inventorying the project knowns, anticipated functions, and tasks and calculating lighting, power, and energy compliance. Room names, from which functions can be deduced, and numbers for tracking should be clearly marked on architectural backgrounds. The applications and tasks cited in Table 31.2 | Miscellaneous Applications Illuminance Recommendations should be reviewed against the project knowns and correlated with the named space types and functions to establish recommended illuminance criteria. Seek clarification with the client where discrepancies occur between programming information, the list of room names, and the available application and task citations in Table 31.2.

In many situations in courts and correctional facilities, security is an inherent part of the task: securing detainees and prisoners to prevent their escape or destructive actions to property, self, or others; securing key personnel of courts and correctional facilities from harm. Lighting plays a role, but only as part of a much broader security program to be effective. Lighting hardware itself must be considered a target of destructive behavior in some of these situations. The designer must review the programming information and consult with the team and owner to establish the full extent of security issues affecting lighting.

The following discussion is keyed to major application headings in Table 31.2. Couple this with topics in Table 31.1 for comprehensive qualitative and quantitative criteria.

31.2.1 Accenting

Accenting affects people's brightness perceptions and provides visual relief. Accenting is also used for visual attraction, inspection, and wayfinding. Accenting enhances architectural spatial forms and limits and impressions of spatial volume. See Tables 12.1a, 12.1b, and 12.2. Accenting can make spaces appear less institutional.

31.2.2 Administration

Lighting for administrative areas is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. The architectural scheme and even task specifics will vary based on the miscellaneous facilities involved. In some projects these details should affect the lighting

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design, from the kinds of lighting effects to lighting equipment styling to luminances and illuminances. In other projects, notably more secure areas of police stations, the straightforward requirements of security and abuse will override some lighting effects and equipment styling aspects.

The administrative areas are typically consolidated into a single area, wing, or building. Several aspects may affect the degree to which the lighting design in the administrative area is sympathetic to or different from that of the other applications and tasks at the facility in question:

- Owner wishes and architectural desires
- Visual connection between administrative areas and other areas of the facility
- Management style

See also 32 | LIGHTING FOR OFFICES.

31.2.3 Atria and Courtyards

Lighting for atria and courtyards is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

31.2.4 Banking

See Section 31.2.8 Financial Facilities.

31.2.5 Building Entries

Lighting for building entries is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

31.2.6 Circulation

Given varying security requirements, lighting for circulation is addressed in respective application areas of miscellaneous facilities. Default criteria are cited in TRANSITION SPACES.

31.2.7 Conferencing

Various forms of conferencing are used in miscellaneous facilities. Lighting for conferencing is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

31.2.8 Financial Facilities

Banking and trading applications involve a wide range of visual tasks. Some involve extended reading of multiple computer screens or paperwork or facial assessment or some combination. Additionally, some lighting is closely integrated with the retail brand of the respective financial corporation. Across these tasks and branding strategies is a level of security typically involving surveillance or recording cameras. Camera locations and orientations should be coordinated with lighting layouts to minimize image washout. Additionally, uniformity ratios should be confirmed against camera capabilities to avoid situations where cameras lose images while panning across space.

Lighting effects and hardware styling, sizes, and layouts can contribute to an urbane setting. Daylighting is considered a significant benefit, but the type, location, and size of daylight media must be coordinated with the security consultant.

Lighting for a few key applications and tasks is outlined below.

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Table 31.2 | Miscellaneous Applications Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
ACCENTING	Accenting influences observers' overall brightness perceptions and provides visual relief. Accenting is also used for visual attraction, inspection, and wayfinding. See 15.1.1.3 Accent Lighting. These are criteria for consideration in any application.										
• Art	On artwork plane (typically vertical). See 21 | LIGHTING FOR ART for preservation-worthy materials.								see Table 15.2		
• Feature Wall	On wall plane								see Table 15.2		
• Important Focal Point	On focal point plane			see Table 15.2					see Table 15.2		
• Perimeter	On wall plane								see Table 15.2		
ADMINISTRATION	See 22 | LIGHTING FOR COMMON APPLICATIONS										
ATRIA and COURTYARDS	See 22 | LIGHTING FOR COMMON APPLICATIONS										
BANKING	See FINANCIAL FACILITIES										
BUILDING ENTRIES	See 22 | LIGHTING FOR COMMON APPLICATIONS										
CIRCULATION	See specific applications or see TRANSITION SPACES/Circulation Corridors for default values.										
CONFERENCING	See 22 | LIGHTING FOR COMMON APPLICATIONS										
FINANCIAL FACILITIES	Coordinate lighting with security cameras.										
• ATMs											
• Drive-up	See FINANCIAL FACILITIES/Drive-up Services										
• Walk-up											
• Indoor	E_h @3' AFF; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Outdoor	See FINANCIAL FACILITIES/Drive-up Services										
• Drive-up Services	**OUTDOOR** applications										
• Covered											
• Face of transaction device	Highlight touch-action system unless internally illuminated. Some devices' components in some situations may exhibit glossy or polished finishes and may create veiling reflections. Coordinate lighting with security cameras.										
◦ LZ4[i]	E_v @3'-4' AFG						L	37.5	75	150	Avg
◦ LZ3[i] (and LZ4 curfew)	E_v @3'-4' AFG						K	25	50	100	Avg
◦ LZ2[i] (and LZ3 curfew)	E_v @3'-4' AFG						J	20	40	80	Avg
◦ LZ1[i] (and LZ2 curfew)	E_v @3'-4' AFG						I	15	30	60	Avg
◦ LZ0[i] (and LZ1 curfew)	E_v @3'-4' AFG and control with motion sensors.[j]						H	10	20	40	Avg
◦ LZ0[i] curfew	Control with motion sensors.[j]						-	0	0	0	

Table 31.2 | Miscellaneous Applications Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	see 15.1.1.3		☀	◪	■	
	see 15.1.1.3		☀		■	
	see 15.1.1.3		☀	◪	■	
	see 15.1.1.3		☀		■	
	3:1		☀	◪	■	
2:1	3:1			◪	■	
2:1	3:1 (6:1)			◪	■	
2:1	3:1 (6:1)			◪	■	
2:1	3:1 (6:1)			◪	■	
2:1				◪	■	

Notes for Table 31.2

The table column headings are discussed in detail in 31.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 31.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 31.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 31.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like object under glass or CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◪ signals high likelihood; gray and white ◪ signals moderate likelihood; pale gray and white ◪ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

l. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, or conference table a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

m. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 31.2 | Miscellaneous Applications Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
FINANCIAL FACILITIES	(Outdoor Drive-up Services/Covered continued)										
• General	Lighting should address an area within 10' radius of the transaction or to edge of cover or property lines or rights-of-way, whichever is less. E_v should be on planes oriented toward the transaction area. Coordinate lighting with security cameras.										
◦ LZ4[i]	E_h @grade; E_v @5' AFG	K	25	50	100	Avg	H	10	20	40	Avg
◦ LZ3[i] (and LZ4 curfew)	E_h @grade; E_v @5' AFG	J	20	40	80	Avg	G	7.5	15	30	Avg
◦ LZ2[i] (and LZ3 curfew)	E_h @grade; E_v @5' AFG	I	15	30	60	Avg	F	5	10	20	Avg
◦ LZ1[i] (and LZ2 curfew)	E_h @grade; E_v @5' AFG	H	10	20	40	Avg	E	4	8	16	Avg
◦ LZ0[i] (and LZ1 curfew)	E_h @grade E_v @5' AFG and control with motion sensors.[j]	G	7.5	15	30	Avg	D	3	6	12	Avg
◦ LZ0[i] curfew	Control with motion sensors.[j]	-	0	0	0		-	0	0	0	
• Non-covered											
• Face of transaction device	Highlight touch-action system unless internally illuminated. Some devices' components in some situations may exhibit glossy or polished finishes and may create veiling reflections. Coordinate lighting with security cameras.										
◦ LZ4[i]	E_v @3'-4' AFG						J	20	40	80	Avg
◦ LZ3[i] (and LZ4 curfew)	E_v @3'-4' AFG						I	15	30	60	Avg
◦ LZ2[i] (and LZ3 curfew)	E_v @3'-4' AFG						H	10	20	40	Avg
◦ LZ1[i] (and LZ2 curfew)	E_v @3'-4' AFG						G	7.5	15	30	Avg
◦ LZ0[i] (and LZ1 curfew)	E_v @3'-4' AFG and control with motion sensors.[j]						F	5	10	20	Avg
◦ LZ0[i] curfew	Control with motion sensors.[j]						-	0	0	0	
• General	Lighting should address an area within 10' radius of the transaction or to edge of cover or property lines or rights-of-way, whichever is less. E_v should be on planes oriented toward the transaction area. Coordinate lighting with security cameras.										
◦ LZ4[i]	E_h @grade; E_v @5' AFG	I	15	30	60	Avg	F	5	10	20	Avg
◦ LZ3[i] (and LZ4 curfew)	E_h @grade; E_v @5' AFG	H	10	20	40	Avg	E	4	8	16	Avg
◦ LZ2[i] (and LZ3 curfew)	E_h @grade; E_v @5' AFG	G	7.5	15	30	Avg	D	3	6	12	Avg
◦ LZ1[i] (and LZ2 curfew)	E_h @grade; E_v @5' AFG	F	5	10	20	Avg	C	2	4	8	Avg
◦ LZ0[i] (and LZ1 curfew)	E_h @grade E_v @5' AFG and control with motion sensors.[j]	E	4	8	16	Avg	B	1	2	4	Avg
◦ LZ0[i] curfew	Control with motion sensors.[j]	-	0	0	0		-	0	0	0	
• Banking Lobbies											
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Teller Window	E_h @floor; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Writing Table	E_h @3' 6" AFF; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Processing Centers	Alternatively, see READING AND WRITING tasks and normalize to illuminance of most important task or most common task.										
• Adjustments	Presumed projected microforms	L	37.5	75	150	Avg	I	15	30	60	Avg
• Distribution	E_h @3' 6" AFF; E_v @5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Encoding	E_h @2' 6" AFF; Ev @3' 6" AFF[k]	R	250	500	1000	Avg	N	75	150	300	Avg
• Reconciling	E_h @2' 6" AFF; Ev @3' 6" AFF[k]	R	250	500	1000	Avg	N	75	150	300	Avg
• Sorter	E_h @3' 6" AFF; E_v @5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Statements	Alternatively, see READING AND WRITING tasks and normalize to illuminance of most important task or most common task.										
• Filing	E_h @3' 6" AFF; E_v @5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Statement Assembly/Mailing	E_h @3' 6" AFF; E_v @5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Workstation	E_h @2' 6" AFF; E_v @3' 6" AFF[k]	R	250	500	1000	Avg	O	100	200	400	Avg

Table 31.2 | Miscellaneous Applications Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
2:1	3:1					
2:1	3:1 (6:1)					
2:1	3:1 (6:1)					
2:1	3:1 (6:1)					
2:1						
2:1	3:1					
2:1	3:1 (6:1)					
2:1	3:1 (6:1)					
2:1						
2:1	3:1 (6:1)					
2:1	3:1					
2:1	3:1 (6:1)					
2:1	3:1 (6:1)					
2:1	3:1 (6:1)					
2:1						
	3:1					
	3:1					
	3:1					
	see Table 12.6					
	3:1					
	see Table 12.6					
	see Table 12.6					
	3:1					
	3:1					
	3:1					
	3:1					
	see Table 12.6					

Notes for Table 31.2

The table column headings are discussed in detail in 31.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 31.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 31.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 31.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like object under glass or CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

l. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, or conference table a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

m. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 31.2 | Miscellaneous Applications Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
FINANCIAL FACILITIES	(continued)											
• Safe Deposit Boxes												
• General	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
• Deposit Boxes	E_h @3' AFF at face of deposit boxes; E_v over face of deposit boxes	O	100	200	400	Avg	M	50	100	200	Avg	
• Inspection Table	E_h @floor; E_v @5' AFF on racks	R	250	500	1000	Avg	O	100	200	400	Avg	
• Trading	Alternatively, see READING AND WRITING tasks and normalize to illuminance of most important task or most common task.											
• General	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
• Workstation	E_h @2' 6" AFF; E_v @3' 6" AFF[k]	P	150	300	600	Avg	N	75	150	300	Avg	
FIRE STATIONS	See MUNICIPAL FACILITIES											
IT	See 22 | LIGHTING FOR COMMON APPLICATIONS											
MUNICIPAL FACILITIES												
• City Hall												
• Administrative Areas	See 22 | LIGHTING FOR COMMON APPLICATIONS/ADMINISTRATION											
• Auditorium	See 24 | LIGHTING FOR EDUCATION/AUDITORIA											
• Council Chambers												
• Audience												
◦ AV	Notetaking is intended. E_h @2' AFF; E_v @4' AFF	K	25	50	100	Avg	G	7.5	15	30	Avg	
◦ No AV	E_h @2' AFF; E_v @4' AFF	M	50	100	200	Avg	J	20	40	80	Avg	
• Screen (front projection)	Cited values are for screen plane when screen is in use											
◦ Feature presentation								10	10	10	Max	
◦ Periodic reference								50	50	50	Max	
• Council Dais	Lighting at the council members											
◦ AV												
Face(s)	E_v @4' AFF							Avg ≤3 times audience task E_h				
Task surface	E_h @2' 6" AFF		Avg ≤3 times audience task E_h									
◦ No AV	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
• Circulation	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.											
◦ AV	E_h @floor; E_v @5' AFF		2	2	2	Min	F	5	10	20	Avg	
◦ All-but-AV-or-performance	E_h @floor; E_v @5' AFF		10	10	10	Min	I	15	30	60	Avg	
• Control Booths	See 28 | LIGHTING FOR HOSPITALITY AND ENTERTAINMENT											
• Garages												
• General	E_h @floor; E_v @5' AFF	R	250	500	1000	Avg	P	150	300	600	Avg	
• Provisional	Provide for portable worklights as needed											
• Task at bench and hood	E_h and E_v @3' 6" AFF	T	500	1000	2000	Avg	R	250	500	1000	Avg	
• Lobbies	See TRANSITION SPACES/Lobbies and Waiting Rooms											
• Public Business Center	See TRANSITION SPACES/Lobbies and Waiting Rooms											
• Emergency Call Center	See READING AND WRITING tasks and normalize to illuminance of most important task or most common task.											

Table 31.2 | Miscellaneous Applications Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1		■			■
	3:1		■		■	
	3:1		■		■	
	3:1		■			■
	see Table 12.6		■	■	■	■
						■
						■
						■
						■
	2:1					■
	3:1		■			■
2:1					■	
2:1					■	
	2:1				■	
	2:1				■	
	3:1		■		■	
	5:1/3:1				■	
	10:1/3:1		■		■	
	3:1		■			
1.5:1	1.5:1		■		■	

Notes for Table 31.2

The table column headings are discussed in detail in 31.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 31.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 31.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 31.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon ■ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like object under glass or CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ■ signals high likelihood; gray and white ■ signals moderate likelihood; pale gray and white ■ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

l. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, or conference table a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

m. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 31.2 | Miscellaneous Applications Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
MUNICIPAL FACILITIES	(continued)										
• Fire Station											
• Administrative Areas	See 22 | LIGHTING FOR COMMON APPLICATIONS/ADMINISTRATION										
• Apparatus Bays	Interface controls with alarm or motion sensors.										
• General	E_h @floor; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Perimeter Turnout Gear	E_h @3' AFF; E_v @5' AFF	Q	200	400	800	Avg	O	100	200	400	Avg
• Provisional	Provide for portable worklights as needed										
• Circulation	See TRANSITION SPACES/Circulation Corridors										
• Dayroom	See MUNICIPAL FACILITIES/Fire Station/Living Room										
• Dormitory	Criteria relate to individual sleep rooms or to general quarters										
• Casual Reading	E_h @2' AFF; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Desk	E_h @2' 6" AFF; E_v @4' AFF	Q	200	400	800	Avg	N	75	150	300	Avg
• Dining	E_h @2' 6" AFF; E_v @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• General	E_h @floor; E_v @5' AFF	J	20	40	80	Avg	G	7.5	15	30	Avg
• Game Room											
• Electronic	E_h @2' 6" AFF; E_v @4' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Traditional	E_h @tables; E_v @4' AFF	P	150	300	600	Avg	K	25	50	100	Avg
• Hose Tower	E_h and E_v @3' AFF of each floor elevation across entire area intended for hose drying.	P	150	300	600	Avg	N	75	150	300	Avg
• Kitchen											
• In-suite	E_h and E_v @3' AFF	R	250	500	1000	Avg	L	37.5	75	150	Avg
• Institutional	See 22 | LIGHTING FOR COMMON APPLICATIONS/Food Service										
• Laundry	E_h and E_v @3' AFF	P	150	300	600	Avg	K	25	50	100	Avg
• Living Room	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	K	25	50	100	Avg
• Media Lounge	E_h @2' 6" AFF; E_v @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Training	See 24 | LIGHTING FOR EDUCATION/CLASSROOMS										
• Turnout Gear Room	E_h @3' AFF; Ev @5' AFF. Interface controls with alarm or motion sensors.	Q	200	400	800	Avg	O	100	200	400	Avg
• Police Station	Coordinate lighting with security cameras.										
• Administrative Areas	See 22 | LIGHTING FOR COMMON APPLICATIONS/ADMINISTRATION										
• Armory											
• General	E_h @floor; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Inspection Table	E_h @floor; E_v @5' AFF on racks	T	500	1000	2000	Avg	P	150	300	600	Avg
• Racks	E_h @3' AFF; E_v @5' AFF on racks	R	250	500	1000	Avg	O	100	200	400	Avg
• Attorney/Client Interview Rooms	E_h @2' 6" AFF; E_v @4' AFF	Q	200	400	800	Avg	N	75	150	300	Avg
• Cells											
• Group Holding Cells											
◦ Day	E_h @floor; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg
◦ Night	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Individual Cells											
◦ General											
Day	E_h @floor; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg
Night	E_h @floor; E_v @4' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Task Areas	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg

Table 31.2 | Miscellaneous Applications Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1		■			
	3:1		■		■	
see Table 12.6			■	■	■	
see Table 12.6			■	■	■	
	3:1		■	■	■	
	4:1		■			■
	3:1		■	■		■
see Table 12.6			■		■	
	3:1		■			■
see Table 12.6			■		■	
	3:1		■			■
	3:1		■	■		■
	3:1		■		■	
						■
	3:1		■			■
	3:1		■		■	
	3:1		■		■	
	3:1		■			■
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	3:1		■			■
			■			■
	3:1		■			■
	3:1		■			■
	3:1		■		■	

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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
MUNICIPAL FACILITIES	(Police Station continued)										
• Circulation Corridors	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• Public	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Secure											
◦ Day	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
◦ Night	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Lockdown	E_h @floor; E_v @5' AFF	Q	200	400	800	Avg	P	150	300	600	Avg
• Staff	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Elevators	See TRANSITION SPACES/Elevators										
• Firing Range	**INDOOR** E_h @shooting line 3' AFG; E_v @area of target	P	150	300	600	Avg	T	500	1000	2000	Avg
• Intake and Release Area	Also see 23 | LIGHTING FOR COURTS AND CORRECTIONAL FACILITIES										
• General	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Hygiene Suite											
◦ Changing Room	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
◦ Shower	E_h @floor; E_v @3'-5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
◦ Toilet	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Identification Processing	E_h @3' 6"; E_v @5' AFF	R	250	500	1000	Avg	Q	200	400	800	Avg
• Property											
◦ Inventory	E_h @3' 6"; E_v @5' AFF	R	250	500	1000	Avg	Q	200	400	800	Avg
◦ Property Room											
◦ Face of Shelving or Racks	E_h @3' 6"; E_v over face of shelving	P	150	300	600	Avg	M	50	100	200	Avg
◦ General	Eh @floor; Ev @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Sally Port	See MUNICIPAL FACILITIES/Police Station/Vehicle Sally Port										
• Secure Storage	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Security Screening	E_h @3' AFF; E_v @5' AFF	Q	200	400	800	Avg	O	100	200	400	Avg
• Toilets											
◦ Detainees and Inmates	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
◦ Public	See TOILETS/LOCKER ROOMS										
◦ Staff	See TOILETS/LOCKER ROOMS										
• Waiting											
◦ Detainees											
◦ Group (TV Room)	E_h @floor; E_v @4' AFF	L	37.5	75	150	Avg	J	20	40	80	Avg
◦ Isolation Cell	E_h @floor; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg
◦ Public	See TRANSITIONAL SPACES/Lobbies and Waiting Rooms										
• Lobby	See TRANSITION SPACES/Lobbies and Waiting Rooms										
• Vehicle Sally Port											
• Day	E_h @3' AFF; E_v @5' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
• Night	E_h @3' AFF; E_v @5' AFF	M	50	100	200	Avg	J	20	40	80	Avg
• Watch Desk	See TRANSITION SPACES/Lobbies and Waiting Rooms/Reception										
PARKING	See 26 | LIGHTING FOR EXTERIORS										
PEDESTRIAN WAYS	See 26 | LIGHTING FOR EXTERIORS										

Table 31.2 | Miscellaneous Applications Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1		■			■
	2:1		■			■
	2:1		■			■
	2:1		■			■
	2:1		■			■
		2:1	■		■	
	3:1		■			■
	3:1		■			■
	2:1		■			■
	3:1		■			■
	3:1		■		■	
	3:1		■		■	
	3:1		■			■
	2:1		■		■	
	3:1		■			■
	3:1		■			■
	3:1		■			■
	3:1		■			■
	3:1		■			■

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a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 31.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

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d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like object under glass or CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

l. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, or conference table a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

m. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 31.2 | Miscellaneous Applications Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
POLICE STATIONS	See MUNICIPAL FACILITIES											
POST OFFICES	Coordinate lighting with security cameras											
• Consumer Lobby												
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg	
• Postal Window	E_h @floor; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Writing Table	E_h @3' 6" AFF; E_v @5' AFF	P	150	300	600	Avg	K	25	50	100	Avg	
• P.O. Boxes												
• General	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
• Mailboxes	E_h at 3' AFF at face of mailboxes; E_v over face of mailboxes	M	50	100	200	Avg	O	100	200	400	Avg	
• Inspection Table	E_h @floor; E_v @5' AFF on racks	P	150	300	600	Avg	I	15	30	60	Avg	
• Processing Center	Alternatively, see READING AND WRITING tasks and normalize to illuminance of most important task or most common task											
• Distribution	E_h @3' 6" AFF; E_v @5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
• Encoding	E_h @2' 6" AFF; Ev @3' 6" AFF[k]	R	250	500	1000	Avg	N	75	150	300	Avg	
• Security Inspection	E_h and E_v @3' 6" AFF	T	500	1000	2000	Avg	P	150	300	600	Avg	
• Sorter	E_h @3' 6" AFF; E_v @5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg	
• Receiving/Shipping	See SUPPORT SPACES/Receiving/Shipping											
READING AND WRITING												
• Computer	See READING AND WRITING/VDT Screen and Keyboard											
• Electronic Readers												
• Electronic Ink Devices	E_h and E_v @height of device	P	150	300	600	Avg	N	75	150	300	Avg	
• LCD or LED Devices	E_h and E_v @height of device	N	75	150	300	Avg	K	25	50	100	Avg	
• Facsimile												
• Analog	E_h @2' 6" AFF; E_v @4' AFF[k]	R	250	500	1000	Avg	M	50	100	200	Avg	
• Digital	E_h @2' 6" AFF; E_v @4' AFF[k]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Handwritten Work	Based on fair-to-good penmanship/hand print on white or canary paper											
• Pencil												
• Graphite/HB	E_h @2' 6" AFF; E_v @4' AFF[k]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Red	E_h @2' 6" AFF; E_v @4' AFF[k]	R	250	500	1000	Avg	M	50	100	200	Avg	
• Ballpoint/Rollerpoint/Felt-tip												
• Black	E_h @2' 6" AFF; E_v @4' AFF[k]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Red, Green, Blue	E_h @2' 6" AFF; E_v @4' AFF[k]	Q	200	400	800	Avg	L	37.5	75	150	Avg	
• Laptop	See READING AND WRITING/VDT Screen and Keyboard											
• Microforms (Projected)		L	37.5	75	150	Avg	I	15	30	60	Avg	
• Print Media	Digital-printing-press-generated, white paper											
• 6-pt Font												
• Matte paper and ink	E_h @2' 6" AFF; E_v @4' AFF[k]	R	250	500	1000	Avg	L	37.5	75	150	Avg	
• Specular paper and ink	E_h @2' 6" AFF; E_v @4' AFF[k]	R	250	500	1000	Avg	L	37.5	75	150	Avg	
• 8- and 10-pt Font												
• Matte paper and ink	E_h @2' 6" AFF; E_v @4' AFF[k]	P	150	300	600	Avg	K	25	50	100	Avg	
• Specular paper and ink	E_h @2' 6" AFF; E_v @4' AFF[k]	P	150	300	600	Avg	K	25	50	100	Avg	
• 12-pt Font												
• Matte paper and ink	E_h @2' 6" AFF; E_v @4' AFF[k]	O	100	200	400	Avg	K	25	50	100	Avg	
• Specular paper and ink	E_h @2' 6" AFF; E_v @4' AFF[k]	O	100	200	400	Avg	K	25	50	100	Avg	

Table 31.2 | Miscellaneous Applications Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
3:1						
3:1						
3:1						
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3:1						
3:1						
see Table 12.6						
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b. Values cited are to be maintained over time on the area of coverage.

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d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like object under glass or CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

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j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

l. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, or conference table a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

m. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
READING AND WRITING	(continued)										
• VDT Screen and Keyboard											
• CSA/ISO Types I and II	See Figure 12.16 | CSA/ISO Computer Screen Qualities										
• Positive polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[k]	P	150	300	600	Avg	N	75	150	300	Avg
• Negative polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[k]	N	75	150	300	Avg	K	25	50	100	Avg
• CSA/ISO Type III	See Figure 12.16 | CSA/ISO Computer Screen Qualities										
• Positive polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[k]	N	75	150	300	Avg	K	25	50	100	Avg
• Negative polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[k]	L	37.5	75	150	Avg	I	15	30	60	Avg
• White Board											
• Analog or Digital											
• Reading (reference)							N	75	150	300	Avg
• Reading (with presenter)	Presenter at white board						P	150	300	600	Avg
• Xerograph	Copier- and printer-generated on white paper										
• ≥8-pt type, common graphics	Select progressively next-higher letter category of illuminance for each 2-point-type decrease in fonts/graphics)										
• Color											
◦ Analog	E_h @2' 6" AFF; E_v @4' AFF[k]	R	250	500	1000	Avg	M	50	100	200	Avg
◦ Digital	E_h @2' 6" AFF; E_v @4' AFF[k]	P	150	300	600	Avg	L	37.5	75	150	Avg
• Grayscale and/or B+W Print											
◦ Analog	E_h @2' 6" AFF; E_v @4' AFF[k]	P	150	300	600	Avg	L	37.5	75	150	Avg
◦ Digital	E_h @2' 6" AFF; E_v @4' AFF[k]	O	100	200	400	Avg	K	25	50	100	Avg
SUPPORT SPACES											
• Break Rooms/ Lunch Rooms	E_h @2' 6" AFF; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Coat Check or Coat Rooms	E_h @3' 0"; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Copy/Print Rooms											
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Machines	E_h and E_v @3' 6" AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Interstitial Space°	E_h @floor; E_v @4' AFF	I	15	30	60	Avg	G	7.5	15	30	Avg
• Janitor's Closet	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Mail Facility											
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	J	20	40	80	Avg
• Security Inspection	E_h and E_v @3' 6" AFF	T	500	1000	2000	Avg	P	150	300	600	Avg
• Sorting	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	L	37.5	75	150	Avg
• Receiving/Shipping											
• Dock	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Receiving/Staging	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Storage	E_h @floor; E_v @4' AFF										
• Equipment		O	100	200	400	Avg	K	25	50	100	Avg
• Bulky items		K	25	50	100	Avg	H	10	20	40	Avg
• Medium items		M	50	100	200	Avg	I	15	30	60	Avg
• Small items		O	100	200	400	Avg	K	25	50	100	Avg

Table 31.2 | Miscellaneous Applications Illuminance Recommendations continued next page

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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
TOILETS/LOCKER ROOMS											
• Fixtures	E_h @top of plumbing fixture; E_v @3'-5' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• General	E_h @floor; E_v @3'-5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Lockers	E_h @floor; E_v @locker faces	K	25	50	100	Avg	K	25	50	100	Avg
• Showers	E_h @floor; E_v @3'-5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Vanities	E_h @3' AFF; E_v @3'-5' AFF	N	75	150	300	Avg	O	100	200	400	Avg
TRANSITION SPACES											
• Circulation Corridors	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• Public	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Secure	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Staff	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Elevators											
• Freight											
• Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Threshold											
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Public											
• Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Threshold											
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Secure											
• Cab interior	E_h @floor; E_v @3' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Threshold											
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg

Table 31.2 | Miscellaneous Applications Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1		✓		■	
	2:1		✓			■
	2:1		✓		■	
	2:1		✓			■
	2:1		✓		■	
	2:1		✓			■
	2:1		✓			■
	2:1		✓			■
	2:1		✓			■
	2:1		✓		■	
	2:1		✓		■	
	2:1		✓			■
	2:1		✓		■	
	2:1		✓			■
	2:1		✓		■	
	2:1		✓			■

Notes for Table 31.2

The table column headings are discussed in detail in 31.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 31.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 31.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 31.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon ✓ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like object under glass or CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ✓ signals high likelihood; gray and white ✓ signals moderate likelihood; pale gray and white ✓ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

l. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, or conference table a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

m. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 31.2 | Miscellaneous Applications Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
TRANSITION SPACES	(continued)										
• Entries	See 22 | LIGHTING FOR COMMON APPLICATIONS										
• Escalators/Moving Walkways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Lobbies and Waiting Rooms											
• Circulation, Elevator Lobbies	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• General											
• At building entries	Close proximity to exterior. Lighting should be designed to assist with adaptation when passing to/from exterior.										
◦ Day	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
◦ Night	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Distant from entries	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Security Screening											
• Private Rooms	E_h @3' AFF; E_v @5' AFF	Q	200	400	800	Avg	O	100	200	400	Avg
• Public Lobbies	E_h @3' AFF; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Reading/Waiting Areas	E_h and E_v @2' 6" at sitting areas	P	150	300	600	Avg	N	75	150	300	Avg
• Reception	Such as visitor registration or informational/directional assistance.										
• Desk	Age determination may be as or more relevant with respect to visitors than staff.										
• Desk top	E_h @3' 6" AFF; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Focal wall behind desk	On wall plane								see Table 15.2		
• Stairs	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• High Activity[m]	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Live Surveillance	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Typical	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1		☀		■	
	4:1		☀			■
	4:1					■
	4:1		☀			■
	2:1		☀		■	
	2:1		☀		■	
	4:1		☀		■	
see Table 12.6			☀		■	
			☀		■	
	2:1		☀			■
	2:1		☀			■
	2:1		☀			■

Notes for Table 31.2

The table column headings are discussed in detail in 31.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 31.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 31.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 31.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like object under glass or CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◥ signals high likelihood; gray and white ◥ signals moderate likelihood; pale gray and white ◥ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

l. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, or conference table a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

m. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 31.3 | SI Dimensional Conversions

US Customary	SI
General	**Hard Conversion**
inches	mm [inches × 25.40]
feet	m [feet × 0.30]
Specific	**Convenient Conversions[a]**
2'	610 mm or 0.6 m
2' 6"	760 mm or 0.75 m
3'	915 mm or 0.9 m
3' 6"	1065 mm or 1.1 m
4'	1220 mm or 1.2 m
5'	1525 mm or 1.5 m

a. Hard conversions rounded for reporting convenience. Not to be confused with metric-sized luminaires or other building materials. Not for precision construction.

IESH/10e CSA/ISO

> 12.5 Task Factors
- for information on CSA/ISO computer screen qualities

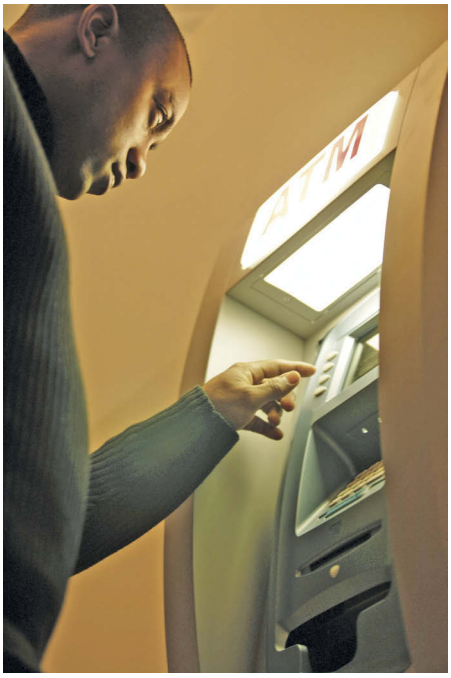


Figure 31.1 | ATM
Integrated electric lighting might satisfy illuminance criteria for the visual tasks at the ATM when daylight is insufficient. If there is no integrated lighting or if it is insufficient, then lighting design should address criteria in Table 31.2.
» Image ©Ocean/Corbis

31.2.8.1 ATMs
Ubiquitous automated teller machines may have sufficient lighting from within to address the visual tasks. This may be the most efficient way to light the task area (see Figure 31.1). If the designer determines that the ATM's integral lighting is insufficient, then provisions should be made to meet criteria cited in Table 31.2. In outdoor situations, criteria are cited for the immediate vicinity and for the face of the transaction device. Depending on the nature of the facility and degree of security, luminaire construction may need to be rugged to withstand tampering and physical abuse. Lamps insensitive to sudden shock are appropriate. Motion sensors on time clock to energize luminaires on demand after curfew should be considered regardless of nighttime outdoor lighting zone.

31.2.8.2 Banking Lobbies
Lobbies for retail banking might simply comprise a queue, teller stations for cash and check transactions, and a courtesy transaction table. Visual tasks are not overly complicated, but involve a high degree of accuracy. For face-to-face transactions, illuminances need not accommodate a high degree of speed, though bank personnel and security cameras should be able to assess facial features and demeanor. See Figure 31.2.

Teller stations may be separated from the banking lobby with security glazing. This introduces veiling reflections and, if high-wattage luminaires are used, reflected glare. Consideration should be made for eliminating or minimizing these effects in the customer transaction zone, though it is unlikely these can be addressed for those in the queue. Indirect lighting can minimize harshness, though veiling reflection patterns are likely to be larger. Low-wattage direct luminaires can minimize harshness, though the number of veiling reflection patterns will increase.

In facilities offering additional banking services, such as loans and account applications and closings, workstations adjacent to the lobby or in spaces independent of the lobby are used. A review of reading and writing tasks by the designer is in order to establish recommended illuminance criteria.

31.2.8.3 Processing Centers
Checks are processed for payment between banks to cover client transactions. Visual tasks include deciphering payment amounts and encoding checks accordingly. The designer must survey tasks in the processing centers to determine if paper or computers are predominant. Illuminance criteria may need to be revised to address the respective reading and writing tasks.

31.2.8.4 Safe Deposit Boxes
Lighting here should address the vertical face of the deposit boxes to allow for box identification. Inspection tables should be illuminated to allow for convenient review of box contents.

31.2.8.5 Trading
Some financial facilities are involved in trading commodities, equities, or other assets. The trading task typically includes interaction with computers, other people, and paper. This might be on the scale of one or several workstations or entire building floors. Default illuminance criteria cited in Table 31.2 accommodate most paper tasks and computer tasks. However, if programming or task surveys reveal tasks specifics, the designer should establish illuminance criteria based on the specific reading and writing tasks by using the READING AND WRITING task citations in Table 31.2. See Figure 31.3.

31.2.9 IT

Lighting for IT facilities is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

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31.2.10 Municipal Facilities

Municipal facilities include city halls, emergency call centers, fire stations, and police stations. Those used for emergency calls, fire, and police demand lighting that is efficient and effective in facilitating performance of the critical tasks. However, the lighting of these facilities can also effect civic pride. Accenting community art, well controlled luminances, orderly layout of lighting equipment, accentuation of spatial form, and well maintained luminaires can all help define a place of pride.

Some of these tasks and applications will require continuous operation for public safety, emergency management, national security, or business continuity and, therefore, critical operations power systems (COPS) will be employed as part of the electrical design [3]. If the lighting designer is someone other than the electrical engineer, then close coordination between the designer and the engineer will be necessary to determine the need for any special control zoning, instant-on lamps, and specific luminaire wiring or ballasting details affecting the lighting layout and specification.

31.2.10.1 City Halls

These facilities primarily house administrative space. See Chapter 22 | LIGHTING FOR COMMON APPLICATIONS for discussion and criteria on administrative spaces. City halls also include council chambers. As the seat of the local government, chambers should have a flexible lighting system to accommodate presentations, deliberations, and forums. Garages are also part of city facilities, though these are typically at some location distant from city hall proper.

31.2.10.2 Emergency Call Centers

Call centers should be carefully programmed and designed accordingly. The visual tasks and the degree of multi-tasking should be used to identify the most common or most critical task and illuminance criteria established accordingly.

31.2.10.3 Fire Stations

Small volunteer stations or those manned with on-call firefighters might include apparatus bays with perimeter gear turnout storage and not much more. Luminaire layouts and optics should accommodate the large equipment. See Figure 31.4. Larger stations can include living quarters, a kitchen, a hose tower, and other spaces necessary for self-sufficiency.

Exterior maintenance and staging areas may be part of a station's site. If lighting is deemed necessary for these areas for nighttime operation, then see 26 | LIGHTING FOR EXTERIORS. The designer may also need to determine illuminance criteria based on the programmed activities and the categories in Table 4.1 | Recommended Illuminance Targets.

31.2.10.4 Police Stations

Police stations may be small precinct stations consisting of a community desk and some offices and support spaces to large central facilities. Larger facilities may include holding cells. The secure movement of detainees is facilitated by a sally port where secure vehicles have access to secure entries. Sally ports are usually fully enclosed porte cocheres or garages. Lighting serves both an adaptation function as vehicles move from exterior to interior and vice versa and as a security function. Although daylighting can be used to limit energy use, its application must be made with great care. Daylight media must itself be secure of breach by people or gunfire and must prevent direct-view situations from any vantage point outside the sally port to limit identification and tracking of those inside.

31.2.11 Parking

Lighting for parking facilities is discussed in 26 | LIGHTING FOR EXTERIORS. In secure parking situations, lighting must accommodate camera and surveillance requirements.

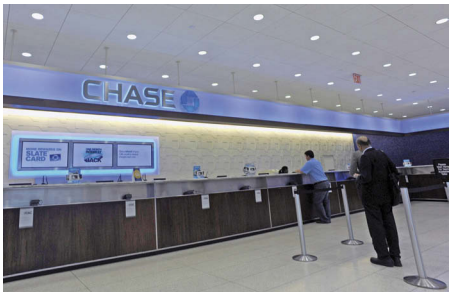


Figure 31.2 | Retail Bank Lobby
A regular array of downlights provides uniform horizontal and vertical illuminance throughout the lobby space. The uniformity is important to visual assessment of faces throughout the space.

Accenting the wall behind the teller stations introduces a sense of spaciousness (see Table 12.2 | Subjective Impressions) and contributes to spatial definition (see Table 12.1b | Spatial Factors: Part Two). The regular array of downlights and the single linear wall slot contribute to pleasantness (see Table 12.1a | Spatial Factors: Part One).

» Image ©Peter Foley/epa/Corbis

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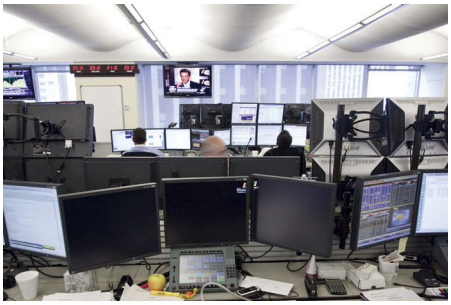


Figure 31.3 | Trading Floor
Indirect/direct linear pendant luminaires provide general lighting throughout this trading floor to accommodate the tasks of paperwork, computer work, and facial modeling. The relative softness of the indirect lighting yields no veiling reflections on CSA/ISO Type I and II monitors in positive or negative polarity in the near vertical orientation. However, screens in the near horizontal orientation exhibit veiling reflections.
» Image ©James Leynse/Corbis

31.2.12 Pedestrian Ways

Lighting for pedestrian ways is discussed in 26 | LIGHTING FOR EXTERIORS. In secure pedestrian-way situations, lighting must accommodate camera and surveillance requirements.

31.2.13 Post Offices

Depending on the size and type of the postal facility, applications might include a consumer lobby, P.O. boxes for mail pickup, a processing center, and shipping/receiving. The consumer lobby may consist of one or several postal windows and writing tables. P.O. boxes might be lined on one or several walls of the lobby or in larger facilities may require separate room or rooms. Lighting must address the vertical face of the wall or walls of boxes.

The processing center involves, reading, encoding, and sorting. A security area might include scanning equipment with video imaging. Visual inspection should also be accommodated. In larger facilities, automated equipment is used to read envelope addresses and sort mail accordingly.

31.2.14 Support Spaces

Lighting for support spaces is briefly addressed in 22 | LIGHTING FOR COMMON APPLICATIONS.

Coat rooms and copy centers are considered support spaces, though these may be decentralized depending on the type of facility. For example, a judge's chamber might need both a coat room and a copy center to address the volume of use and security requirements afforded by in-suite facilities.

Mail rooms in financial and municipal facilities may be relatively small, but there is likely need for an area and lighting to address sorting and to address security inspection. If inspection is an inherent part of sorting, then the security inspection criteria should be applied at all mail room work areas.

31.2.15 Toilets/Locker Rooms

Restrooms are best addressed by highlighting specific task areas. This offers energy efficiency while meeting the different illuminance criteria involved. Highlighting toilets, urinals, and vanities offers a more clean, crisp appearance than the haze of general diffuse lighting. Vanity positions require vertical illuminance on an imaginary facial plane (roughly a zone of sufficient size to encompass faces at standing or seated height) in front of the mirror. See Figure 22.7 for several methods of vanity lighting for non secure toilet facilities. Color of light is important for grooming. Lamps exhibiting 2700 K to 3500 K CCT and CRI ≥82, using triphosphor CFLs as benchmark, are appropriate.

31.2.16 Transition Spaces

How front-of-house transition spaces in many applications are designed and lighted defines the place and welcomes employees and guests. These spaces are transitions from exterior to interior and vice versa or from one kind of interior space to another. Illuminance criteria and accents are an important aspect of making comfortable and safe transitions.

Public spaces in some financial and municipal facilities may be of a particular sequence of passage, ceremonial in nature, or of special importance. To appropriately serve these roles, subjective impressions outlined in Table 12.2 should guide the application of lighting effects. Illuminances associated with artwork and features that assist with these subjective impressions are outlined in Table 31.2.

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Security screening areas in public spaces such as lobbies require some additional horizontal and vertical illuminance relative to the background lighting necessary for the normal space function. See Figure 25.1. Where special security procedures demand private screening, horizontal and vertical illuminance criteria should accommodate the situation. Illuminances and lighting hardware locations and light distributions must be coordinated with security cameras. Controls for these rooms may be purposely centralized or limited to motion sensors. The designer must coordinate requirements with the security consultant.

For purposes of visual consistency and of maintenance convenience, lamp types and color qualities should match those used elsewhere.



Figure 31.4 | Apparatus Bays
Linear recessed luminaires are arranged so that some rows are positioned between vehicles to best illuminate the sides of vehicles and into the vehicle compartments. Depending on garage door type, this arrangement also minimizes shadowing by overhead doors.
» Image ©Ocean/Corbis

31.3 Illuminance Criteria

Illuminance criteria, when fully deployed, are a robust set of quantitative values that influence visibility, visual performance, and visual comfort and attention. Short-circuiting the criteria selection or designing to a single criterion value, such as horizontal illuminance, to address worst-case tasks will surely result in dissatisfaction. Even if clients accept the visual results, not getting the most from the energy expended or, worse, energy waste is a likely result. Following are notes related to various topics outlined in Table 31.2.

31.3.1 Applications and Tasks

Applications and tasks encountered on any given project may be different from those identified in Table 31.2 and may warrant different illuminance criteria. Cross-referencing closely-associated applications or tasks is appropriate. Sometimes naming trends or conventions for space types or functions change to conform to current practice, client programming, or architectural conventions, but the actual activities and tasks remain the same and this cross-referencing works. Failing this technique, reviewing the list in Table 36.2 may be in order to determine if any applications or tasks exhibit a similar visual-component to the unique applications or tasks. Otherwise, reviewing 4.12 An Illuminance Determination System and Table 4.1 is necessary to establish a task category based on the task characteristics or visual performance descriptions most closely associated with the unique applications or tasks. These exercises as well as any deviations from recommendations the designer intends to make should be carefully documented for the record.

31.3.2 Notes

The notes in Table 31.2 may refer to other task headings in the table or to other handbook chapters as appropriate. Where some degree of clarification is warranted, notes are made.

31.3.3 Recommended Maintained Illuminance Targets

Values cited are maintained on the area of coverage for the task under consideration. Illuminance is additive. Where practical and without negatively affecting the intended application of light, target values are achieved with any combination of daylighting and/or electric lighting in whatever mix of ambient, task, and accent lighting is deemed appropriate to meet these and the other lighting goals established during design. See 12 | COMPONENTS OF LIGHTING DESIGN and see 10.7.1 Light Loss Factors.

With respect to light loss factors, account for anticipated losses through the point in time at which group relamping and cleaning should occur. Group relamping and cleaning should be standard practice, though these need not occur at the same frequency. Periodic cleaning and group relamping essentially maintain the illuminance at criteria and make the most efficient use of the installed equipment. For purposes of sustainability, cleaning and group relamping can no longer be presumed to be infrequent or unlikely. Maintenance procedures must be part of the design discussions with the client. See the IES document

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IESNA/NALMCO RP-36 Recommended Practice for Planned Indoor Lighting Maintenance for additional information. Where maintenance is deferred or practiced poorly or not at all, the actual illuminance values will fall below criteria targets. This is inefficient, unsustainable, and may be unsafe while adversely affecting users' quality of life or work. Ratcheting initial illuminances higher is poor practice and not recommended. Maintenance procedures may be especially problematic with LEDs where promises of extraordinarily long life may be offered, but usually with the caveat that lamp lumen depreciation (LLD) at that rated life is 70% or perhaps even as low as 50% of initial rating. If replacement cycles are presumed to be rated life, then LLD alone must be 0.7 or 0.5 or whatever lumen rating is certified by the LED vendor. See 13.3 Life and Lumen Maintenance.

Targets cited are consensus and recommended for respective functional activity. For some applications, IES recommendations are within 10% of code requirements. This apparently is an artifact of metrication. Footcandle conversions of any values cited in Table 31.2 should be made at 1 fc to 10 lx. This soft conversion avoids a redundant diminishing of illuminance values after multiple citations and conversions over time. This also eliminates a false sense of accuracy advanced by an ever-increasing number of decimal places and a false sense of urgency advanced by eccentric fractional values introduced by hard conversions. Nevertheless, a lighting design must meet code and the mechanics of which must be coordinated amongst the design team. The IES recommendations should not, do not, and cannot reflect all of the various code requirements in force in all jurisdictions at any given time.

Targets are intended to apply to the dominant plane of the task, typically, but not always, horizontal or vertical. In some situations, illuminance criteria are cited for one plane, such as the vertical plane for perimeter display walls in a trial jury suite, while the other plane is blank. The blank signifies that illuminance on that plane is unimportant and may be a consequence of the illuminance of other tasks within the vicinity or by whatever illuminance results from meeting the target illuminance for the prescribed plane of interest.

In some situations, no light is anticipated on at least one plane of a task. A 0 indicates no light or zero light is recommended for the task or application.

31.3.3.1 Target Planes

Many, though certainly not all, tasks are performed with the task in roughly a horizontal orientation or vertical orientation. A dominant orientation must be assigned and the illuminance target determined accordingly. There may be situations where the IES recommended target relating to the typical planar mode of a task must be applied to a different plane.

Nearly all tasks are expected to have both a horizontal illuminance component (E_h) and a vertical illuminance component (E_v). This allows some degree of task flexibility for off-plane viewing and accommodates various aspects of the task.

Where illuminance targets are intended at differing planar elevations, this is indicated under "Notes." Note the implication for observers' visual ages. Establishing and tracking task orientations and addressing both horizontal and vertical illuminance is necessary. If orientations in the project under consideration are programmed to be flipped from what might be considered normal-viewing, then criteria must be adjusted accordingly. If a task is scheduled to be oriented on some plane off axis from horizontal or vertical by more than 10°, say, then the illuminance criteria must be applied to that off-axis orientation. This is an important distinction for luminaire optical selection and aiming capabilities and for layout, calculations, and field measurements.

For planes related to vertical illuminance targets, some guidance is indicated under "Notes." However, the designer may elect to use alternate or multiple vertical planes. In some situations the vertical planes could be oriented in a number of directions and the designer must determine which are most appropriate for the situation.

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31.3.3.2 Visual Ages of Observers

Illuminance criteria are based on the visual ages of more than half the intended observers. This aspect should be resolved during programming with the client. It may be determined that illuminance criteria for an age group other than that representing the majority of the intended observers is appropriate. However, this may result in overlighting, underlighting, harsh lighting, visual displeasure, or visual discomfort for many of the observers. See 12.5.5 Illuminance and 4.12 An Illuminance Determination System for additional information and guidance. In some situations, such as front projection AV presentations, lighting must meet the requirements of the screen technology to maximize visibility for all age groups and, therefore, is not tied to ages of observers.

31.3.3.3 Illuminance Categories

Illuminance categories are designated by letters A through Y. These are shown in Table 31.2 for more convenient reference to Table 4.1 | Recommended Illuminance Targets should the designer wish to explore other criteria targets or if applications or tasks on a specific project are not readily correlated to the table citations.

31.3.3.4 Gauge

The common gauge for determining illuminance target compliance is cited for each application. All gauges presume that point-by-point techniques are used for predictive calculations and presume that uniformity criteria are closely monitored. Where an average illuminance value over the area of coverage can satisfy target compliance, "Avg" is cited. In applications or tasks where a minimum or maximum target is necessary, the gauge for compliance is "Min" or "Max" respectively.

The designer may elect to use other methods to evaluate target compliance, such as criterion rating (CR) or coefficient of variation (C_v). See 4.12.4.5 Tasks at Uncertain Locations Over a Large Area.

In any event, once illuminance targets and uniformities are established, then any calculated deviation from them should be limited. Standard engineering allowance of ±10% might be acceptable for targets gauged as average unless contractual or code obligations demand otherwise. Minima and maxima must be achieved as intended.

Designs should be adjusted until predictions are within allowance for averages and meet minima and maxima. For additional information, see 4.12.4.1 Recommended Illuminances at Design Time, 4.12.5 Illuminance Ratios, 9.15.1.1 Average Illuminance, and 10.8 Assessing Computed Results.

31.3.4 Uniformity Targets

Illuminance uniformity targets work in conjunction with luminance uniformities and surface reflectances all of which must be addressed as part of the design to avoid visual discomfort, glare, and strain. Uniformity ratios are targets that define the widest recommended ranges. In many situations, uniformity ratio criteria are those between average values of an array of points and the minimum value in the same array of points. Uniformity targets apply to both horizontal and vertical illuminances over the area of coverage. Where horizontal uniformity criterion is different from vertical uniformity criterion, two ratios are reported with the first value for horizontal illuminance (E_h).

Generally the more important speed and accuracy and the more demanding the visual task, the tighter the ratio.

31.3.4.1 Maximum-to-average

This is the recommended ratio of maximum illuminance to the average illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations sensitive to even a relatively small degree of overlighting.

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31.3.4.2 Average-to-minimum

This is the recommended ratio of average illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where illuminance too far below average conditions is noticeable and detrimental to task performance or inconsistent with normal expectations.

31.3.4.3 Maximum-to-minimum

This is the recommended ratio of maximum illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where too much variation in illuminance is considered undesirable and untenable from a performance or safety perspective.

31.3.5 Daylighting Advancement

Generally, design strategies should embrace any combination of daylighting and electric lighting to achieve target values during daylight hours. The preference is for daylighting to provide all or most of the recommended illuminance presuming that all aspects of daylighting are properly addressed. A sunburst icon depicts those applications and tasks where daylighting is considered a strategic candidate. Use photocells and stepped-dimming or continuous dimming to reduce or eliminate electric lighting during daylight hours. However, this may not be practical or appropriate in council chambers or trading floors unless continuous dimming is used on slow response rates. See 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Even for those applications where daylighting is not traditionally a strategic candidate, it may be determined that very careful and coordinated design will offer great sustainability opportunities.

31.3.6 Veiling Reflections

IESH/10e CSA/ISO

> 12.5 Task Factors

- for information on CSA/ISO computer screen qualities

Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper or, worse, both, are prone to veiling reflections. The likelihood of particular applications and tasks predisposed to veiling reflections is indicated by a "reflected light" icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood. Veiling reflections are minimized by controlling the overall amount and direction of light with respect to the task locations and orientations. Alternatively, tasks sensitive to veiling reflections can be screened or isolated. Effective strategies include employing indirect soft, diffuse electric lighting or direct electric lighting with multiple low-output luminaires, or positioning tasks and luminaires and luminance patterns to avoid harsh reflections from tasks. Addressing luminance recommendations (see Table 12.4 | Default Luminance and Luminaire Intensity Recommendations for VDT Applications) minimizes veiling reflections. Changing the task will reduce or eliminate veiling reflections, such as use of CSA/ISO Type I or II computer screens and matte paper versus their specular counterparts.

31.3.7 Defining Areas of Coverage

In addition to establishing planes of task orientation, the areas of coverage to which targets apply must be determined. Typical areas of task illuminance coverage are identified here, but these may not be appropriate to specific project situations. One area of coverage is "task proper or task area." Here, the illuminance criteria are applied to the task itself or to a relatively small area to which the task is confined. See 12.5.5.1 Tasks and Applications and Figure 12.22 | Task Coverage Example. In some situations, such as accenting, the "task" area may consist of the entire wall when "feature wall" or "perimeter" accenting is desired. It is important to remember that illuminance is additive, that is, task illuminance can be achieved with some combination of ambient lighting, task lighting, and/or accent lighting, providing that the total illuminance on the task proper or task area meets the illuminance criteria outlined in Table 31.2.

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Another area of coverage is "room or designated area." In this situation, illuminance criteria are applied to the room or an area of fairly substantive size representing the zone in which the applications and tasks are expected to occur. The designated area is typically established by the furniture layout, for example, or might be established by the design team or client. The area-of-coverage citations in Table 31.2 are based on traditional notions. So, for example, it may be determined that a "task proper or task area" coverage would result in some amount of LPD reduction when compared to "room or designated area" coverage. If the task can be confined to one area rather then multiple areas, if the room or area in which the task is located is itself relatively small, such as a single-occupant office, and if the other design goals and criteria outlined in 12 | COMPONENTS OF LIGHTING DESIGN are addressed, then this strategy of redefining area of coverage has merit.

An assessment and determination must be made on which area of coverage best satisfies the lighting goals on a particular project.

31.4 Designing

Information provided here is specific to the miscellaneous facilities cited and should be used as part of the design and documentation processes outlined in Chapters 12, 15, and 20. Equipment selection and location strategies may need to address the possibility of lighting equipment abuse. For outdoor applications, lamps and ballasts, transformers, and drivers must be selected for ambient temperature conditions, some of which are extremely hot and others extremely cold. See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY for additional information on respective aspects. Addressing all code requirements is a must. Energy efficient and sustainable practices are an integral part of all IES recommendations. Key design tenets include, but are not limited to:

- designing for the satisfaction of the observers of significance intended to use the project
- using baseline reflectances of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively) in interior production, holding, and work-oriented spaces
- using daylighting that meets luminance and illuminance criteria
- using highest-efficacy lamps that meet color, optical and electrical control, and output criteria
- using highest-efficiency luminaires that meet aesthetic, abuse, and luminance criteria
- using accenting to provide luminance balancing or improve brightness perceptions where necessary
- using controls liberally, preferably automated varieties such as presets, occupancy and vacancy sensors, astronomical time clocks, and photocells
- establishing IES-recommended illuminance criteria to meet programmed tasks
- establishing layouts that just meet IES-recommended illuminance criteria
- addressing outdoor environmental needs
- using calculations, photometrically-realistic renderings, and operational samples and mockups to prove concepts
- identifying and designing to code-specific requirements, if any, for ambient, task, and accent lighting
- documenting all code-, energy-, sustainability-, and IES-criteria compliance
- documenting criteria and design deviations and rationale and subsequent disposition by team, client, or AHJ
- documenting clearly the layouts, controls, and luminaire and lamp selections

Designing for the satisfaction of the observers of significance is the paramount design tenet and must be kept in perspective during all aspects of design. Here, the designer

IESH/10e Economics Resources

> 15.3.3 Budgets
  - for more on budgets and value engineering

> 18 | ECONOMICS
  - for more on estimating costs
  - for more on life cycle costs
  - for more on paybacks and rates of return

IESH/10e Energy Efficiency Resources

> 17.2 New Construction
  - for more on designing for daylighting
  - for more on electric lighting equipment
  - for more on lighting controls

> 17.4 Lighting Codes, Regulations and Standards
  - for more on application standards
  - for more on equipment regulations

IESH/10e Lighting Exteriors Resources

> 12.5.5.6 Nighttime Outdoor Illuminances
  - for more on lamp efficacies under mesopic adaptation

> 26 | LIGHTING FOR EXTERIORS
  - for more on criteria

IESH/10e Sustainability Resources

> 13.11 Sustainability
  - for more on lamps

> 19 | SUSTAINABILITY
  - for more on controls
  - for more on earth resources
  - for more on energy
  - for more on life cycle analyses
  - for more on lighting design
  - for more on recycling

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must establish the significant observers and their related lighting requirements. If the observers' expectations are not fulfilled, then how much energy could be saved is moot, as is how many fewer earth resources were spared, as is how much the whole affair cost or how much value engineering saved or the photogenic qualities of the project. See sidebar references for additional guidance on the key tenets. The design effort must be undertaken with coordinated and realistic expectations by all involved on initial and life cycle costs. Budgeting should include designer input and dialogue with the team and client at project commencement and design milestones. In other words, and paraphrasing Thomas Edison, genius is, indeed, just 1% inspiration and 99% perspiration.

31.5 References

[1] Immanuel Kant. WorldofQuotes.com. 2011 [Internet]. [cited April 9, 2001]. Available from: http://www.worldofquotes.com/topic/Miscellaneous/19/index.html.

[2] Mark S. Rea, ed. 2000. The IESNA lighting handbook: Reference and application. 9th Edition. New York: IESNA.

[3] [NFPA] National Fire Protection Association. 2001. Article 708. In: NFPA 70 National Electrical Code. 12th Edition. Quincy: NFPA.

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32 | LIGHTING FOR OFFICES

The best vision is insight.
Malcolm S. Forbes, 20th Century Publisher

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Lighting is most efficient and sustainable when it is recognized for what it can accomplish and then leveraged for maximum benefit. Figure 32.1 shows typical annual lighting costs that are but a small fraction of the costs of the people and real estate necessary for office operations [1]. The real bottom line is not in securing quick and cheap commodity lighting during the relatively brief project construction period, but rather in leveraging the lighting equipment and their effects and energy value to maximize worker comfort, productivity, and retention over the life of the system. Visually effective and appealing, high quality lighting provides the best employee, environmental, and operating value.

Electric lighting accounts for about 39% of the electricity used in offices [2]. Figure 32.2 shows the breakdown of office electricity use. This amounts to 82 TWh for lighting, which is about a 5% reduction since 1995 while total electricity use in offices increased by more than 25%. The need to design and specify well-controlled efficient lighting remains important, if not a priority. However, it makes little sense to design and specify lighting that is so power-starved and so confoundingly controlled (or not at all) that occupants cannot see well or lighting quality is so poor that few people are willing and/or able to adapt to the prescribed setting. Daylighting and views are integral to simultaneously reducing energy consumption and attracting and retaining a productive workforce. What follows is a discussion of the key aspects affecting lighting: project status; space types; activities; application-specific design goals, and illuminance criteria in office facilities.

Comprehensive design efforts rely on material in this chapter combined with material in 12 | COMPONENTS OF LIGHTING DESIGN, 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS, 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Design tenets deemed appropriate from those chapters must be identified and lighting goals and strategies developed accordingly. This chapter primarily addresses specifics related to lighting for offices which should influence luminaire optical selections, lamping, and final layouts based on previously developed thought-starters (see 15.2 A Lighting Scheme). Use of the material in this chapter to the exclusion of material in Chapters 12, 13, 14, and 15 will likely lead to unsatisfactory results. Previous and current IES related documents serve as archival and reference sources [3] [4].

Deliberate thought must be given to details beyond the recommended illuminances in this chapter. For example, periodic visual rest from many of the usual reading and writing tasks is appropriate and cannot generally be achieved simply on the basis of task or application illuminance criteria. Accenting artworks or architectural features or providing exterior views are in order. Such situations must be studied carefully before solutions are recommended, particularly those solutions that seem obvious. These kinds of specific details are not enumerated for most tasks. Table 32.1 offers a checklist of IES lighting topics and criteria. The design team is responsible for determining and addressing indoor and outdoor lighting and energy criteria set forth by authorities having jurisdiction (AHJ) which may be different from and supersede IES criteria. See also 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

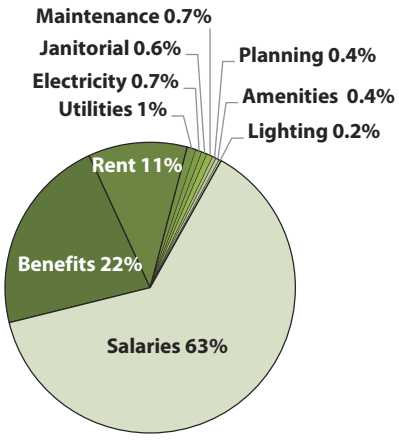


Figure 32.1 | Office Costs
Average annual costs associated with running an office.

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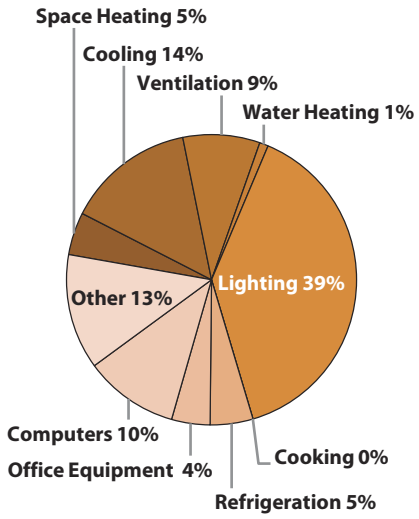


Figure 32.2 | Office Electricity Use
Based on 2003 data from the US DOE's Energy Information Administration, lighting accounts for 39% of electricity use in office buildings (electricity use for Cooking rounds to 0%). Office buildings themselves account for about 20% of electricity use by all commercial and institutional buildings.

32.1 Project Type and Status

Before any design work, an understanding of the project type and scope is necessary. This will establish the extent to which daylighting can address most or many or some of the lighting goals. New, renovation, and restoration projects each offer varying opportunities. See 11.2 Planning, 11.3.1 Pre-design, and 11.3.2 Schematic Design. At every opportunity the lighting designer should give every consideration to daylighting as a light source. Given hours of operation of many office facilities, daylighting can be a primary light source. Critically, this means addressing the host of lighting design factors identified in 12 | COMPONENTS OF LIGHTING DESIGN. Daylight demands determined attention to moderate or eliminate glare and balance visible and thermal energy.

32.2 Application Types

To develop lighting solutions that meet quality, quantity, and operational criteria, an inventory is made of the office space types under consideration and the anticipated occupants, functions, and tasks (see Table 11.2 | Programming: Inventory Scope and Specific Examples and Table 12.3 | Sample Visual Task Survey). Otherwise, lighting cannot be best targeted to the users, their expectations, functions and tasks.

Space type definitions are required early in the project design in order to track design efforts that include inventorying the project knowns, anticipated functions, and tasks and calculating lighting, power, and energy compliance. Room names and department names in large open areas from which functions can be deduced, and numbers for tracking should be clearly marked on architectural backgrounds. The applications and tasks cited in Table 32.2 | Office Facilities Illuminance Recommendations should be reviewed against the project knowns and correlated with the named space types and functions to establish recommended illuminance criteria. Seek clarification with the client where discrepancies occur between programming information, the list of room names, and the available application and task citations in Table 32.2.

The following sections are keyed to the major application and task headings in Table 32.2. These discussions, those highlighted in Table 32.1, and material in Table 32.2 offer comprehensive qualitative and quantitative criteria.

32.2.1 Accenting

Accenting affects people's brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. Default accent lighting criteria are discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. Also see 15.1.1.3 Accent Lighting.

32.2.2 Administration

Administrative functions on many projects typically include circulation, conferencing, counseling, lounges, filing or records, interviewing, lobbies, mail sorting, and officing. These functions constitute most office facilities. Each of these functions in turn may involve a number of specifics including some form or degree of acknowledgment, conversation, reading, periods of respite or relaxation, and writing. Acknowledgement of other people and conversation, for example, require some vertical illuminance at face height (seating or standing depending on the nature of the application). Vertical illuminance criteria are cited for such applications.

The architectural scheme and even task specifics will vary based on the associated facility function and type, from insurance to banking to manufacturing to advertising to electronic software or hardware development, and so on. These variations should affect the lighting design—from kinds of lighting effects to lighting equipment styling to luminances and illuminances.

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The administrative areas may be dispersed throughout a facility or complex or may be centralized into a single area, wing, or building. Depending on client wishes and architectural desires, this centralization or decentralization may affect the degree to which the lighting design in administrative areas is sympathetic to or different from that of other applications.

See also 32.2.8 Offices.

32.2.3 Building Entries

Lighting for building entries is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. For building entries of office facilities several distinct variables are time of need, anticipated levels of activity, and the nighttime outdoor lighting zone. Nighttime activity levels may vary by type of office facility, such as a call center with several night shift changes, and by size. This may be best served by a control system capable of addressing various settings at various times of the night through manual intervention, automated time clock, and photocell functions.

The nighttime outdoor lighting zone within which the facility is located establishes the categories of illuminance for outdoor tasks. Nighttime outdoor lighting zones vary by local ordinance, sustainability guides, or the team's own definition of place.

After-hours security needs, such as on-site or remote monitoring or recording, may require that some luminaires at building entries remain energized through the night or placed on motion sensors or interconnected with camera operations. Control zones and time clock functions must be designed accordingly. Where remote monitoring is done with infrared cameras, lighting may be unnecessary.

32.2.4 Conferencing

Conferencing runs the gamut from very simple single-purpose functionality (for example, meet to discuss) to rather complex multipurpose tasks (for example, meet to discuss, present, strategize, and learn, or video conference with others). The lighting is influenced accordingly and also by the formality of the setting. Where presentations are common, such as a board room or a meeting room, and where the participants might number two dozen, the lighting should help define the formality and procedural aspects of the meeting. Accenting on presenter positions is appropriate. Some conference settings strike a balance. In these situations, presentations are common, but intended as a group-think-discuss learning situation. Here, although presentation surfaces are still accented, presenters might not be illuminated. In larger spaces, lighting presets are used to respond to room setups and functions. Figure 32.3 illustrates a training room. Figure 32.4 illustrates a traditional conference room. Figure 32.5 illustrates meeting rooms. Although illuminances are quite similar in the examples, the resolutions vary based on ceiling conditions, architectural styles, and programming requirements and priorities such as flexibility, efficiency, hardware and installation costs. See also Figures 15.5d, 15.16, and 22.5.

Video conferencing criteria are directly related to camera technology and user expectations. Vertical illuminances and uniformity criteria at faces and background wall surfaces are most important. Coordinate illuminance criteria with latest camera requirements. Telepresence is a variation on video conferencing. Portable all-in-one camera and monitor setups, from single to multiple monitors, offer video conferencing in non-dedicated settings. Preset controls should be used for convenient and consistent toggling between typical conferencing functions and video conferencing.

32.2.5 Drafting and Design

Drafting and design tasks typically involve reading computer screens, writing to computer screens, and periodically referencing a keyboard or other interactive device and, in some situations, paper documents. Programming should identify the kinds of computer screens

Table 32.1 | Office Lighting Checklist

Topics
✔ **IES Criteria and Design Resources**
Accenting
15.1.1.3 Accent Lighting
Table 12.2 | Subjective Impressions
Table 15.2 | Accent Illuminance Ratios
Table 22.2 | Common Applications Illuminance Recommendations
Appearance
12.2 Spatial Factors
Color
12.5.6 Color Considerations
Controls
16 | LIGHTING CONTROLS
Daylighting
14 | DESIGNING DAYLIGHTING
Electric Lighting
15 | DESIGNING ELECTRIC LIGHTING
Flicker
4.6 Flicker and Temporal Contrast Sensitivity
Glare
4.10.1 Discomfort Glare
4.10.2 Disability Glare
Illuminance
This Chapter: Table 32.2
12.5.5.1 Applications and Tasks
Table 12.6 | Default Illuminance Ratio Recommendations
Figure 12.22 | Task Coverage Example
Light Distribution
12.3.2 Subjective Impressions
Luminances
12.5.2 Luminance
Table 12.5 | Default Luminance Ratio Recommendations
Maintenance
15.4.4 Installation and Maintenance
Systems Integration
12.6 Systems Factors
Veiling Reflections
This Chapter: Section 32.3.6
12.5.4 Veiling Reflections
Visual Tasks
This Chapter: Section 32.2
This Chapter: Table 32.2
Table 11.2 | Programming: Inventory Scope and Specific Examples
12.5.1 Visual Tasks
Table 12.3 | Sample Visual Task Survey

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Table 32.2 | Office Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
ACCENTING	Accenting influences observers' overall brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. See 22 | LIGHTING FOR COMMON APPLICATIONS/ACCENTING for default accenting criteria for consideration in any application.										
ADMINISTRATION	See 22 | LIGHTING FOR COMMON APPLICATIONS										
• Circulation	See TRANSITION SPACES										
• Conferencing	See CONFERENCING										
• Copy/Print Room	See SUPPORT SPACES										
• Counseling	See ADMINISTRATION/Interviews										
• Filing	E_h @2' 6" AFF; E_v at front face of filing cabinet over area from 1' AFF to top of filing cabinet or filing system.										
• Constant		P	150	300	600	Avg	O	100	200	400	Avg
• Intermittent		N	75	150	300	Avg	M	50	100	200	Avg
• Seldom		M	50	100	200	Avg	L	37.5	75	150	Avg
• Interviews	E_h @2' 6" AFF; E_v @4' AFF										
• Conversational		N	75	150	300	Avg	L	37.5	75	150	Avg
• Formal	Includes form-filling and reading	Q	200	400	800	Avg	N	75	150	300	Avg
• Lobbies	See TRANSITION SPACES										
• Mail Sorting	See SUPPORT SPACES/Mail Facility										
• Offices	See READING AND WRITING, establish tasks and normalize to illuminance of most important task or most common task; use controls to provide illuminance variability if tasks so demand.										
• Training	See CONFERENCING. Alternatively, see READING and WRITING, establish tasks and normalize to illuminance of most important task or most common task; use controls to provide illuminance variability if tasks so demand.										
BUILDING ENTRIES	See 22 | LIGHTING FOR COMMON APPLICATIONS										
CONFERENCING											
• Meeting	Periodic notetaking, reading, and facial detail										
• Discourse	E_h @2' 6"; E_v @4' AFF	P	150	300	600	Avg	L	37.5	75	150	Avg
• Presentation Surfaces	Vertical poster boards, presentation boards, tack surfaces						M	50	100	200	Avg
• White boards											
◦ Analog or Digital											
Reading (reference)							N	75	150	300	Avg

Table 32.2 | Office Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	see Table 12.6					
	3:1					
	3:1					
	3:1					
	3:1					
	see Table 12.6					
	3:1					
	3:1					

Notes for Table 32.2

The table column headings are discussed in detail in 32.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 32.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 32.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 32.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, or conference table a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

j. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

k. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 32.2 | Office Facilities Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
CONFERENCING	(Meeting continued)										
• Presentation											
• Formal speaking											
◦ AV	E_h @2' 6"; E_v @4' AFF	I	15	30	60	Avg	I	15	30	60	Max
◦ Non-AV											
Presentation surfaces	Vertical poster boards, presentation boards, tack surfaces						M	50	100	200	Avg
Reports, handouts	See READING AND WRITING, establish tasks and normalize to illuminance of most important task or most common task; use controls to provide illuminance variability if tasks so demand.										
• White boards											
◦ Analog or Digital											
Reading (presentation)	Interactive use as part of formal presentation						P	150	300	600	Avg
◦ Presenter	At fixed presentation podium or position										
Face	E_v @5' AFF						Avg ≥1 times but ≤ 3 times audience task E_h				
Task surface	E_h @3' 6" AFF	Avg ≥1 times but ≤ 3 times audience task E_h									
• Telepresence	See CONFERENCING/Video Conferencing										
• Video Conferencing	Coordinate lighting criteria with camera and display requirements. Where camera and display technologies permit criteria lower than reported here, use the lower criteria to reduce visual fatigue and discomfort common under relatively high vertical illuminances over long durations of sedentary activity. Address criteria citations for table and wall reflectances. See IES DG-17 Fundamentals of Lighting for Videoconferencing for additional information.										
• Displays											
• Front-screen projection	Over front surface of screen							50	50	50	Max
• Rear-screen projection	Over front surface of screen							150	150	150	Max
• Video displays or monitors	Over front surface of display							200	200	200	Max
• Faces	E_h @4' AFF; E_v @3'-5' AFF in direction(s) of camera(s)		300	300	300	Avg		400	400	400	Avg
• Tables	Matte surface reflectance of 40% is recommended for table. Illuminance recommendations accommodate intermittent reading of reference materials consisting of paper tasks and CSA/ISO Types I and II positive polarity computer screens. See READING AND WRITING if other reference materials must be accommodated.										
• 40% matte reflectance	E_h @2' 6" AFF		300	300	300	Avg					
• Walls	Matte surface reflectances are recommended for walls.										
• 40% matte reflectance	E_v @2' 6"-6' 6" AFF							400	400	400	Avg
• 50% matte reflectance	E_v @2' 6"-6' 6" AFF							300	300	300	Avg
• 60% matte reflectance	E_v @2' 6"-6' 6" AFF							200	200	200	Avg
DRAFTING AND DESIGN											
• Blueline Blueprint	Also see READING AND WRITING/Xerograph	R	250	500	1000	Avg	M	50	100	200	Avg
• CAD (exclusively)	See READING AND WRITING/VDT Screen and Keyboard										
• CAD/Paper Mixed	See READING AND WRITING, establish tasks and normalize to illuminance of most important task or most common task; use controls to provide illuminance variability if tasks so demand.										
FOOD SERVICE	See 22 | LIGHTING FOR COMMON APPLICATIONS										
IT	See 22 | LIGHTING FOR COMMON APPLICATIONS										

Table 32.2 | Office Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
3:1						
	3:1					
	3:1					
	3:1					
	2:1					
2:1						
2:1						
2:1						
	1.5:1					
	1.5:1					
	1.5:1					
	1.5:1					
	1.5:1					
see Table 12.6						

Notes for Table 32.2

The table column headings are discussed in detail in 32.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 32.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 32.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 32.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

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j. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

k. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 32.2 | Office Facilities Illuminance Recommendations continued from previous page

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		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
OFFICES	See READING AND WRITING, establish tasks and normalize to illuminance of most important task or most common task; use controls to provide illuminance variability if tasks so demand.											
PARKING	See 26 | LIGHTING FOR EXTERIORS											
PEDESTRIAN WAYS	See 26 | LIGHTING FOR EXTERIORS											
READING AND WRITING												
• Computer	See READING AND WRITING/VDT Screen and Keyboard											
• Electronic Readers												
• Electronic Ink Devices	E_h and E_v @height of device	P	150	300	600	Avg	N	75	150	300	Avg	
• LCD or LED Devices	E_h and E_v @height of device	N	75	150	300	Avg	K	25	50	100	Avg	
• Facsimile												
• Analog	E_h @2' 6" AFF; E_v @4' AFF[j]	R	250	500	1000	Avg	M	50	100	200	Avg	
• Digital	E_h @2' 6" AFF; E_v @4' AFF[j]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Handwritten Work	Based on fair-to-good penmanship/hand print on white or canary paper											
• Pencil												
• Graphite/HB	E_h @2' 6" AFF; E_v @4' AFF[j]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Red	E_h @2' 6" AFF; E_v @4' AFF[j]	R	250	500	1000	Avg	M	50	100	200	Avg	
• Ballpoint/Rollerpoint/Felt-tip												
• Black	E_h @2' 6" AFF; E_v @4' AFF[j]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Red, Green, Blue	E_h @2' 6" AFF; E_v @4' AFF[j]	Q	200	400	800	Avg	L	37.5	75	150	Avg	
• Laptop	See READING AND WRITING/VDT Screen and Keyboard											
• Microforms (Projected)		L	37.5	75	150	Avg	I	15	30	60	Avg	
• Print Media	Digital-printing-press-generated, white paper											
• 6-pt Font												
• Matte paper and ink	E_h @2' 6" AFF; E_v @4' AFF[j]	R	250	500	1000	Avg	L	37.5	75	150	Avg	
• Specular paper and ink	E_h @2' 6" AFF; E_v @4' AFF[j]	R	250	500	1000	Avg	L	37.5	75	150	Avg	
• 8- and 10-pt Font												
• Matte paper and ink	E_h @2' 6" AFF; E_v @4' AFF[j]	P	150	300	600	Avg	K	25	50	100	Avg	
• Specular paper and ink	E_h @2' 6" AFF; E_v @4' AFF[j]	P	150	300	600	Avg	K	25	50	100	Avg	
• 12-pt Font												
• Matte paper and ink	E_h @2' 6" AFF; E_v @4' AFF[j]	O	100	200	400	Avg	K	25	50	100	Avg	
• Specular paper and ink	E_h @2' 6" AFF; E_v @4' AFF[j]	O	100	200	400	Avg	K	25	50	100	Avg	
• VDT Screen and Keyboard												
• CSA/ISO Types I and II	See Figure 12.16 | CSA/ISO Computer Screen Qualities											
• Positive polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[j]	P	150	300	600	Avg	N	75	150	300	Avg	
• Negative polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[j]	N	75	150	300	Avg	K	25	50	100	Avg	
• CSA/ISO Type III	See Figure 12.16 | CSA/ISO Computer Screen Qualities											
• Positive polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[j]	N	75	150	300	Avg	K	25	50	100	Avg	
• Negative polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[j]	L	37.5	75	150	Avg	I	15	30	60	Avg	
• White Board												
• Analog or Digital												
• Reading (reference)							N	75	150	300	Avg	
• Reading (with presenter)	Presenter at white board						P	150	300	600	Avg	

Table 32.2 | Office Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
2:1					i	i
2:1					i	i
see Table 12.6					i	i
see Table 12.6					i	i
see Table 12.6					i	i
see Table 12.6					i	i
see Table 12.6					i	i
see Table 12.6					i	i
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see Table 12.6					i	i
3:1						
3:1						

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a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 32.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 32.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

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j. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

k. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 32.2 | Office Facilities Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
READING AND WRITING	(continued)											
• Xerograph	Copier- and printer-generated on white paper											
• ≥8-pt type, common graphics	Select progressively next-higher letter category of illuminance for each 2-point-type decrease in fonts/graphics)											
• Color												
◦ Analog	E_h @2' 6" AFF; E_v @4' AFF[j]	R	250	500	1000	Avg	M	50	100	200	Avg	
◦ Digital	E_h @2' 6" AFF; E_v @4' AFF[j]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Grayscale and/or B+W Print												
◦ Analog	E_h @2' 6" AFF; E_v @4' AFF[j]	P	150	300	600	Avg	L	37.5	75	150	Avg	
◦ Digital	E_h @2' 6" AFF; E_v @4' AFF[j]	O	100	200	400	Avg	K	25	50	100	Avg	
SUPPORT SPACES												
• Break Rooms/ Lunch Rooms	E_h @2' 6" AFF; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg	
• Coat Check or Coat Rooms	E_h @3' 0"; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Copy/Print Rooms												
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg	
• Machines	E_h and E_v @3' 6" AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Janitor's Closet	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg	
• Mail Facility												
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	J	20	40	80	Avg	
• Security Inspection	E_h and E_v @3' 6" AFF	T	500	1000	2000	Avg	P	150	300	600	Avg	
• Sorting	E_h @2' 6" AFF; E_v @4' AFF	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Receiving/Shipping												
• Dock	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg	
• Receiving/Staging	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Storage												
• Food	See 22 | LIGHTING FOR COMMON APPLICATIONS/Food Service											
• Frequent Use	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg	
• Infrequent Use	E_h @floor; E_v @4' AFF	K	25	50	100	Avg	H	10	20	40	Avg	
TOILETS/ LOCKER ROOMS	See 22 | LIGHTING FOR COMMON APPLICATIONS											
TRAINING ROOMS	See 24 | LIGHTING FOR EDUCATON/CLASSROOMS											
TRANSITION SPACES												
• Circulation Corridors	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.											
• Adjacency Passageways	E_h @floor; E_v @5' AFF	Avg ≥0.3 times task E_h of adjacent space or as cameras require, but with min ≥10 lx					Avg ≥0.3 times task E_v of adjacent space or as cameras require					
• Breakout Passageways	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg	
• Independent Passageways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
• Elevators												
• Freight												
• Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
• Threshold												
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	

Table 32.2 | Office Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
see Table 12.6					[i]	[i]
see Table 12.6					[i]	[i]
see Table 12.6					[i]	[i]
see Table 12.6					[i]	[i]
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		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
TRANSITION SPACES	(Elevators continued)										
• Passenger											
• Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Threshold											
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Entries	See 22 | LIGHTING FOR COMMON APPLICATIONS/BUILDING ENTRIES										
• Escalators/Moving Walkways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Lobbies											
• Circulation, Elevator Lobbies	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• At building entries	Close proximity to exterior. Lighting should assist with adaptation when passing to/from exterior..										
◦ Day	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
◦ Night	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Distant from entries	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Displays											
• Awards/Trophy cases	See 24 | LIGHTING FOR EDUCATION/CLASSROOMS/Arts/Graphic Arts/Displays										
• Posting boards							N	75	150	300	Avg
• Information Desk		P	150	300	600	Avg	M	50	100	200	Avg
• Lounges											
• Break		M	50	100	200	Avg	K	25	50	100	Avg
• Reception/Waiting Areas											
• Reception Desk		Q	200	400	800	Avg	N	75	150	300	Avg
• Waiting Areas		O	100	200	400	Avg	M	50	100	200	Avg
• Stairs	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• High activity[k]	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Live-surveillance	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Typical	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1		☀			■
	2:1		☀		■	
	2:1		☀		■	
	2:1		☀		■	
	3:1		☀			■
	3:1					■
	3:1		☀			■
	3:1		☀	◪	■	
see Table 12.6			☀		■	
	3:1		☀			■
see Table 12.6			☀		■	
	3:1		☀			■
	2:1		☀			■
	2:1		☀			■
	2:1		☀			■

Notes for Table 32.2

The table column headings are discussed in detail in 32.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 32.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 32.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 32.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◪ signals high likelihood; gray and white ◪ signals moderate likelihood; pale gray and white ◪ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. For applications where task position is indefinite, such as some types of flexible meeting rooms, the typical area of coverage is "Room or Designated Area." For applications where task position is known, such as an office desk or a reading chair, or conference table a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area."

j. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

k. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 32.3 | SI Dimensional Conversions

US Customary	SI
General	**Hard Conversion**
inches	mm [inches × 25.40]
feet	m [feet × 0.30]
Specific	**Convenient Conversions[a]**
2'	610 mm or 0.6 m
2' 6"	760 mm or 0.75 m
3'	915 mm or 0.9 m
3' 6"	1065 mm or 1.1 m
4'	1220 mm or 1.2 m
5'	1525 mm or 1.5 m

a. Hard conversions rounded for reporting convenience. Not to be confused with metric-sized luminaires or other building materials. Not for precision construction.

IESH/10e CSA/ISO

> 12.5 Task Factors
- for information on CSA/ISO computer screen qualities

and the nature of the computer aided design (CAD) task. The designer must review the various reading and writing tasks identified in Table 32.2 and establish which are appropriate to the project at hand. In some situations, one set of illuminance criteria might appropriately address a task. For example, where little reference, if any, is made to paper documents, this is considered an exclusive CAD task. The type of computer screen and its contrast settings determine the degree of sensitivity to light and the need for light. See Figure 12.16 | CSA/ISO Computer Screen Qualities.

Where paper documents are part of the work task, a review of the types of paper tasks is necessary. If these tasks are quite varied and require very different illuminance criteria, it may be necessary to consider a dimmable task lighting system to illuminate just the paper document reference area. An ambient lighting system may be appropriate to address the illuminance criteria of the VDT screen and keyboard. If the paper document reference area is fixed in location and size, then portable or architectural task lighting may be appropriate. For flexible locations and variable sizes of paper document reference areas, dimmable portable task lighting may be most appropriate. Regardless, the optical control of the task lighting solution must be evaluated for its effect on the computer screens. Light spill on CSA/ISO negative polarity Type III monitors may be intolerable by veiling graphic details. Alternatively, CSA/ISO positive polarity Type I monitors may be sufficiently visible even with an ambient lighting system that addresses the paper tasks. Mockups are appropriate to test proposed lighting solutions.

Drafting and design may be housed in a dedicated space or may be one of several tasks performed as part of an office setting. The designer must confirm early in programming the intended application in order to develop appropriate illuminance criteria recommendations and lighting system solutions.

32.2.6 Food Service

Lighting for food service is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. Figure 32.6 illustrates a dining room setup in a multi-functional space (top image) and a lunch room or canteen (bottom image). Many times multi-functional spaces must be capable of accommodating any number of applications from meetings to dining to project room or work room. As the design team explores architectural and furnishing



Figure 32.3 | Training Room
Conferencing and meetings are accommodated here with six dimmable fluorescent control zones: ❶ is a wall slot at the white board and AV screen; ❷ is a wall slot at the buffet; ❸ is two wall slots running the length of the room; ❹ is two downlights near the AV screen; ❺ is the remainder of the downlights; and ❻ is the four-sided cove. Preset scenes available are HIGH, LOW, BREAK, AV, and ALL OFF.

Perimeter accenting is used liberally contributing to: spatial definition; preference; and spaciousness. See Table 12.1b | Spatial Factors: Part Two and Table 12.2 | Subjective Impressions. The indirect lighting and surface washes contribute to vertical surface lighting and facial lighting.

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layouts, lighting criteria for the various applications and potential approaches are also reviewed so that a lighting solution most capable of meeting various illuminance criteria and the architectural style requirements of the project can be proposed. Controls play a significant role in meeting the challenge of multiple functions.

32.2.7 IT

Lighting for IT tasks is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

32.2.8 Offices

Illuminance criteria for offices revolves around reading and writing and intermittent oral communication. Accenting serves multiple purposes in office situations where users are relatively sedentary and need periodic visual relief from tasks and need relatively consistent visual backgrounds against which to work without visual fatigue. Accenting can help improve the overall environment when subjective impressions are addressed (see Table 12.2 | Subjective Impressions. In any event, accenting need not consume much energy and is typically more efficient and visually interesting than using high-output general lighting.

Illuminance criteria and areas of coverage for office tasks must be carefully established to meet energy requirements, sustainability goals, visual comfort, and task appropriateness. Overlighting leads to energy waste and overly bright tasks which, after several hours of viewing, can lead to visual fatigue. The challenge is establishing which reading and writing tasks should be addressed and determining how to meet the recommended illuminance criteria. See 12.5 Task Factors and Table 12.3 | Sample Visual Task Survey for guidance.

If a number of tasks are involved, prioritize by importance and select criteria accordingly. Alternatively, normalize to tasks with common illuminance criteria, providing this addresses the majority, if not all, of the tasks involved. Another method is to address divergent illuminance criteria using both task and ambient lighting systems. Use an ambient lighting system to meet the lower illuminance criteria for one set of tasks and use a task lighting system to supplement the ambient lighting to address the greater illuminance criteria of a second set of tasks. This solution of task and ambient systems can be more energy effective and visually interesting than that of an ambient system alone to meet illuminance criteria. See 15.1.1.1 Ambient Lighting, and 15.1.1.2 Task Lighting.

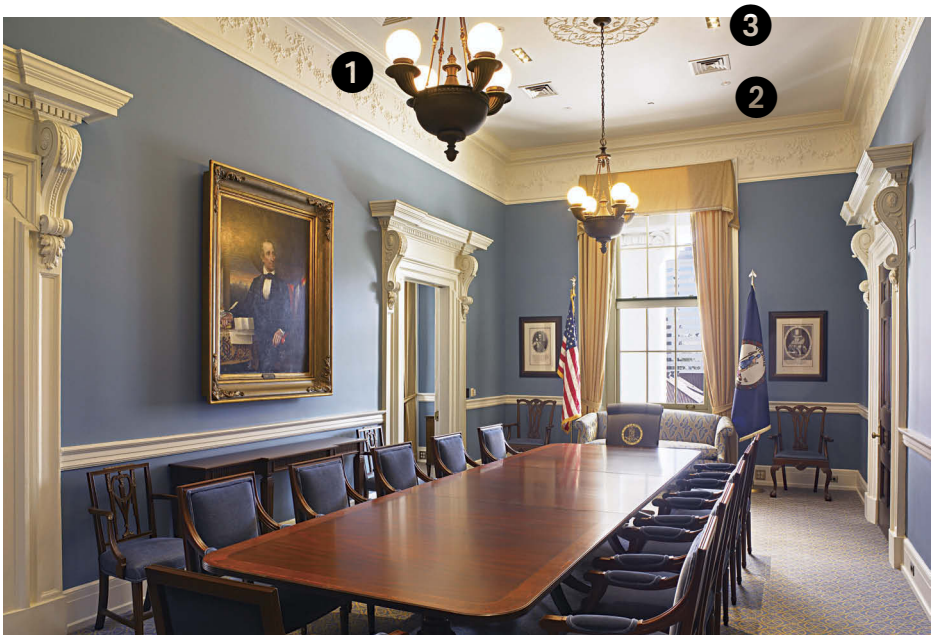


Figure 32.4 | Conference Room
The Governor's Conference Room in the Virginia Capitol is lighted by: ❶ historic reproduction pendant luminaires lamped with 2700 K CFLs; ❷ recessed trimless adjustable pinhole luminaires lamped with halogenIR_{LV} MR16 lamps (not to be confused with the more readily visible air diffusers); and ❸ recessed trimless adjustable multi-lamp linear luminaires also lamped with halogenIR_{LV} MR16 lamps.

Recessed trimless luminaires for drywall or plaster ceilings exhibit no visible trim flange. Plaster or a skim coat is finished to the aperture of the luminaire. Trimless luminaires are less noticeable and improve the monolithic appearance of drywall ceilings. On decorative plaster ceilings, the simplicity of trimless luminaires results in greater visual attraction to the decorative plaster work.

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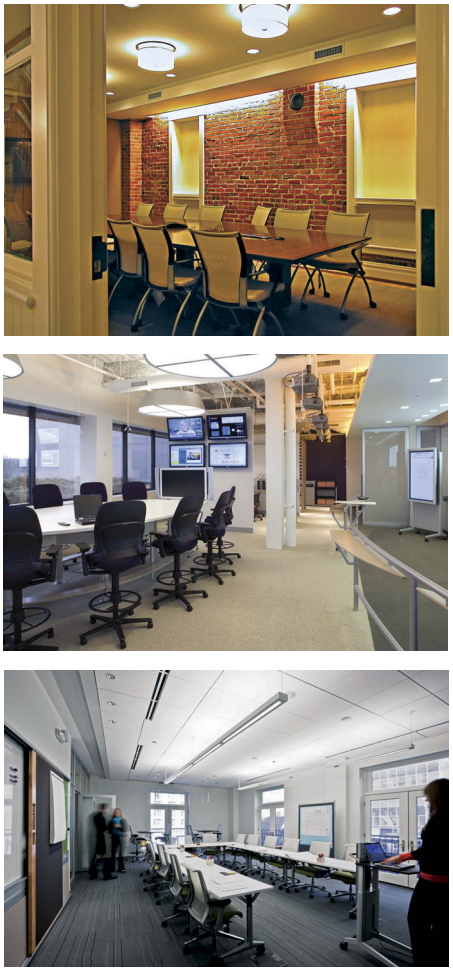


Figure 32.5 | Meeting Rooms
The means to the end of IES illuminance criteria compliance can vary considerably. Surface luminances and both surface color and color of light greatly contribute to the overall appearance. Daylight and view have marked effects.

The majority of the lamps in these three examples are fluorescent varieties exhibiting CCT of 3000 K and CRI ≥82. In the middle image, red and gold fluorescent lamps are used in a cove detail along the upper right. In the bottom image, halogenIR$_{LV}$ MR16 adjustable accent luminaires highlight the left wall and LED decorative pendants are used at break tables near the far end of the room.

The painted-out white plenum condition in the middle image greatly improves overall lighting efficiency.

Linear pendant luminaires with both indirect and direct lighting components such as those shown in the bottom image can offer very efficient approaches.

» Top Image ©Gary Steffy Lighting Design Inc.
» Middle Image ©Steelcase Inc.
» Bottom Image ©Workspring

There are no definitive rules on the ratio of ambient to task illuminance. However, ambient, task, and accent lighting systems and room surface reflectances should be designed such that the resulting luminances are in accordance with Table 12.5 | Default Luminance Ratio Recommendations and the resulting illuminance ratios are in accordance with Table 12.6 | Default Illuminance Ratio Recommendations. Since illuminance is additive, any combination of ambient, task, and accent lighting can be used to meet the illuminance target criteria identified in Table 32.2 for any given task. In an open office, for example, and depending on the photometric properties of the task and ambient lighting systems and the layout and density of the furnishings, it is possible and reasonable for the ambient lighting system to contribute between one-third to two-thirds of the total illuminance required. A task lighting system provides the balance of the illuminance necessary to meet the target criteria. Ambient illuminance is typically applied throughout an entire room. Task illuminance is typically applied to a task proper or task area (see Figure 12.22 | Task Coverage Example).

Figures 32.7, 32.8, and 32.9 illustrate a variety of office situations. In each situation, an ambient lighting system provides a general illuminance throughout the office space that is between one-third and two-thirds of the IES recommended illuminance criteria. In each situation, task lighting is localized to the task proper or task area and contributes the remainder of the illuminance necessary to meet IES criteria. Accenting is used in Figures 32.7 and 32.9 while extensive daylighting fulfills the accenting role in Figure 32.8.

Accent lighting affects brightness perceptions and may also contribute to spatial definition and subjective impressions. See 15.1.1.3 Accent Lighting, Table 12.1b | Spatial Factors: Part Two, and Table 12.2 | Subjective Impressions. To maintain an efficient lighting solution, the contributions to illuminance criteria from the ambient, task, and accent systems must be analyzed and adjusted accordingly. For example, the lighting of the wall to the right in Figure 32.9 sufficiently contributes illuminance in the vicinity of the extemporaneous meeting area that a row of recessed indirect ambient luminaires was unnecessary.

Daylighting success is facilitated by seamless operation of electric lighting and daylighting mechanisms, such as shades. See 14 | DESIGNING DAYLIGHTING for more information. To minimize disruption, maintain comfort, and maximize energy savings, these aspects deserve particular attention:

1. Automate dimming and educate client on functionality
2. Design any east- and west-elevation daylighting with great care relative to glare and hours of operation
3. Automate window treatment or educate client of manual operation and expected time of use
4. Maintain some degree of exterior view
5. Avoid daylight designs requiring near-continual or complete manual shade deployment
6. Perform daylight simulations to limit areas of overlighting and assist with glazing transmittance and shading treatment selections
7. Address luminance ratios (see Table 12.5)
8. Coordinate daylighting with mechanical engineer to assure thermal comfort

Control systems are key to providing seamless operation and daylight integration.

32.2.9 Parking

Lighting for parking facilities is discussed in 26 | LIGHTING FOR EXTERIORS.

32.2.10 Pedestrian Ways

Lighting for pedestrian ways is discussed in 26 | LIGHTING FOR EXTERIORS.

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32.2.11 Reading and Writing

Reading and writing tasks occur within various applications. Familiarity with these tasks will aid with assessment of specific application tasks and activities. Additionally, familiarity with client requirements will help the design team tailor lighting criteria and lighting solutions to best meet client needs. This is a departure from some long-held practices of blanketing rooms and, therefore, buildings with an illuminance level intended to accommodate most any reading task, but which typically resulted in less efficient, less comfortable, and bland lighting.

32.2.12 Support Spaces

These relatively back-of-house citations are self-explanatory. For purposes of maintenance convenience, lamp types and color qualities should match those used elsewhere.

32.2.13 Toilets/Locker Rooms

Lighting for toilets and locker rooms is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

32.2.14 Transition Spaces

Although most of these spaces are self-explanatory, a few deserve discussion in the context of office facilities.

Adjacency passageways refer to a condition where circulation areas are encompassed by larger work or task areas. An example is shown in Figure 32.7 where the adjacency passageway is between the workstations and the architectural wall on the right (marked with ❸). Given their adjacency to the open and visually accessible work or task areas, their illuminances, confined to the passageway proper, should be ratios of the nearby task illuminances. This avoids annoying contrasts within the work setting. In Figure 32.7, however, the task of filing also occurs in this zone and must be accommodated with criteria cited in Table 32.2 under ADMINISTRATION/Filing. The wallwash lighting accomplishes three lighting goals: accenting; circulation; and filing.

Lobbies, reception and waiting areas, and breakout passageways should relate stylistically to the office facility. These spaces should take advantage of the efficiencies and visual variety associated with using task, ambient, and accent lighting systems. See Figure 32.10. Programmatically, these areas sometimes serve multiple functions. For example, the reception/waiting area in the middle image of Figure 32.10 was programmed as potential work or meeting space for future expansion. If controls are planned for the work or meeting area, these can be used to adjust illuminances to address criteria for a reception and waiting area. The design team must track space names and functions in these situations to properly document energy allowances and compliance.

For purposes of maintenance convenience, lamp types and color qualities should match those used elsewhere unless distinct differences are an intentional design feature.



Figure 32.6 | Food Service
Food service in office facilities might consist of traditional dining rooms (top image) or lunch rooms (bottom image). Dining rooms in multi-tenant office facilities may be dedicated to a single client or might be available to all tenants. Dining rooms may be multifunctional spaces where meetings and conferences are accommodated through controls.

The lighting criteria need to be established according to anticipated use: conferencing; dining; and project room, for example. Conferencing tasks, if any, must be determined and criteria established. Dining tasks must also be determined from citations in Table 22.2 at FOOD SERVICE/Dining Areas or from the citation in Table 32.2 at SUPPORT SPACES/Break Rooms/Lunch Rooms. Project rooms might be used like private offices for short, but dedicated work efforts on assignments. Alternatively, these might be work spaces for teams involved in long-term projects. In any event, task needs must be defined and lighting criteria assigned accordingly.

» Top Image ©2003 Gene Meadows
» Bottom Image ©Beth Singer Photographer, Inc.

32.3 Illuminance Criteria

Illuminance criteria, when fully deployed, are a robust set of quantitative values that influence visibility, visual performance, and visual comfort and attention. Short-circuiting the criteria selection or designing to a single criterion value, such as horizontal illuminance, to address worst-case tasks will surely result in dissatisfaction. Even if clients accept the visual results, not getting the most from the energy expended or, worse, energy waste is a likely result. Following are notes related to various aspects outlined in Table 32.2.

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Figure 32.7 | Recessed Direct Low-brightness Ambient
Single-lamp parabolic luminaires with semi-specular large-cell baffles ❶ provide 300 lx of ambient horizontal illuminance on work surfaces in this low-ceiling open office. Task lighting under binder bins ❷ light the reference area and limit shadows. Uniform wall washing from low wattage fluorescent wallwashers ❸ brightens what would be a dark space with the parabolic luminaires (note the comparatively low luminance of the ceiling). Uniform wall lighting also affects a sense of spaciousness. The diffuse wall lighting along with the relatively soft uniform downlighting from the parabolic luminaires generate consistent vertical illuminances for facial recognition. Note how the luminance of the CSA/ISO positive polarity and Type III (glossy) screen is balanced with paper tasks and surrounding surfaces. The ambient lighting luminaires address the candlepower and luminaire luminance criteria in Table 12.4.
» Image ©Robert Eovaldi

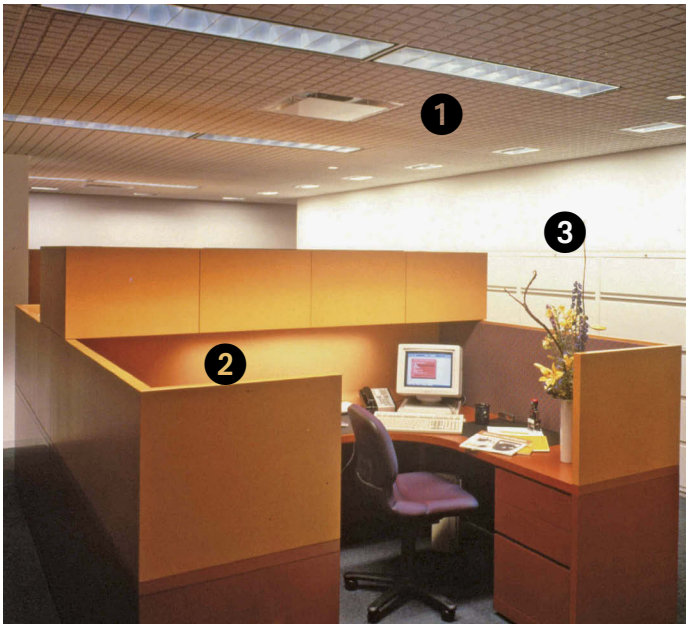


Figure 32.8 | Linear Pendant Indirect Ambient
Linear pendant uplights with widespread distribution optics uniformly illuminate the ceiling ❶. The luminance ratio from the brightest portion of the ceiling ❶ to the dimmest ❷ is 3-to-1. This diffuse light reflects to the workplane and provides 300 lx of ambient horizontal illuminance on work surfaces. Task lighting under binder bins light the paperwork area, limit shadows, and help brightness impressions.
» Image ©Robert Eovaldi

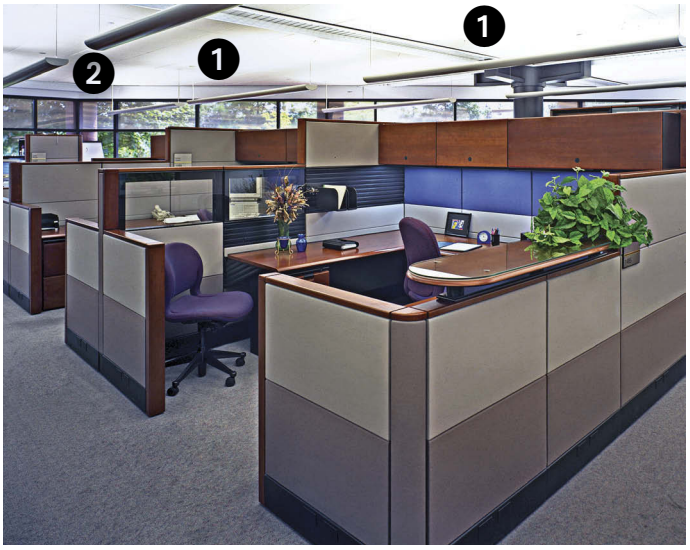
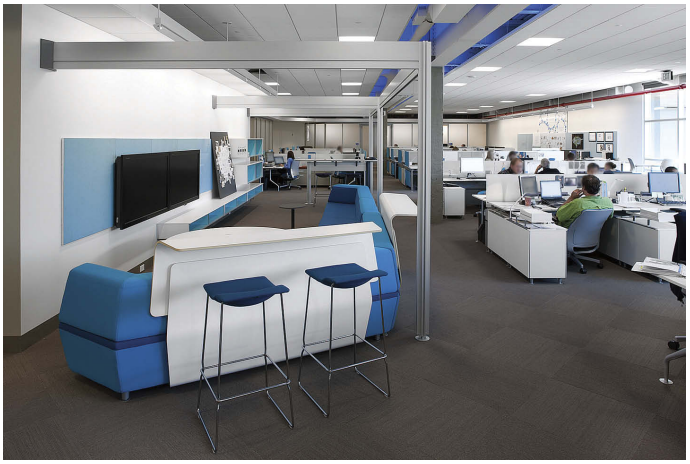


Figure 32.9 | Recessed Direct Architecturally-dimensional Ambient
2' by 2' recessed direct architecturally-dimensional luminaires may be appropriate where a mix of paperwork and computer tasks occur. This family of luminaires is typically less glary than traditional prismatic lensed counterparts. Several varieties are available from "basket" types where lamps are housed in a basket-like compartment with most or all light directed to a reflector at the top of the luminaire for redirection into the room. See Figure 12.19. Another variety consists of an arrangement of high-efficiency lenses and directional optics to limit direct glare. Both varieties exhibit dimensional detailing and intentional brightness variations that diminish the dominant visual mass of previous generations of monolithic-lensed recessed luminaires (effects that are not fully conveyed in photographs). Where computer screens are CSA/ISO positive polarity Type I, some versions of these luminaires may be acceptable. However, with other computer screen types or negative polarity settings, or luminaires with high output lamping, these may not address criteria outlined in Table 12.4. Mockups are recommended to determine suitability and acceptance by clients.
» Image ©Steelcase Inc.



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32.3.1 Applications and Tasks

Applications and tasks encountered on any given project may be different from those identified in Table 32.2 and may warrant different illuminance criteria. Cross-referencing closely-associated applications or tasks is appropriate. Sometimes naming trends or conventions for space types or functions change to conform to current practice, client programming, or architectural conventions, but the actual activities and tasks remain the same and this cross-referencing works. Failing this technique, reviewing the list in Table 32.2 may be in order to determine if any applications or tasks exhibit a similar visual-component to the unique applications or tasks. Otherwise, reviewing 4.12 An Illuminance Determination System and Table 4.1 is necessary to establish a task category based on the task characteristics or visual performance descriptions most closely associated with the unique applications or tasks. These exercises as well as any deviations from recommendations the designer intends to make should be carefully documented for the record.

32.3.2 Notes

The notes in Table 32.2 may refer to other task headings in the table or to other handbook chapters as appropriate. Where some degree of clarification is warranted, notes are made.

32.3.3 Recommended Maintained Illuminance Targets

Values cited are maintained on the area of coverage for the task under consideration. Illuminance is additive. Where practical and without negatively affecting the intended application of light, target values are achieved with any combination of daylighting and/or electric lighting in whatever mix of ambient, task, and accent lighting is deemed appropriate to meet these and the other lighting goals established during design. See 12 | COMPONENTS OF LIGHTING DESIGN and see 10.7.1 Light Loss Factors.

With respect to light loss factors, account for anticipated losses through the point in time at which group relamping and cleaning should occur. Group relamping and cleaning should be standard practice, though these need not occur at the same frequency. Periodic cleaning and group relamping essentially maintain the illuminance at criteria and make the most efficient use of the installed equipment. For purposes of sustainability, cleaning and group relamping can no longer be presumed to be infrequent or unlikely. Maintenance procedures must be part of the design discussions with the client. See the IES document IESNA/NALMCO RP-36 Recommended Practice for Planned Indoor Lighting Maintenance for additional information. Where maintenance is deferred or practiced poorly or not at all, the actual illuminance values will fall below criteria targets. This is inefficient, unsustainable, and may be unsafe while adversely affecting users' quality of life or work. Ratcheting initial illuminances higher is poor practice and not recommended. Maintenance procedures may be especially problematic with LEDs where promises of extraordinarily long life may be offered, but usually with the caveat that lamp lumen depreciation (LLD) at that rated life is 70% or perhaps even as low as 50% of initial rating. If replacement cycles are presumed to be rated life, then LLD alone must be 0.7 or 0.5 or whatever lumen rating is certified by the LED vendor. See 13.3 Life and Lumen Maintenance.

Targets cited are consensus and deemed appropriate for respective functional activity. For some applications, IES recommendations are within 10% of code requirements. This apparently is an artifact of metrication. Footcandle conversions of any values cited in Table 32.2 should be made at 1 fc to 10 lx. This soft conversion avoids a redundant diminishing of illuminance values after multiple citations and conversions over time. This also eliminates a false sense of accuracy advanced by an ever-increasing number of decimal places and a false sense of urgency advanced by eccentric fractional values introduced by hard conversions. Nevertheless, a lighting design must meet code and the mechanics of which must be coordinated amongst the design team. The IES recommendations should not, do not, and cannot reflect all of the various code requirements in force in all jurisdictions at any given time.







Figure 32.10 | Transition Spaces
A breakout passageway is shown in the top image. In situations where the breakout area is clearly defined and unlikely to be reconfigured, illuminance criteria for "breakout passageway" can be applied just to the breakout area while illuminance criteria for circulation can be applied to the zone which is clearly for circulation. The designer must determine areas of coverage which affect lighting power and energy and equipment costs.

In the middle image, a waiting and reception area is also setup to accommodate future expansion when this area will be a workstation or two or a meeting area. Controls can be used to adjust lighting accordingly.

A lobby in a multi-tenant office building, in the bottom image, serves as the "front door" and first impression for the tenants' visitors and is used as an amenity when marketing to potential tenants.

» Top Image ©Workspring
» Middle Image www.jmaconochie.com
» Bottom Image Christopher Lark, Inc.

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Targets are intended to apply to the dominant plane of the task, typically, but not always, horizontal or vertical. In some situations, illuminance criteria are cited for one plane, such as the vertical plane for white board, while the other plane is blank. The blank signifies that illuminance on that plane is unimportant and may be a consequence of the illuminance of other tasks within the vicinity or by whatever illuminance results from meeting the target illuminance for the prescribed plane of interest.

32.3.3.1 Target Planes

Many, though certainly not all, tasks are performed with the task in roughly a horizontal orientation or vertical orientation. Additionally, most tasks are expected to have both a horizontal illuminance component (E_h) and a vertical illuminance component (E_v). Where these illuminance components are intended at differing planar elevations, such is indicated under "Notes." For example, for conferencing meetings, horizontal illuminances apply to the table top while vertical illuminances apply to seated-face-plane height of 4' AFF oriented in which may be in the direction or directions facing the primary viewer or viewers.

Nearly all tasks are expected to have both a horizontal illuminance component (E_h) and a vertical illuminance component (E_v). This allows some degree of task flexibility for off-plane viewing and accommodates various aspects of the task. In some applications, like conventional conference rooms accommodating a variety of presentation media, horizontal- and vertical-plane illuminances of the various media tasks address the typical situation where simultaneously some work or some portion of the work is on horizontal planes while other work or portion is on vertical planes.

Where illuminance targets are intended at differing planar elevations, this is indicated under "Notes." Tracking task orientations and addressing both horizontal and vertical illuminance is necessary. If orientations in the project under consideration are programmed to be flipped from what might be considered normal-viewing, then criteria must be adjusted accordingly. If a task is scheduled to be oriented on some plane off axis from horizontal or vertical by more than 10°, say, then the illuminance criteria must be applied to that off-axis orientation. This is an important distinction for luminaire optical selection and aiming capabilities and for layout, calculations, and field measurements.

For planes related to vertical illuminance targets, some guidance is indicated under "Notes" where the directional orientation of the plane is straightforward and easily identified. However, the designer may elect to use alternate or multiple vertical planes. In some situations the vertical planes could be oriented a number of directions and the designer must determine which are most appropriate for the situation. For example, in a meeting room, the furnishing layout of the space might suggest the number of directions. If the room is to be flexible in its furniture arrangement, then it might be determined that the orientation directions are satisfactorily addressed by assigning vertical criteria at face plane to the four cardinal directions. In a meeting room with a linear table and chairs on the long sides each facing the other side, it may be determined that one orientation direction for each side suffices.

32.3.3.2 Visual Ages of Observers

Illuminance criteria are based on the visual ages of more than half the intended observers. This aspect should be resolved during programming with the client. An efficient, productive, and comfortable workplace can only be achieved if illuminance levels are targeted for the intended audience. Illuminance criteria are presented based on age groupings associated with at least half the observers in a particular application. The designer is always at liberty to reselect criteria based on his own experience or on client direction. In closed offices, age requirements can be readily accommodated. However, the designer should review implications of turnover. In open offices, age differences and turnover may present significant challenges that require the design team and client to review office planning.

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Controls can be employed on discrete zones of ambient lighting to allow adjustment of these zones to greater or lesser illuminances. Additionally, task lighting can be specified or also controlled to provide greater or lesser illuminances. All of this demands a concerted design effort and, after completion, dedicated monitoring by the client.

32.3.3.3 Illuminance Categories

Illuminance categories are designated by letters A through Y. These are shown in Table 32.2 for more convenient reference to Table 4.1 | Recommended Illuminance Targets should the designer wish to explore other criteria targets or if applications or tasks on a specific project are not readily correlated to the table citations.

32.3.3.4 Gauge

The common gauge for determining illuminance target compliance is cited for each application. All gauges presume that point-by-point techniques are used for predictive calculations and presume that uniformity criteria are closely monitored. Where an average illuminance value over the area of coverage can satisfy target compliance, “Avg” is cited. In applications or tasks where a minimum or maximum target is necessary, the gauge for compliance is “Min” or “Max” respectively.

The designer may elect to use other methods to evaluate target compliance, such as criterion rating (CR) or coefficient of variation (C_v). See 4.12.4.5 Tasks at Uncertain Locations Over a Large Area.

In any event, once illuminance targets and uniformities are established, then any calculated deviation from them should be limited. Standard engineering allowance of ±10% might be acceptable for targets gauged as average unless contractual or code obligations demand otherwise. Minima and maxima must be achieved as intended.

Designs should be adjusted until predictions are within allowance for averages and meet minima and maxima. For additional information, see 4.12.4.1 Recommended Illuminances at Design Time, 4.12.5 Illuminance Ratios, 9.15.1.1 Average Illuminance, and 10.8 Assessing Computed Results.

32.3.4 Uniformity Targets

Illuminance uniformity targets work in conjunction with luminance uniformities and surface reflectances all of which must be addressed as part of the design to avoid visual discomfort, glare, and strain. Uniformity ratios are targets that define the widest recommended ranges. In many situations, uniformity ratio criteria are those between average values of an array of points and the minimum value in the same array of points. Uniformity targets apply to both horizontal and vertical illuminances over the area of coverage. Where horizontal uniformity criterion is different from vertical uniformity criterion, two ratios are reported with the first value for horizontal illuminance (E_h).

Generally the more important speed and accuracy and the more demanding the visual task, the tighter the ratio.

32.3.4.1 Maximum-to-average

This is the recommended ratio of maximum illuminance to the average illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations sensitive to even a relatively small degree of overlighting.

32.3.4.2 Average-to-minimum

This is the recommended ratio of average illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where illuminance too far below average conditions is noticeable and detrimental to task performance or inconsistent with normal expectations.

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32.3.4.3 Maximum-to-minimum

This is the recommended ratio of maximum illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where too much variation in illuminance is considered undesirable and untenable from a performance or safety perspective.

32.3.5 Daylighting Advancement

Generally, design strategies should embrace any combination of daylighting and electric lighting to achieve target values during daylight hours. The preference is for daylighting to provide all or most of the recommended illuminance presuming that all aspects of daylighting are properly addressed. A sunburst icon depicts those applications and tasks where daylighting is considered a strategic candidate. Use photocells and continuous dimming or stepped-dimming to reduce or eliminate electric lighting during daylight hours. See 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Even for those applications where daylighting is not traditionally a strategic candidate, it may be determined that very careful and coordinated design will offer great sustainability opportunities along with positive influences associated with daylight and views.

32.3.6 Veiling Reflections

IESH/10e CSA/ISO

> 12.5 Task Factors
- for information on CSA/ISO computer screen qualities

Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper or, worse, both, are prone to veiling reflections. The likelihood of particular applications and tasks predisposed to veiling reflections is indicated by a "reflected light" icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood. Veiling reflections are minimized by controlling the overall amount and direction of light with respect to the task locations and orientations. Alternatively, tasks sensitive to veiling reflections can be screened or isolated. Effective strategies include employing indirect soft, diffuse electric lighting or direct electric lighting with multiple low-output luminaires, or positioning tasks and luminaires and luminance patterns to avoid harsh reflections from tasks. Addressing luminance recommendations (see Table 12.4 | Default Luminance and Luminaire Intensity Recommendations for VDT Applications) minimizes veiling reflections. Changing the task will reduce or eliminate veiling reflections, such as use of CSA/ISO Type I or II computer screens and matte paper versus their specular counterparts.

32.3.7 Defining Areas of Coverage

In addition to establishing planes of task orientation, the areas of coverage to which targets apply must be determined. Typical areas of task illuminance coverage are identified here, but these may not be appropriate to specific project situations. One area of coverage is "task proper or task area." Here, the illuminance criteria are applied to the task itself or to a relatively small area to which the task is confined. See 12.5.5.1 Tasks and Applications and Figure 12.22 | Task Coverage Example. In some situations, such as accenting, the "task" area may consist of the entire wall when "feature wall" or "perimeter" accenting is desired. It is important to remember that illuminance is additive, that is, task illuminance can be achieved with some combination of ambient lighting, task lighting, and/or accent lighting, providing that the total illuminance on the task proper or task area meets the illuminance criteria outlined in Table 32.2.

Another area of coverage is "room or designated area." In this situation, illuminance criteria are applied to the room or an area of fairly substantive size representing the zone in which the applications and tasks are expected to occur. The designated area is typically established by the furniture layout, for example, or might be established by the design team or client. The area-of-coverage citations in Table 32.2 are based on traditional notions. So, for example, it may be determined that a "task proper or task area" coverage would result

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in some amount of LPD reduction when compared to "room or designated area" coverage. If the task can be confined to one area rather then multiple areas, if the room or area in which the task is located is itself relatively small, such as a single-occupant office, and if the other design goals and criteria outlined in 12 | COMPONENTS OF LIGHTING DESIGN are addressed, then this strategy of redefining area of coverage has merit.

An assessment and determination must be made on which area of coverage best satisfies the lighting goals on a particular project.

32.4 Designing

Information provided here is specific to office facilities and should be used as part of the design and documentation processes outlined in Chapters 12, 15, and 20. See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY for additional information on those respective aspects. Addressing all code requirements is a must. Energy efficient and sustainable practices are an integral part of all IES recommendations. Key design tenets include, but are not limited to:

- designing for the satisfaction of the observers intended to use the project
- using baseline reflectances of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively) in interior production and work-oriented spaces
- using daylighting that meets luminance and illuminance criteria
- using highest-efficacy lamps that meet color, optical and electrical control, and output criteria
- using highest-efficiency luminaires that meet aesthetic and luminance criteria
- using accenting to provide luminance balancing or improve brightness perceptions where necessary
- using controls liberally, preferably automated varieties such as presets, occupancy and vacancy sensors, astronomical time clocks, and photocells
- establishing IES-recommended illuminance criteria to meet programmed tasks
- establishing layouts that just meet IES-recommended illuminance criteria
- addressing outdoor environmental needs
- using calculations, photometrically-realistic renderings, and operational samples and mockups to prove concepts
- identifying and designing to code-specific requirements, if any, for ambient, task, and accent lighting
- documenting all code-, energy-, sustainability-, and IES-criteria compliance
- documenting criteria and design deviations and rationale and subsequent disposition by team, client, or AHJ
- documenting clearly the layouts, controls, and luminaire and lamp selections

Designing for the satisfaction of the observers is the paramount design tenet and must be kept in perspective during all aspects of design. If the observers' expectations are not fulfilled, then how much energy could be saved is moot, as is how many fewer earth resources were spared, as is how much the whole affair cost or how much value engineering saved or the photogenic qualities of the project. See sidebar references for additional guidance on the key tenets. The design effort must be undertaken with coordinated and realistic expectations by all involved on initial and life cycle costs. Budgeting should include designer input and dialogue with the team and client at project commencement and design milestones. In other words, and paraphrasing Thomas Edison, genius is, indeed, just 1% inspiration and 99% perspiration.

IESH/10e Economics Resources

> 15.3.3 Budgets
  - for more on budgets and value engineering

> 18 | ECONOMICS
  - for more on estimating costs
  - for more on life cycle costs
  - for more on paybacks and rates of return

IESH/10e Energy Efficiency Resources

> 17.2 New Construction
  - for more on designing for daylighting
  - for more on electric lighting equipment
  - for more on lighting controls

> 17.4 Lighting Codes, Regulations and Standards
  - for more on application standards
  - for more on equipment regulations

IESH/10e Lighting Exteriors Resources

> 12.5.5.6 Nighttime Outdoor Illuminances
  - for more on lamp efficacies under mesopic adaptation

> 26 | LIGHTING FOR EXTERIORS
  - for more on criteria

IESH/10e Sustainability Resources

> 13.11 Sustainability
  - for more on lamps

> 19 | SUSTAINABILITY
  - for more on controls
  - for more on earth resources
  - for more on energy
  - for more on life cycle analyses
  - for more on lighting design
  - for more on recycling

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32.5 References

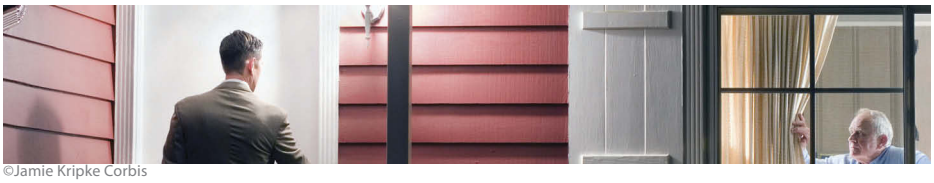
[1] Light Right Consortium. 2008. The benefits of quality lighting [Internet]. Light Right Consortium. [cited December 2008]. Available from: http://www.lightright.org/market/values.htm.

[2] [DOE] US Department of Energy, Energy Information Administration. 2008. Table E5A. In: Electricity Consumption (kWh) by End Use for All Buildings, 2003 [Internet]. DOE. [cited December 2008]. Available from: http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html#enduse03.

[3] Mark S. Rea, ed. 2000. The IESNA lighting handbook: Reference and application. 9th Edition. New York: IESNA. Ch 11.

[4] [IESNA] Illuminating Engineering Society of North America. 2004. American National Standard Practice for Office Lighting, ANSI/IESNA RP-1-04. New York: IESNA. 63 p.

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33 | LIGHTING FOR RESIDENCES

Every moment of light and dark is a miracle.
Walt Whitman, 19th Century American Poet

Many homes are refuge. Lighting sets the scene for senses of comfort and protection. However, some activities in a residence are quite demanding visually. Occupants' ages may vary significantly. Some members of the household may use the residence primarily during dark hours for at least four or five days of the week. The majority of use by other occupants may occur during daylight hours. Tasks and activities within the same space may require very different lighting conditions. Yet, as convenient as it may have been long ago, using a limited number of luminaires that accommodate universal-base lamps up to very high wattages has never been the best way to address all of these variables. Electric lighting accounts for about 15% of the electricity used in residences (see Figure 33.1). [1] Efficient lighting and its careful application are appropriate and important. Inventive use of daylighting is a necessity. What follows is a discussion of the key aspects affecting lighting: project status; space types; activities; application-specific design goals, and illuminance criteria for normal-sighted people of all ages in *residential facilities*.

Comprehensive design efforts involve synthesizing the information in this chapter with material in 12 | COMPONENTS OF LIGHTING DESIGN, 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS, 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Design tenets deemed appropriate from those chapters must be identified and lighting goals and strategies developed accordingly. This chapter primarily addresses illuminance specifics related to lighting for residential applications which should influence luminaire optical selections, lampings, and final layouts based on design thought-starters (see 15.2 A Lighting Scheme). Use of the material in this chapter to the exclusion of material in Chapters 12, 13, 14, and 15 will likely lead to unsatisfactory results. Previous IES related documents provide archival reference [2] [3].

Careful thought must be given to details beyond the illuminance citations in this chapter. For example, in Table 33.2 the citation RESIDENTIAL INTERIORS/Circulation Corridors/Independent Passageways identifies illuminance for residential hallways in a more conventional, closed plan situation. The uniformity ratio is broad and, therefore, non-uniform lighting quite appropriate. However, at the cited illuminances, such a hallway will appear dark. To some people, this is appealing, but for others this is undesirable. To address the subjective impressions of preference and relaxation in Table 12.2, a wall sconce or two, a table light or two, an art accent or two, some subtle wallwashing or any combination of these techniques will brighten the hallway. These techniques alone may meet the illuminance criteria for the passageway. Such specific details are not enumerated for all tasks. Table 33.1 offers a checklist of IES lighting topics and criteria. The design team is responsible for determining and addressing indoor and outdoor lighting and energy criteria set forth by authorities having jurisdiction (AHJ) which may be different from and supersede IES criteria. See also 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

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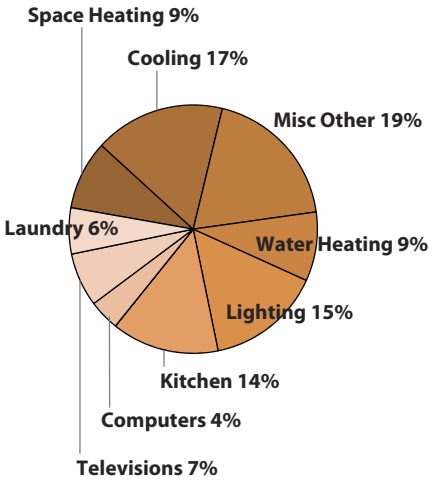


Figure 33.1 | Electricity Use of Homes
Based on 2008 data from the US DOE's Energy Information Administration, lighting accounts for 15% of electricity use in homes.

Residential facilities is used here to reference detached or semi-detached houses, apartments, condominiums, or other dwelling units where family living spaces are intended for an independent lifestyle regardless of family members' ages.

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Table 33.1 | Residential Lighting Checklist

Topics
✔ **Criteria and Design Resources**
Accenting
15.1.1.3 Accent Lighting
Table 12.2 | Subjective Impressions
Table 15.2 | Accent Illuminance Ratios
Table 22.2 | Common Applications Illuminance Recommendations
Appearance
12.2 Spatial Factors
Color
12.5.6 Color Considerations
Controls
16 | LIGHTING CONTROLS
Daylighting
14 | DESIGNING DAYLIGHTING
Electric Lighting
15 | DESIGNING ELECTRIC LIGHTING
Flicker
4.6 Flicker and Temporal Contrast Sensitivity
Glare
4.10.1 Discomfort Glare
4.10.2 Disability Glare
Illuminance
This Chapter: Table 33.2
12.5.5.1 Applications and Tasks
Table 12.6 | Default Illuminance Ratio Recommendations
Figure 12.22 | Task Coverage Example
Light Distribution
12.3.2 Subjective Impressions
Luminances
12.5.2 Luminance
Table 12.5 | Default Luminance Ratio Recommendations
Maintenance
15.4.4 Installation and Maintenance
Nighttime Outdoor Environment
Table 15.6 | Nighttime Operational Strategies for Improved Outdoor Environmental Regard
Systems Integration
12.6 Systems Factors
Veiling Reflections
This Chapter: Section 33.3.6
12.5.4 Veiling Reflections
Visual Tasks
This Chapter: Section 33.2
This Chapter: Table 33.2
Table 11.2 | Programming: Inventory Scope and Specific Examples
12.5.1 Visual Tasks
Table 12.3 | Sample Visual Task Survey

33.1 Project Type and Status

Before any design work, an understanding of the project type and scope is necessary. New, renovation, and restoration projects each offer varying opportunities. See 11.2 Planning, 11.3.1 Pre-design, and 11.3.2 Schematic Design. This will establish the extent to which daylighting can address most or many or some of the lighting goals. Every opportunity should be given to daylight as a light source. For some applications and tasks, daylighting can be the primary if not sole light source. To be a success, daylighting must address the host of lighting design factors identified in 12 | COMPONENTS OF LIGHTING DESIGN. Daylight demands attention to moderate or eliminate glare and balance visible and thermal energy.

Exterior residential lighting criteria discussed here apply to normal-sighted individuals living in single-family homes. Interior residential lighting criteria discussed here apply to those normal-sighted individuals living in single-family detached homes, duplexes, apartments, condominiums or other residential complexes. Individuals with specific vision impairments may require more or less light depending on the visual condition and tasks. These impairments should be identified in programming and require that the lighting be designed accordingly [4].

33.2 Application Types

To develop lighting solutions that meet quality, quantity, and operational aspects, the residential application space types under consideration and consequently the anticipated occupants, functions, and tasks are inventoried (see Table 11.2 | Programming: Inventory Scope and Specific Examples and Table 12.3 | Sample Visual Task Survey). Otherwise, lighting cannot be best targeted to the users, their expectations, functions and tasks.

Space type definitions are required early in the project design in order to track design efforts that include inventorying the project knowns, anticipated functions, and tasks and calculating lighting, power, and energy compliance. Room names, from which functions can be deduced, and numbers for tracking should be clearly marked on architectural backgrounds. The applications and tasks cited in Table 33.2 | Residential Facilities Illuminance Recommendations should be reviewed against the project knowns and correlated with the named space types and functions to establish recommended illuminance criteria. Seek clarification with the client where discrepancies occur between programming information, the list of room names, and the available application and task citations in Table 33.2.

Unlike most other project types, residential applications are quite personal and involve one or two stakeholders. It is possible that criteria cited here may not align with programmed applications and functions or with a homeowner's expressed desires, which may range from "I want it to be moody" to "It has to be bright." The designer must interpret these and assess what, if any, illuminance criteria fill the need in the context of a specific project's architecture and finish scheme and then seek the homeowner's approval. A review of Table 4.1 | Recommended Illuminance Targets may be in order to establish criteria suited to the personal specifics of the homeowner. Accenting will greatly assist in brightness perceptions. Dark and high contrast can be beneficial in creating mood in a residence providing these do not compromise safety and sense of security or the homeowner's preferences. In the absence of a homeowner, such as speculative projects, a developer is the client. Here, the designer must project the needs and desires of the anticipated homeowner.

To an end of visual variety expected of residential settings and because residential activities are not encumbered with commercial-like productivity, many uniformity ratios are broader here than in commercial and institutional applications. Where homeowner

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direction is for more uniform and consistent lighting throughout, ratios should be narrowed as the designer determines. This may be achieved with more luminaires, though not necessarily much, if any, more wattage or broader-beam optics and will result in a more homogenous look.

The following discussion is keyed to major application headings in Table 33.2. Couple this with topics in Table 33.1 for comprehensive qualitative and quantitative criteria.

33.2.1 Residential Exteriors

For this discussion on exteriors, residents of single-family properties and duplexes are considered during nighttime hours. For larger operations, see relevant applications in 22 | LIGHTING FOR COMMON APPLICATIONS and 26 | LIGHTING FOR EXTERIORS. An overriding dictum is to use exterior lighting only if, when, and where needed. For residential exteriors several conditions influence lighting:

- Number and types of house entry points
- Number of outdoor settings and paths connecting those settings
- Anticipated nighttime activity levels and likely ages of users
- Nighttime outdoor lighting zone for the project under consideration
- Security needs perceived or real

Lighting key entries, site circulation routes and intersections, and elevation changes in between are important to navigating residential sites where nighttime activity is anticipated. For small, simple or pre-existing sites with a straightforward front entry to the home it may be determined that only lighting at the front door is sufficient. For large or new sites with complicated geometry and extensive landscaping it may be determined that lighting at multiple locations may be best to assist in safe navigation and offer a sense of security.

The architectural and landscape schemes will vary based on pre-existing conditions or the homeowner's desires and the architect's and landscape architect's interpretations. These variations should affect the lighting design—from kinds of lighting effects to lighting equipment styling to luminances and illuminances.

The kinds and number of outdoor activities and the homeowner's age affect illuminance criteria and where it is applied. For economy, efficiency, and sustainability, this requires careful and detailed planning rather than uniform single-level-illuminance lighting.

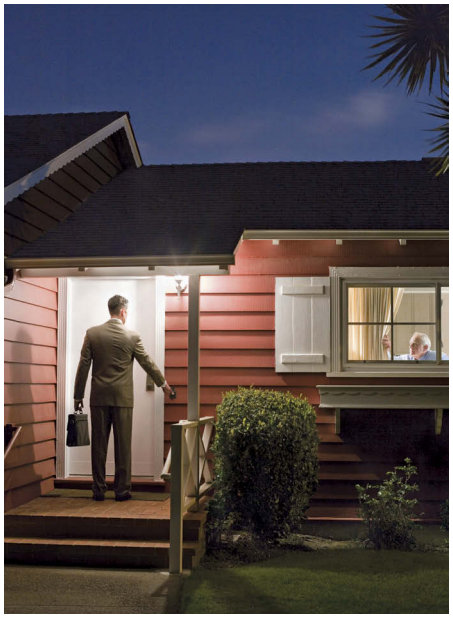




Figure 33.2 | Residential Entries
Both entries are lighted to address functional needs of defining the main entry, identifying visitors, and minimizing light spill. In the image on the far left, the porch roof and elevation of the luminaire work together to limit light spill in one direction, but still illuminate the leading edges of the treads. In the image at the near left, downlights grazing a near-white wall provide diffuse light for rendering visitors' full frontal body for easy identification of faces and clothing. Surface reflectances are important to the success of this approach.
» Far Left Image ©Jamie Kripke/Corbis
» Near Left Image ©Ocean/Corbis

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Table 33.2 | Residential Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
RESIDENTIAL EXTERIORS	**OUTDOOR** residential applications and tasks cited here. See 22 | LIGHTING FOR COMMON APPLICATIONS and 26 | LIGHTING FOR EXTERIORS for outdoor commercial and public applications.											
• Entries	Width of door; Eh @grade at threshold; Ev within 3' of entry and @5' AFG in direction of ingress or security camera.											
• Primary	Front door or doors used frequently.											
• LZ4[i]	E_h @grade; E_v @5' AFG	F	5	10	20	Avg	H	10	20	40	Avg
• LZ3[i] (and LZ4 curfew)	E_h @grade; E_v @5' AFG	E	4	8	16	Avg	G	7.5	15	30	Avg
• LZ2[i] (and LZ3 curfew)	E_h @grade; E_v @5' AFG	D	3	6	12	Avg	F	5	10	20	Avg
• LZ1[i] (and LZ2 curfew)	E_h @grade; E_v @5' AFG	C	2	4	8	Avg	E	4	8	16	Avg
• LZ0[i] (and LZ1 curfew)	E_h @grade; E_v @5' AFG	B	1	2	4	Avg	D	3	6	12	Avg
• Secondary	Side doors and garage doors or doors used infrequently. Control with motion sensors.[j]											
• LZ4[i]	E_h @grade; E_v @5' AFG	D	3	6	12	Avg	B	1	2	4	Avg
• LZ3[i] (and LZ4 curfew)	E_h @grade; E_v @5' AFG	C	2	4	8	Avg	A	0.5	1	2	Avg
• LZ2[i] (and LZ3 curfew)	E_h @grade; E_v @5' AFG	B	1	2	4	Avg	-	0	0	0	
• LZ1[i] (and LZ2 curfew)	E_h @grade; E_v @5' AFG	A	0.5	1	2	Avg	-	0	0	0	
• LZ0[i] (and LZ1 curfew)	E_h @grade; E_v @5' AFG	-	0	0	0		-	0	0	0	
• Entry Walks	E_v in directions of ingress/egress.											
• Path	General lighting might address a task area comprising the walk within 5'-10' of entry and 5'-10' of an unlighted street.											
• LZ4[i]	E_h @grade; E_v @5' AFG	C	2	4	8	Avg	B	1	2	4	Avg
• LZ3[i] (and LZ4 curfew)	E_h @grade; E_v @5' AFG	B	1	2	4	Avg	A	0.5	1	2	Avg
• LZ2[i] (and LZ3 curfew)	E_h @grade; E_v @5' AFG	A	0.5	1	2	Avg	-	0	0	0	Avg
• LZ1[i] (and LZ2 curfew)	E_h @grade; E_v @5' AFG	A	0.5	1	2	Avg	-	0	0	0	
• LZ0[i] (and LZ1 curfew)	E_h @grade; E_v @5' AFG	-	0	0	0		-	0	0	0	
• Ramps, Stairs, and Steps	Lighting should address the area of the steps and landings. Alternatively, draw attention to elevation changes with contrast lighting.[k]											
• LZ4[i]	E_h @treads/landings; E_v @5' AFG	C	2	4	8	Avg	B	1	2	4	Avg
• LZ3[i] (and LZ4 curfew)	E_h @treads/landings; E_v @5' AFG	B	1	2	4	Avg	A	0.5	1	2	Avg
• LZ2[i] (and LZ3 curfew)	E_h @treads/landings; E_v @5' AFG	A	0.5	1	2	Avg	-	0	0	0	
• LZ1[i] (and LZ2 curfew)	E_h @treads/landings; E_v @5' AFG	A	0.5	1	2	Avg	-	0	0	0	
• LZ0[i] (and LZ1 curfew)	E_h @treads/landings; E_v @5' AFG	A	0.5	1	2	Avg	-	0	0	0	
• Pool and Hot Tub	See RESIDENTIAL INTERIORS/Pool and Hot Tub for interior situations											
• In-hot-tub	This highly-specialized application is often best addressed with equipment and layouts recommended by hot tub or lighting vendors. Consult with respective vendors. Use more lower-wattage luminaires in favor of fewer higher-wattage luminaires.											
• In-pool	This highly-specialized application is often best addressed with equipment and layouts recommended by pool or lighting vendors. Consult with respective vendors. Do not center lights in swimming lanes of lap pools; Use more lower-wattage luminaires in favor of fewer higher-wattage luminaires.											
• Pool and Hot Tub Deck	Pool and hot tub presumed to be internally lighted. Lighting should address a circulation zone or the deck area as well as access points to the area of deck.											
• LZ4[i]	E_h @grade	C	2	4	8	Avg	-	0	0	0	
• LZ3[i] (and LZ4 curfew)	E_h @grade	B	1	2	4	Avg	-	0	0	0	
• LZ2[i] (and LZ3 curfew)	E_h @grade	A	0.5	1	2	Avg	-	0	0	0	
• LZ1[i] (and LZ2 curfew)	E_h @grade	A	0.5	1	2	Avg	-	0	0	0	
• LZ0[i] (and LZ1 curfew)	E_h @grade	-	0	0	0		-	0	0	0	

Table 33.2 | Residential Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
4:1	4:1					
4:1	4:1 (8:1)					
4:1	4:1 (8:1)					
4:1	4:1 (8:1)					
4:1						
4:1	4:1					
4:1	4:1 (8:1)					
4:1	4:1 (8:1)					
4:1	4:1 (8:1)					
4:1						
4:1	4:1					
4:1	4:1 (8:1)					
4:1	4:1 (8:1)					
4:1	4:1 (8:1)					
4:1	4:1					
4:1	4:1 (8:1)					
4:1	4:1 (8:1)					
4:1	4:1 (8:1)					
4:1						
5:1	4:1					
5:1	4:1 (8:1)					
5:1	4:1 (8:1)					
5:1	4:1 (8:1)					

Notes for Table 33.2

The table column headings are discussed in detail in 33.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 33.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 33.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 33.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. Identifying elevation changes can be achieved with lighting over the area of interest or by introducing contrast lighting at the change in elevation, such as can be achieved with steplights, in-tread uplights, linear tread nose lights, or other luminaires that accentuate the risers or treads or the edges that define elevation change. Figure 15.13 illustrates one example.

l. For applications where task position is indefinite, the typical area of coverage is "Room or Designated Area." For applications where task position is known, target illuminance is applied to the "Task Proper or Task Area."

m. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

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Table 33.2 | Residential Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b,c,d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
RESIDENTIAL EXTERIORS	(continued)											
• Social Areas	Balconies, Decks, Gazebos, Porches, Ramadas, Terraces. E_v in directions of expected primary back/forth viewing.											
• Gaming/Reading/Barbecue	Analog games. This may require primary planar orientation other than horizontal. Lighting should address the task area.											
• LZ4[i]	E_h @2' 6"; E_v @4' AFG	N	75	150	300	Max	J	20	40	80	Max
• LZ3[i] (and LZ4 curfew)	E_h @2' 6"; E_v @4' AFG	M	50	100	200	Max	I	15	30	60	Max
• LZ2[i] (and LZ3 curfew)	E_h @2' 6"; E_v @4' AFG	L	37.5	75	150	Max	H	10	20	40	Max
• LZ1[i] (and LZ2 curfew)	E_h @2' 6"; E_v @4' AFG	K	25	50	100	Max	G	7.5	15	30	Max
• LZ0[i] (and LZ1 curfew)	E_h @2' 6"; E_v @4' AFG	J	20	40	80	Max	F	5	10	20	Max
• General	Lighting should address key access points and a circulation zone. E_v in at least two primary opposing views.											
• LZ4[i]	E_h @grade; E_v @4' AFG	E	4	8	16	Avg	C	2	4	8	Avg
• LZ3[i] (and LZ4 curfew)	E_h @grade; E_v @4' AFG	D	3	6	12	Avg	B	1	2	4	Avg
• LZ2[i] (and LZ3 curfew)	E_h @grade; E_v @4' AFG	C	2	4	8	Avg	A	0.5	1	2	Avg
• LZ1[i] (and LZ2 curfew)	E_h @grade; E_v @4' AFG	B	1	2	4	Avg	-	0	0	0	
• LZ0[i] (and LZ1 curfew)	E_h @grade; E_v @4' AFG	A	0.5	1	2	Avg	-	0	0	0	
• Security call system access	E_v on call-interface device, unless self-illuminated						H	10	20	40	Avg
• Site Paths	Control with motion sensors.[j]										
• LZ4[i]	E_h @grade	B	1	2	4	Avg	-	0	0	0	
• LZ3[i] (and LZ4 curfew)	E_h @grade	B	1	2	4	Avg	-	0	0	0	
• LZ2[i] (and LZ3 curfew)	E_h @grade	A	0.5	1	2	Avg	-	0	0	0	
• LZ1[i] (and LZ2 curfew)	E_h @grade	A	0.5	1	2	Avg	-	0	0	0	
• LZ0[i] (and LZ1 curfew)	E_h @grade	-	0	0	0		-	0	0	0	
• Site Ramps, Stairs, and Steps	Control with motion sensors.[j] Lighting should address the area of the steps and landings. Alternatively, draw attention to elevation changes with contrast lighting.[k]											
• LZ4[i]	E_h @grade	B	1	2	4	Avg	-	0	0	0	
• LZ3[i] (and LZ4 curfew)	E_h @grade	B	1	2	4	Avg	-	0	0	0	
• LZ2[i] (and LZ3 curfew)	E_h @grade	A	0.5	1	2	Avg	-	0	0	0	
• LZ1[i] (and LZ2 curfew)	E_h @grade	A	0.5	1	2	Avg	-	0	0	0	
• LZ0[i] (and LZ1 curfew)	E_h @grade	A	0.5	1	2	Avg	-	0	0	0	
• Site Gated Entries	See 22 | LIGHTING FOR COMMON APPLICATIONS											
RESIDENTIAL INTERIORS	**INDOOR** residential applications and tasks cited here. See 22 | LIGHTING FOR COMMON APPLICATIONS for indoor applications relevant to multi-family buildings.											
• Accenting	Accenting influences observers' overall brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding.											
• Art	On artwork plane (typically vertical). See 21 | LIGHTING FOR ART for preservation-worthy materials..								see Table 15.2			
• Feature Wall	On wall plane								see Table 15.2			
• Important Focal Point	On focal point plane			see Table 15.2					see Table 15.2			
• Perimeter	On wall plane								see Table 15.2			
• Arts, Crafts and Collecting	E_h @2' 6" AFF; E_v @4' AFF	R	250	500	1000	Avg	P	150	300	600	Avg
• Bar											
• Bar Top	E_h @bar top; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Work Counter	E_h @work surface; E_v @5' AFF	M	50	100	200	Avg	H	10	20	40	Avg

Table 33.2 | Residential Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
4:1	4:1					
4:1	4:1 (8:1)					
4:1	4:1 (8:1)					
4:1	4:1 (8:1)					
4:1						
5:1	4:1					
5:1	4:1 (8:1)					
5:1	4:1 (8:1)					
5:1	4:1 (8:1)					
5:1						
	2:1					
5:1	4:1					
5:1	4:1 (8:1)					
10:1	4:1 (8:1)					
10:1	4:1 (8:1)					
4:1	4:1					
4:1	4:1 (8:1)					
4:1	4:1 (8:1)					
4:1	4:1 (8:1)					
4:1						
	see 15.1.1.3					
	see 15.1.1.3					
	see 15.1.1.3					
	see 15.1.1.3					
	3:1					
	5:1					
	3:1					

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The table column headings are discussed in detail in 33.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 33.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 33.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 33.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. Identifying elevation changes can be achieved with lighting over the area of interest or by introducing contrast lighting at the change in elevation, such as can be achieved with steplights, in-tread uplights, linear tread nose lights, or other luminaires that accentuate the risers or treads or the edges that define elevation change. Figure 15.13 illustrates one example.

l. For applications where task position is indefinite, the typical area of coverage is "Room or Designated Area." For applications where task position is known, target illuminance is applied to the "Task Proper or Task Area."

m. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

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Table 33.2 | Residential Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b,c,d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
RESIDENTIAL INTERIORS	(continued)										
• Bathrooms											
• Showers/Tubs	E_h @floor; Ev @3'-5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Toilets and Bidets	E_h @top of plumbing fixture; E_v @3' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Vanities	Grooming considered more intensive and extensive than casual inspection. Review appropriateness with client. E_h and E_v elevations are shown for standing-counter situations and adult height. Adjust elevations as necessary.										
• Casual inspection	E_h @3' AFF; E_v @5' AFF	O	100	200	400	Avg	O	100	200	400	Avg
• Grooming	E_h @3' AFF; E_v @5' AFF	P	150	300	600	Avg	Q	200	400	800	Avg
• Top-of-head	E_h @5' 9" AFF	Avg = 1.0 times E_v at vanity									
• Bedrooms											
• Desks	See RESIDENTIAL INTERIORS/Reading and Writing										
• General (dressing)	E_h @2' AFF; E_v @4' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Reading in Bed	See RESIDENTIAL INTERIORS/Reading and Writing										
• Sitting Areas	See RESIDENTIAL INTERIORS/Reading and Writing										
• Television Viewing	E_h and E_v @4' AFF	I	15	30	60	Avg	G	7.5	15	30	Avg
• Circulation Corridors	E_v in two opposing views along primary direction of travel.										
• Adjacency Passageways	E_h @floor; E_v @5' AFF	Avg ≥0.2 times task E_h of adjacent space					Avg ≥0.2 times task E_v of adjacent space				
• Independent Passageways	E_h @floor; E_v @5' AFF	I	15	30	60	Avg	D	3	6	12	Avg
• Closets	Luminaire(s) may need to be mounted external of non-walk-in closets if mounting space in closet is insufficient for useful or code-compliant luminaires. Placement and control must be addressed accordingly.										
• Non-walk-in	E_h and E_v @4' AFF @shelf face	M	50	100	200	Avg	J	20	40	80	Avg
• Walk-in	E_h and E_v @4' AFF @shelf face	P	150	300	600	Avg	M	50	100	200	Avg
• Dining											
• Formal	E_h @table plane; E_v @4' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Informal	E_h @table plane; E_v @4' AFF	M	50	100	200	Avg	J	20	40	80	Avg
• Study use	E_h @table plane; E_v @4' AFF	O	100	200	400	Avg	K	25	50	100	Avg
• Dressing Room											
• Full-length Mirror	E_h @floor; E_v @3'-5' AFF						O	100	200	400	Avg
• General	E_h @floor	M	50	100	200	Avg					
• Hanging items	E_v @4' AFF @front shoulder						K	25	50	100	Avg
• Shelved/drawered items	E_v @4' AFF @front face						M	50	100	200	Avg
• Elevator	See 22 | LIGHTING FOR COMMON APPLICATIONS										
• Family Room	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	J	20	40	80	Avg
• Fitness Room	E_h @floor; E_v @3'-5' AFF	N	75	150	300	Avg	J	20	40	80	Avg
• Foyer											
• Day	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Night	E_h @floor; E_v @5' AFF	I	15	30	60	Avg	F	5	10	20	Avg
• Game Room	Intended for informal or spontaneous activity with acquaintances. For sanctioned refereed sports activites see 35 | LIGHTING FOR SPORTS AND RECREATION.										
• Analog Games											
• Board and card games	E_h @2' 6" AFF; E_v @4' AFF	O	100	200	400	Avg	K	25	50	100	Avg
• Competitive table games	E_h @2' 6" AFF; E_v @4' AFF	Q	200	400	800	Avg	N	75	150	300	Avg
• Pinball	E_h @3' AFF; E_v @5' AFF	K	25	50	100	Avg	G	7.5	15	30	Avg
• Digital Games	E_h @floor; E_v @4' AFF	D	3	6	12	Avg	C	2	4	8	Avg

Table 33.2 | Residential Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1		☀		■	
	2:1		☀		■	
	2:1		☀		■	
	2:1		☀		■	
	2:1		☀		■	
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	5:1		☀			■
	3:1		☀			■
	3:1		☀			■
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	5:1		☀			■
	3:1		☀			■
	3:1		☀			■
	3:1		☀			■
	2:1		☀	↘	■	
	2:1		☀		■	
	4:1			↘		■
	4:1			↘		■

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e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

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g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ↘ signals high likelihood; gray and white ↘ signals moderate likelihood; pale gray and white ↘ signals some likelihood; and all-white signals little-to-no likelihood.

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j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. Identifying elevation changes can be achieved with lighting over the area of interest or by introducing contrast lighting at the change in elevation, such as can be achieved with steplights, in-tread uplights, linear tread nose lights, or other luminaires that accentuate the risers or treads or the edges that define elevation change. Figure 15.13 illustrates one example.

l. For applications where task position is indefinite, the typical area of coverage is "Room or Designated Area." For applications where task position is known, target illuminance is applied to the "Task Proper or Task Area."

m. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

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		Horizontal (E_h) Targets					Vertical (E_v) Targets				
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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
RESIDENTIAL INTERIORS	(continued)										
• Garage											
• Vehicle Bay	E_v at vehicles' sides. Position luminaires to avoid shadowing of vehicles' interiors from vehicles' roofs.										
• General	E_h and E_v @4' AFF	K	25	50	100	Avg	K	25	50	100	Avg
• Vehicle maintenance	E_h and E_v @3' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Work Bench											
• Manual	E_h and E_v @3' AFF	Q	200	400	800	Avg	O	100	200	400	Avg
• Power tools											
◦ No tool-integrated light	E_h and E_v @3' AFF	T	500	1000	2000	Avg	R	250	500	1000	Avg
◦ Tool-integrated light	E_h and E_v @3' AFF	Q	200	400	800	Avg	O	100	200	400	Avg
• Kitchen											
• Breakfast Area	E_h @eating surface; E_v @4' AFF	O	100	200	400	Avg	K	25	50	100	Avg
• Cabinets	E_v @face of cabinets						K	25	50	100	Avg
• Cooktops	E_h and E_v @cooking surfaces	P	150	300	600	Avg	K	25	50	100	Avg
• General	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Preparation Counters	E_h and E_v @prep surfaces	R	250	500	1000	Avg	L	37.5	75	150	Avg
• Sinks	E_h and E_v @top of sink	P	150	300	600	Avg	K	25	50	100	Avg
• Laundry											
• Ironing	E_h and E_v @3' AFF	O	100	200	400	Avg	K	25	50	100	Avg
• Wash and Dry	E_h and E_v @3' AFF	O	100	200	400	Avg	K	25	50	100	Avg
• Living Room	E_h @floor; E_v @4' AFF	I	15	30	60	Avg	I	15	30	60	Avg
• Media Lounge											
• Video (theater experience)	E_h over room or designated area, such as aisles; E_v over task proper (screen)										
• LCD/LED/Plasma	E_h @floor; E_v @screen	H	10	20	40	Avg	F	5	10	20	Avg
• Projection	E_h @floor; E_v @screen	B	1	2	4	Avg	B	1	2	4	Max
• Video and Reading	E_h over task proper (chairs); E_v over task proper (screen)										
• LCD/LED/Plasma	E_h @2' 6" AFF; E_v @screen	N	75	150	300	Avg	K	25	50	100	Avg
• Projection	E_h @2' 6" AFF; E_v @screen	N	75	150	300	Avg	F	5	10	20	Max
• Meditation Room											
• Cleanup and Yoga	E_h @floor; E_v @2' 6" AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Meditation	E_h @floor; E_v @2' 6" AFF	B	1	2	4	Avg	-	0	0	0	-
• Mud Room	E_h @floor; E_v @locker/shelf face	L	37.5	75	150	Avg	K	25	50	100	Avg
• Music Room											
• General	E_h @floor; E_v @4' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Instrument (for accenting)	E_h @instrument top; E_v @4' AFF	see Table 15.2					see Table 15.2				
• Reading Music	E_h and Ev @music	O	100	200	400	Avg	O	100	200	400	Avg
• Office	Alternatively, see READING AND WRITING, establish tasks and normalize to illuminance of most important task or most common task; use controls to provide illuminance variability if tasks so demand.										
• Household Office	Tasks not demanding continuous visual work or high degree of speed. E_h @desk; E_v @4' AFF.	O	100	200	400	Avg	I	15	30	60	Avg
• Working Office	E_h @desk; E_v @4' AFF	Q	200	400	800	Avg	L	37.5	75	150	Avg

Table 33.2 | Residential Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1					
	3:1					
	2:1					
	2:1					
	2:1					
	5:1					
	3:1					
	2:1					
	5:1					
	2:1					
	2:1					
	2:1					
	2:1					
	5:1					
	3:1				screen	floor
	3:1				screen	floor
	3:1					
	3:1					
	3:1					
	3:1					
	3:1				locker/shelf face	floor
	3:1					
	see 15.1.1.3					
	2:1					
	see Table 12.6					
	see Table 12.6					

Notes for Table 33.2

The table column headings are discussed in detail in 33.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 33.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 33.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 33.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. Identifying elevation changes can be achieved with lighting over the area of interest or by introducing contrast lighting at the change in elevation, such as can be achieved with steplights, in-tread uplights, linear tread nose lights, or other luminaires that accentuate the risers or treads or the edges that define elevation change. Figure 15.13 illustrates one example.

l. For applications where task position is indefinite, the typical area of coverage is "Room or Designated Area." For applications where task position is known, target illuminance is applied to the "Task Proper or Task Area."

m. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

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Table 33.2 | Residential Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b,c,d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
RESIDENTIAL INTERIORS	(continued)											
• Pool and Hot Tub	See RESIDENTIAL EXTERIORS/Pool and Hot Tub for exterior situations											
• In-hot-tub	This highly-specialized application is often best addressed with equipment and layouts recommended by hot tub or lighting vendors. Consult with respective vendors. Use more lower-wattage luminaires in favor of fewer higher-wattage luminaires.											
• In-pool	This highly-specialized application is often best addressed with equipment and layouts recommended by pool or lighting vendors. Consult with respective vendors. Do not center lights in swimming lanes of lap pools; Use more lower-wattage luminaires in favor of fewer higher-wattage luminaires.											
• Pool and Hot Tub Deck	Pool and hot tub presumed to be internally lighted. Lighting should address the pool and actual deck extension from the pool edge. E_v should be on planes perpendicular to the outline of the pool in two primary directions of travel around the pool.											
• Day	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg	
• Night	E_h @floor; E_v @5' AFF	F	5	10	20	Avg	C	2	4	8	Avg	
• Reading and Writing	Based on anticipated level of concentration and area of coverage at respective location and assumptions about task types. Alternatively, see READING AND WRITING, establish tasks and normalize to illuminance of most important task or most common task; use controls to provide illuminance variability if tasks so demand.											
• Bed Headboard	E_h and E_v @3' AFF, small area	O	100	200	400	Avg	M	50	100	200	Avg	
• Casual Chair	E_h and E_v @2' 6" at sitting areas	O	100	200	400	Avg	K	25	50	100	Avg	
• Desk	E_h @desk; E_v @4' AFF	Q	200	400	800	Avg	L	37.5	75	150	Avg	
• Sewing												
• Hand Sewing or Knitting	E_h and Ev @2' 6" AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Machine (no built-in light)	E_h and Ev @2' 6" AFF	S	375	750	1500	Avg	Q	200	400	800	Avg	
• Machine (with built-in light)	E_h and Ev @2' 6" AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Site Gated Entries	See 22 | LIGHTING FOR COMMON APPLICATIONS/BUILDING ENTRIES											
• Steps/Stairs	Lighting should address the area of the steps and landings. Alternatively, draw attention to elevation changes with contrast.[k]											
• General	E_h @treads	K	25	50	100	Avg						
• Storage												
• Frequent Use	E_h @floor; E_v @4' AFF	K	25	50	100	Avg	H	10	20	40	Avg	
• Infrequent Use	E_h @floor; E_v @4' AFF	I	15	30	60	Avg	F	5	10	20	Avg	
• Wine Cellar	Storage area should be on occupancy sensor to limit exposure to light.											
• Storage	E_h @floor; E_v @4' AFF face of rack	F	5	10	20	Avg	H	10	20	40	Avg	
• Tasting	E_h @3' AFF; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
READING AND WRITING												
• Computer	See READING AND WRITING/VDT Screen and Keyboard											
• Electronic Readers												
• Electronic Ink Devices	E_h and E_v @height of device	P	150	300	600	Avg	N	75	150	300	Avg	
• LCD or LED Devices	E_h and E_v @height of device	N	75	150	300	Avg	K	25	50	100	Avg	
• Facsimile												
• Analog	E_h @2' 6" AFF; E_v @4' AFF[m]	R	250	500	1000	Avg	M	50	100	200	Avg	
• Digital	E_h @2' 6" AFF; E_v @4' AFF[m]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Handwritten Work	Based on fair-to-good penmanship/hand print on white or canary paper											
• Pencil												
• Graphite/HB	E_h @2' 6" AFF; E_v @4' AFF[m]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Red	E_h @2' 6" AFF; E_v @4' AFF[m]	R	250	500	1000	Avg	M	50	100	200	Avg	
• Ballpoint/Rollerpoint/Felt-tip												
• Black	E_h @2' 6" AFF; E_v @4' AFF[m]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Red, Green, Blue	E_h @2' 6" AFF; E_v @4' AFF[m]	Q	200	400	800	Avg	L	37.5	75	150	Avg	

Table 33.2 | Residential Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	5:1					
	5:1					
	3:1					
	see Table 12.6					
	see Table 12.6					
	2:1					
	2:1					
	2:1					
	5:1					
	3:1					
	3:1					
3:1	3:1				rack face	floor
	5:1					
	2:1					
	2:1					
	see Table 12.6					
	see Table 12.6					
	see Table 12.6					
	see Table 12.6					
	see Table 12.6					
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d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

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i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. Identifying elevation changes can be achieved with lighting over the area of interest or by introducing contrast lighting at the change in elevation, such as can be achieved with steplights, in-tread uplights, linear tread nose lights, or other luminaires that accentuate the risers or treads or the edges that define elevation change. Figure 15.13 illustrates one example.

l. For applications where task position is indefinite, the typical area of coverage is "Room or Designated Area." For applications where task position is known, target illuminance is applied to the "Task Proper or Task Area."

m. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

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Table 33.2 | Residential Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
READING AND WRITING	(continued)											
• Laptop	See READING AND WRITING/VDT Screen and Keyboard											
• Print Media	Digital-printing-press-generated, white paper											
• 6-pt Font												
• Matte paper and ink	E_h @2' 6" AFF; E_v @4' AFF[m]	R	250	500	1000	Avg	L	37.5	75	150	Avg	
• Specular paper and ink	E_h @2' 6" AFF; E_v @4' AFF[m]	R	250	500	1000	Avg	L	37.5	75	150	Avg	
• 8- and 10-pt Font												
• Matte paper and ink	E_h @2' 6" AFF; E_v @4' AFF[m]	P	150	300	600	Avg	K	25	50	100	Avg	
• Specular paper and ink	E_h @2' 6" AFF; E_v @4' AFF[m]	P	150	300	600	Avg	K	25	50	100	Avg	
• 12-pt Font												
• Matte paper and ink	E_h @2' 6" AFF; E_v @4' AFF[m]	O	100	200	400	Avg	K	25	50	100	Avg	
• Specular paper and ink	E_h @2' 6" AFF; E_v @4' AFF[m]	O	100	200	400	Avg	K	25	50	100	Avg	
• VDT Screen and Keyboard												
• CSA/ISO Types I and II	See Figure 12.16 | CSA/ISO Computer Screen Qualities											
• Positive polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[m]	P	150	300	600	Avg	N	75	150	300	Avg	
• Negative polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[m]	N	75	150	300	Avg	K	25	50	100	Avg	
• CSA/ISO Type III	See Figure 12.16 | CSA/ISO Computer Screen Qualities											
• Positive polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[m]	N	75	150	300	Avg	K	25	50	100	Avg	
• Negative polarity	E_h @2' 6" AFF; E_v @3' 6" AFF[m]	L	37.5	75	150	Avg	I	15	30	60	Avg	
• Xerograph	Copier- and printer-generated on white paper											
• ≥8-pt type, common graphics	Select progressively next-higher letter category of illuminance for each 2-point-type decrease in fonts/graphics)											
• Color												
◦ Analog	E_h @2' 6" AFF; E_v @4' AFF[m]	R	250	500	1000	Avg	M	50	100	200	Avg	
◦ Digital	E_h @2' 6" AFF; E_v @4' AFF[m]	P	150	300	600	Avg	L	37.5	75	150	Avg	
• Grayscale and/or B+W Print												
◦ Analog	E_h @2' 6" AFF; E_v @4' AFF[m]	P	150	300	600	Avg	L	37.5	75	150	Avg	
◦ Digital	E_h @2' 6" AFF; E_v @4' AFF[m]	O	100	200	400	Avg	K	25	50	100	Avg	

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
see Table 12.6			☀		■	■
see Table 12.6			☀	↑	■	■
see Table 12.6			☀		■	■
see Table 12.6			☀	↑	■	■
see Table 12.6			☀		■	■
see Table 12.6			☀	↑	■	■
see Table 12.6			☀	↑	■	■
see Table 12.6				↑	■	■
see Table 12.6				↑	■	■
see Table 12.6				↑	■	■
see Table 12.6			☀	↑	■	■
see Table 12.6			☀	↑	■	■
see Table 12.6			☀	↑	■	■
see Table 12.6			☀	↑	■	■

Notes for Table 33.2

The table column headings are discussed in detail in 33.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 33.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 33.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 33.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ↑ signals high likelihood; gray and white ↑ signals moderate likelihood; pale gray and white ↑ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

j. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

k. Identifying elevation changes can be achieved with lighting over the area of interest or by introducing contrast lighting at the change in elevation, such as can be achieved with steplights, in-tread uplights, linear tread nose lights, or other luminaires that accentuate the risers or treads or the edges that define elevation change. Figure 15.13 illustrates one example.

l. For applications where task position is indefinite, the typical area of coverage is "Room or Designated Area." For applications where task position is known, target illuminance is applied to the "Task Proper or Task Area."

m. E_h and E_v elevations are based on conventional worksurface and seated eye height. Where other elevations are programmed, designer must adjust illuminance-criteria planes of interest accordingly.

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Table 33.3 | SI Dimensional Conversions

US Customary	SI
General	**Hard Conversion**
inches	mm [inches × 25.40]
feet	m [feet × 0.30]
Specific	**Convenient Conversions[a]**
2'	610 mm or 0.6 m
2' 6"	760 mm or 0.75 m
3'	915 mm or 0.9 m
3' 6"	1065 mm or 1.1 m
4'	1220 mm or 1.2 m
5'	1525 mm or 1.5 m

a. Hard conversions rounded for reporting convenience. Not to be confused with metric-sized luminaires or other building materials. Not for precision construction.

With exterior lighting, the use of optically-appropriate luminaires and automated controls greatly improves energy conservation and the condition of the night environment. Automatically dimming back or switching off lighting at a predetermined curfew is good practice, if not mandated. Lighting can be switched off entirely at curfew and operation transferred to motion sensors or timed switches. Optics can be used to minimize light spill to adjacent sites or skyward. However, as Figure 33.2 illustrates, simple architectural geometries and luminaire positioning can also limit light spill. On skyward spill, uplights should be limited in use and their reflectors designed to direct light onto vertical surfaces or objects. This usually requires careful aiming, use of louvers, baffles, snoots, and lamp-cap accessories.

The nighttime outdoor lighting zone within which the home is located or to which the design team and homeowner elect to design establishes the categories of illuminance for outdoor tasks. Nighttime outdoor lighting zones vary by local ordinance, sustainability guides, or the team's own definition of place.

Security lighting above and beyond recommendations cited in Table 33.2 should be implemented with great deliberation and care. Without monitoring programs and other security measures, additional lighting may be pointless as well as an energy waste and a source of irritation to neighbors.

33.2.1.1 Building Entries

Table 33.2 outlines illuminance criteria for residential primary and secondary entries. Illuminances at building entries are defined at the immediate exterior with respect to horizontal illuminance at the threshold (for the width of the door) and vertical illuminance within a 3-foot zone of the entry. Vertical illuminance may drive the horizontal illuminance higher than criteria depending on the lighting equipment and layout used. The vertical illuminance on an approaching visitor's face and body is important. Clothing colors and skin tones are best rendered when lamp CRI is ≥82. Where a warm color of light is desired, CCT should be 2700 K to 3000 K.

It may be determined secondary entries are to be unlighted except for purposes of security. Security lighting should be on timed switches and motion sensors to limit their use to time of need. Soft, diffuse light is best to limit annoying glare to distant property owners. Alternatively, well-controlled optics and snoots can be used for greater light throw on larger properties while limiting light trespass. Where electronic surveillance is planned, close coordination with the security consultant is necessary. Cameras sensitive to infrared radiation can pick up visitors or intruders and display on video monitors. This avoids the need for continuous operation of electric lighting.

33.2.1.2 Entry Walks

Some portion of the entry walk, typically a short section near the main sidewalk or street if both are not publicly lighted, and any elevation changes along the walk are lighted to a lesser degree than the entry for sake of efficiency and preserving the night environment while still meeting vision requirements for movement. This lighting is not intended to be uniformly applied to the entire walking path and is meant to help the visitor navigate by lighting key points of interest.

33.2.1.3 Pool Decks

Pools are presumed to be internally lighted. This defines the pool and deck edge and provides some low-level vertical illuminance at the deck in close proximity to the pool. This is sufficient to softly light faces of guests. For navigating the pool deck, low illuminances are used in predetermined circulation areas and at access points to the deck. This might occur at the pool deck perimeter and establishes a social area between the lighted pool and this lighted perimeter. Like entry walks, light is used here for purposes of navigating from one area to another and not applied uniformly throughout. As with all applications, adhere to all code requirements.

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Figure 33.3 | Ramada Activity Area
A sitting area is lighted with a total of eight surface mounted downlights. Each downlight exhibits a slightly angled fixed optic lamped with one 40W/PAR20/WFL halogenIR lamp. The downlights are fitted with a linear spread lens to further spread light and reduce direct glare. Two planters are accented with single 20W/MR16/NSP halogen$_{LV}$ lamps in deep-snooted adjustable accent luminaires. This perimeter accenting acts in conjunction with the linear fire pit on the far left and the pool on the near right to address the perimeter lighting modes identified in Table 12.2 for preference and relaxation. Pool lighting is accomplished with RGB LED in-pool luminaires (set here to saturated blue). All luminaires are on preset scene control and can be addressed by handheld wireless devices.
» Image ©Gary Steffy Lighting Design Inc.

33.2.1.4 Social Areas

Gazebos or ramadas or other semi-protected areas establish gathering points for socializing. If these are programmed for use as barbecue, game, or reading areas, illuminances supporting those activities are necessary. However, homeowners should be advised these illuminances are low compared to indoor counterparts for several reasons: the casual nature of the exterior setting and the impracticality of providing interior illuminances in such a setting. Lighting should address the task area only and uniformities within that area may be broad. Figure 33.3 illustrates lighting for a reading and card-playing area at a ramada.

33.2.1.5 Site Paths, Ramps, Stairs, and Steps

Site paths can be addressed similar to entry walks with lighting helping to identify key points along the path to allow for navigation without uniformly lighting the entire path. Very low illuminances and broad uniformity ratios will create this effect. Where paths exhibit switchbacks or are set on irregular terrain, more uniform application of light may be warranted. The designer is challenged with proposing the path of most prominence and, therefore, the path that is deserving of light. Otherwise an entire site may be lighted unwittingly. Ramps, stairs, and the occasional step should be marked with light.

33.2.1.5 Landscapes

There are no illuminance criteria for landscapes cited in Table 33.2. Landscape lighting can provide peripheral accenting and some degree of security by limiting dark areas of cover and silhouetting foreground movement. In residential applications, lamps typically at 20 W or less with beam spreads typically tighter than 25° in luminaires with louvers or snoots suffice for softly accenting key landscape elements while limiting the effects of light trespass and light pollution. Adjustable equipment should exhibit locking tilt and rotation to maintain proper aiming. Automated time clocks should extinguish tree uplighting at a reasonable curfew to better accommodate stargazing. See Figure 33.4. Landscapes can benefit from high color temperature lamps or luminaires fitted with blue-green gels. Since colorful effects may elicit a harsh reaction, these effects should be reviewed with the homeowner. Mockups are an excellent way to explore the use of color or even lamps exhibiting CCTs ≥4100 K.



Figure 33.4 | Landscape Lighting
A mesquite tree is uplighted with three luminaires each lamped with 20W/MR16/NSP halogen$_{LV}$ lamps in deep-snooted accents. Luminaires are aimed into the central branch structure of the canopy. Using such low-wattage, well-controlled equipment is an appropriate way to provide lighting sufficient for outdoor close-view and enjoyment. This tree is located at one end of a barbecue terrace and helps define the boundary and serves as back drop to seated conversation. Time clocks should be used to extinguish lights at a reasonable curfew.
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33.2.2 Residential Interiors

For this discussion on interiors, lighting needs of residents in single-family detached and attached homes and in the living quarters of duplexes, apartments, condominiums or other similar complexes are considered during day- and night-time hours. For public areas in the larger operations, see relevant applications in 22 | LIGHTING FOR COMMON APPLICATIONS and 26 | LIGHTING FOR EXTERIORS. See Figure 33.5. For assisted-living situations, reference relevant applications in 27 | LIGHTING FOR HEALTH CARE. For residential interiors several conditions influence lighting:

- Architectural and interiors styles
- Number and ages of occupants
- Primary hours of use
- Life activities
- Sustainability

Unlike commercial, civic, and institutional projects, residential architectural and interior designs are usually strong reflections of the homeowner's own sense of style. Lighting should respond to traditional, transitional, contemporary, or eclectic styles through luminaire styles and the types of lighting effects. Reviewing luminaire selections and lighting effects with the homeowner is a key component of the design process.

The number of occupants and their ages may influence the diversity of lighting techniques and illuminances available throughout the residence. Lighting for bedrooms and game rooms for people under 25 years of age may establish a convenient means of addressing the likely aesthetic and illuminance differences. Where a large family is involved with young and elder members, the design must review respective spaces and tasks and discuss with the homeowner the options for addressing the age differences. Controls can assist in meeting varying needs based on occupancy, tasks, and time of day. However, for these to be successful, their operation must be quite straightforward.

Some residences require near 24-hour operation while others are primarily used during dark hours on weekdays and daylight hours on weekends. The use patterns may well influence lighting decisions and controls. Daylighting strategies may not have the sustainability benefits if they contribute little to reduced use of electric lights during weekday peak utility demand and may even contribute unfavorably to weekday cooling load. On the other hand, value to future homeowners must be considered. These are aspects that must be explored with the homeowner.

Life activities will influence the kinds of applications and tasks to be performed, will affect design priorities, and will affect the kinds and number of defined areas in the house. Some homeowners are quite active and will have indoor and outdoor areas and equipment to support sports or exercising activities. Some homeowners dedicate life to raising children and, later, grandchildren. Other homeowners are hobbyists and may be involved in such activities as knitting or collecting dolls, stamps, or coins. Still, others cook. Some are movie buffs. Some enjoy entertaining. Some households encompass all of these activities. A good program will detail the life activities, outline space and area requirements, and can serve as an outline of lighting needs.

Energy use and maintenance are sustainability aspects that should weigh on the designer's and homeowner's design selections. Efficient, long-life lamps can result in low connected loads. Dedicated-socket luminaires can assure this low-load over time. Controls can have a positive influence on energy use. Simple vacancy sensors can switch lights off in unoccupied rooms thereby reducing energy use and extending in-service life of lamps and ballasts, drivers, and transformers.

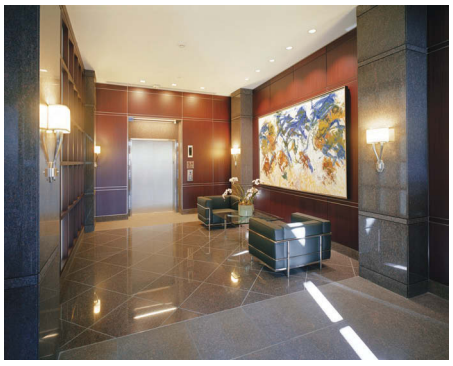


Figure 33.5 | Common Application: Condominium Lobby
Illuminance criteria for lobbies and circulation corridors for apartments and condominium complexes are addressed in Table 22.2 | Common Applications Illuminance Recommendations/Transition Spaces.

Here, fabric-shade wall sconces lamped with 13 W CFLs contribute to a residential atmosphere. Adjustable accents lamped with 20W/PAR20/CMH 25°-beam flood lamps highlight the artwork. The wood surround at the elevator wall is lighted with 26 W CFL wallwashers. A recessed linear, continuous, lensed luminaire of 2½" width and 4' length at the elevator header illuminates the threshold. All lamps exhibit CCT of 3000 K and CRI ≥82.

Daylight in combination with electric light is used to address daytime illuminance criteria.
» Image ©Christopher Lark

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The applications and tasks outlined in Table 33.2 are extensive, if not exhaustive, and many are self-explanatory. However, as is the case with nearly all lighting design efforts, the devil is in the details. Identifying applications or tasks, selecting an illuminance target, and laying out lighting equipment to address that target is a gross foreshortening of the design process. The design components outlined in Chapters 12, 14, and 15 should not be dismissed. Even within the more analytic aspect of laying out equipment to meet illuminances, the reasons for introducing light must be understood. For example, why light a garage? Many answers come to mind, but perhaps not loading or unloading the car. For such common activities, daylighting and electric lighting should be designed to illuminate the sides of the vehicle, thereby allowing some light to enter side windows and doors, preferably from both sides, and assist with the visual requirements of loading and unloading. This sidelight approach also reduces shadowing common when opening hoods, trunks, and hatches.

What follows are brief annotations on lighting of some interior residential applications and tasks.

33.2.2.1 Accenting

Accenting is used to address subjective impressions identified in Chapter 12. Accenting may take several forms, including: art; feature wall; perimeter; and significant focal point. Figures 33.6, 33.7, and 33.8 identify a few techniques for achieving some forms of accenting. Particularly in single-family residences, access to skylight and clerestory techniques can lead to effective daylight accenting solutions. In any event, accenting need not consume much energy and is typically more efficient and visually interesting than using high-output general lighting.

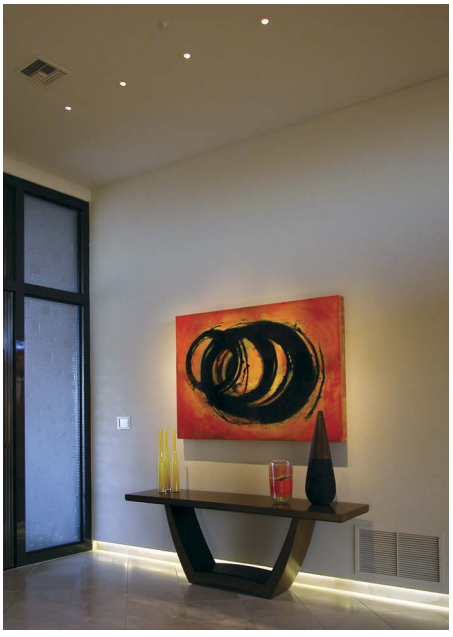


Figure 33.6 | Accenting Art
Although illuminance target and uniformity are important, other design criteria include: scale of luminaire aperture; ceiling height; and the artwork media. Here, four pinhole adjustable accents are used, each lamped with a 20W/MR16/VNSP halogen$_{LV}$ lamp and fitted with soft diffusion and UV filters.
» Image ©Gary Steffy Lighting Design Inc.

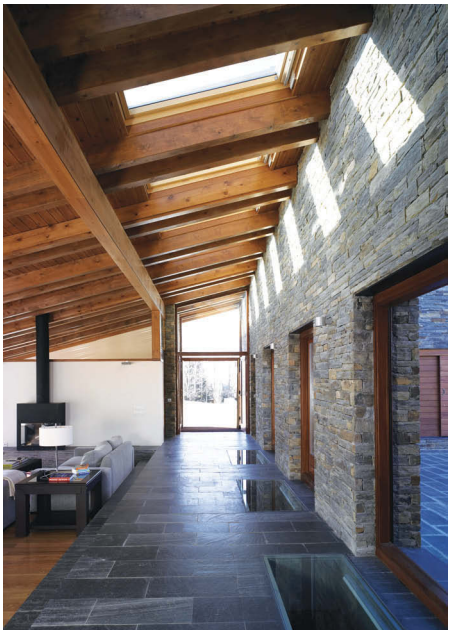


Figure 33.7 | Accenting Perimeter
Daylight apertures are strategically placed to wash the stone wall and balance the brightnesses from other daylight media. In this location and at this angle, the skylights are less likely to create glare for people in the living area than would skylights located directly over the living area.
» Image ©Eugeni Pons/Arcaid/Corbis



Figure 33.8 | Accenting Feature Wall
A skylight is positioned to graze this tile wall with daylight and introduce general light in the vicinity of the bathtub. Skylight geometry can be designed to limit direct glare during the more relaxed function of bathing. Electric lighting must also address direct glare in these situations.
» Image ©Elizabeth Whiting & Associates/Corbis

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Figure 33.9 | Vanities
Mirror-integrated lighting addresses criteria for grooming at the vanities in the modern master bath in the top image. The dimmable long compact fluorescent lamps exhibit CCT of 3000 K and CRI of 82.

Wall sconces achieve a similar result in a more traditional setting in the middle image.

Middle and bottom images clearly show the effect of vertical illuminance on the face generated by well-placed luminaires.

» Top image ©Glen Calvin Moon
» Middle image ©Felix Wirth/Corbis
» Bottom image ©Trinette Reed Blend Images Getty

33.2.2.2 Bathrooms

In an effort to address all task requirements, general lighting alone addresses none very well in bathrooms. Task-functional lighting can be appropriate without the glare and shadows common with one or two high-output ceiling luminaires or a field of downlights. The targeted use of lighting energy is more efficient with a task-functional approach. Grooming is an especially significant task, both in time consumption and in esteem-value and lighting plays a valuable role, and demands frontal lighting of the face. The designer must determine the extent and priority of bathroom tasks for a given homeowner. In some situations, grooming may take place at sit-down vanities and the E_v values cited in Table 33.2 should then be applied to a seated eye-height position corresponding to chair- or stool-height sitting position. Reading in the bathroom may be a homeowner's desire or requirement for which a review of reading tasks is undertaken, such as 12 pt. font under READING AND WRITING in Table 33.2. Figure 33.9 illustrates several lighting approaches to a master bathroom. Although downlights alone might be deemed expeditious, glare and shadows are serious side effects unless great care is taken in selection of optics and lamping. Downlights are used for top lighting the head, thereby addressing the Table 33.2 citation of RESIDENTIAL INTERIORS/Bathrooms/Vanities/Top-of-head.

33.2.2.3 Bedrooms

Bedrooms may be the most multi-functional spaces in a home. Reading for pleasure, watching television, surfing the Internet, dressing, amorous activities, and studying or working at a desk are some of the functions. In addition to a variety of lighting effects, controls are usually employed to address the desired variability. Reading for pleasure in bed may involve separate controls for each side of the bed. If there is a programmed need for reading light for one party independent of the other party, optically well-controlled table luminaires, gooseneck wall luminaires, or even ceiling pinholes may be warranted. Care should be taken by the design team to accommodate a sleep cycle with no light. Where nightlights are deemed appropriate, strategic placement of one or several architecturally-integrated steplights may be in order. To limit sleep disturbance these should be tied to occupancy sensors on timers or photocells. To best limit the disturbance to the circadian rhythm during the sleep cycle, long wavelength sources such as LEDs producing spectra between 600 and 620 nm are appropriate. However, there should be no direct view of the source or optical media and illuminances should be extremely low.

33.2.2.4 Circulation

Where circulation lighting and general lighting throughout a residence are deemed necessary, these need not and usually are not achieved with a complete and distinctly separate lighting system. After developing design strategies to address accents and the host of other application and task requirements in a home, calculation checks are made. Where illuminance results are below design targets for circulation, then additional design work is necessary. This might involve additional accent lighting, additional decorative lighting, or the introduction of lighting for purposes of meeting the circulation illuminance target. This might be daylighting or electric lighting or both to accommodate day and night situations.

In open layouts, circulation zones might be obvious, but no designated or walled-off corridor exists. Here, lighting criteria are quite directly related to the lighting of the adjoining area.

33.2.2.5 Closets

Closet space is always at a premium. Closets are usually small and potentially fitted-out with ceiling-high closet-wide shelving, drawers, hanger rods, or some combination. The very nature of clothing and most stored items, other than linens, make for a low-reflectance room. Code requirements on types of luminaires and their proximity to clothing and storage shelving result in little flexibility for luminaire sizes and locations in small closets. In some situations, the closet is so small that a code-compliant lighting layout cannot be accommodated and it may be necessary to mount the lighting equipment outside of the closet. In these situations, the designer must more carefully consider several items in the context of the adjacent space:

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- luminaire placement and orientation to limit effects of body shadow from users
- luminaire styling and scale
- controls such as keypad or switch, door-activated switch or occupancy sensor

In walk-in closets, needs may be multiple and perhaps for different users. Preset controls can help establish appropriate lighting for each function and user. For dressing room situations, frontal lighting for users standing in front of a mirror is necessary (see Figure 33.10). Where makeup and grooming are accommodated with mirror(s) at perhaps a sitting area, facial lighting at the appropriate elevation is necessary. Criteria for these various tasks from Table 33.2 can be used to set various scenes.

Color discrimination, between navy, black, and dark brown for example, may be best accommodated with the introduction of some accent lighting aimed to a dresser or sorting surface. Daylighting is extremely helpful, but has obvious availability limitations. Lamps should exhibit CRI ≥85. To avoid the effects of spectral deficiencies of any one light source, mixing lamp technologies is beneficial. A combination of some fluorescent with some LED or halogenIR lighting offers good color discrimination and matching when all lighting is used simultaneously.



Figure 33.10 | Dressing Mirror
Full length mirrors work well when diffuse frontal lighting is available across the face of the standing body. Opal-lensed surface mounted or semi-recessed luminaires, electric skylights, and wall sconces are all effective options. Narrow or even wide-beam downlights are typically unsuccessful as these create harsh shadows across the face of the body sometimes creating unflattering views.
» Image ©Adrian Wilson/Corbis

33.2.2.6 Family Rooms and Living Rooms

Family rooms and living rooms have evolved with technology and lifestyle. Televisions have moved to rooms dedicated to their use, like media lounges or home theaters. Family and living rooms are one-in-the-same in many residences and function as conversation areas and places for pleasure reading and entertaining. Figure 33.11 illustrates a room that functions as family room and living room and the lighting employed to address respective architectural cues, subjective impressions, and luminance and illuminance criteria.

33.2.2.7 Kitchens

Lighting for working kitchens is most successful when surface finishes are matte and of high reflectance. Dark cabinetry, counter tops, backs plashes, and floors contribute to an overall dark, though highly-dramatic appearance and exacerbate shadowing. Black, polished stone counter tops exhibit annoying veiling reflections if not discomfort glare caused by luminaire reflections. Lighting can be efficient and pleasant and yet meet what appear to be demanding illuminance criteria. See Figure 33.12.

33.2.2.8 Media Lounges

Home theaters are evolving into media lounges to accommodate the growing variety of media entertainment. Where home theaters are programmed, seating might be tiered, such as in a movie theater, and the experience is intended to be much like that of a theater. Controls play a role in allowing for slow fades from relatively bright settings to theater-dark settings. Vertical illuminance at the video screen are expected to be very low for best picture contrast. Finishes affect the overall light quality, even in the theater-dark scene, as the screen emits enough light to illuminate room surfaces and, consequently, lighter surfaces may make for an undesirably bright experience. On the other hand, as the video screen technologies advance, screen luminance improves to the point where some background luminance is desirable. Soft background lighting and lighter-toned surfaces will minimize screen glare and visual fatigue. The designer must assess the homeowner's intended use of the media lounge and the luminance of the screen to determine appropriate illuminance criteria.

In some situations media lounges replace the traditional TV-watching room where reading for pleasure, conversation, and entertainment occurred. Accommodations should be made for reading and conversation tasks to occur in conjunction with TV-watching. Here, vertical illuminance at the video screen isn't as important as that for the theater experience, but is important for facial recognition for conversation and accommodating varying positions of the reading material.

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Figure 33.11 | Family and Living Rooms
The architectural cues of the cathedral ceiling and the massive fireplace wall helped establish lighting design strategies. Spatial definition and preference suggested wall-washing and art accenting techniques (from Table 12.1b | Spatial Factors: Part Two and Table 12.2 | Subjective Impressions respectively). Illuminance criteria for Family Room/Living Room and for Reading/Writing/Casual Chair were used to finalize lamping in the cove uplight and the number, positioning, and wattage of downlights.
» Image ©Glen Calvin Moon

Where gaming activities are involved, the floor is not tiered and the lighting system and lighting controls must be designed to accommodate the theater experience and the gaming experiences, of which there may be several. Gaming might be an immersive interactive experience or might be a shared, active-sport experience. Each of these should be lighted to address the desired mood and function. Immersive gaming is typically a darker setting with full attention on the video screen while active-sport gaming is typically a lighter setting where visual attention periodically alternates from screen to participants. As these technologies of video and gaming evolve, lighting solutions should as well. Figure 33.13 illustrates variations on a theme for the theater experience.

33.2.2.9 Offices

In the home, the office may take many forms and serve many functions. An office where work from "the office" is performed on a regular and perhaps even full-time basis, should be lighted to support such continuous, fast-paced, productively-accurate, and long-term work. However, where an office at home is used infrequently for the household tasks of paying bills, making weekly or monthly family schedules, reviewing and filing financial statements, and surfing the Internet, which can be done at a less demanding pace and degree of accounting, lighting should be designed accordingly.

33.2.2.10 Reading and Writing

Reading and writing tasks occur within various applications. Familiarity with these tasks will aid with assessment of specific application tasks and activities. This may result in the recommendation of illuminance criteria different than that proposed in Table 33.2 for a particular application. For example, if the homeowner is inclined or required to read documents printed in small typeface such as 6 point font, then illuminance criteria at areas where this reading is to take place should reflect this.

Electronic readers may revolutionize the reading task. The technologies employed in various versions of these readers determine the illuminance criteria. As these technologies evolve, the designer needs to periodically assess lighting requirements and adjust designs accordingly.

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33.3 Illuminance Criteria

Illuminance criteria, when fully deployed, are a robust set of quantitative values that influence visibility, visual performance, and visual comfort and attention. Short-circuiting the criteria selection or designing to a single criterion value, such as horizontal illuminance, to address worst-case tasks will surely result in dissatisfaction. Even if clients accept the visual results, not getting the most from the energy expended or, worse, energy waste is a likely result. Following are notes related to various topics outlined in Table 33.2.

33.3.1 Applications and Tasks

Applications and tasks encountered on any given project may be different from those identified in Table 33.2 and may warrant different illuminance criteria. Cross-referencing closely-associated applications or tasks is appropriate. Sometimes naming trends or conventions for space types or functions change to conform to current practice, client programming, or architectural conventions, but the actual activities and tasks remain the same and this cross-referencing works. Failing this technique, reviewing the list in Table 33.2 may be in order to determine if any applications or tasks exhibit a similar visual-component to the unique applications or tasks. Otherwise, reviewing 4.12 An Illuminance Determination System and Table 4.1 is necessary to establish a task category based on the task characteristics or visual performance descriptions most closely associated with the unique applications or tasks. These exercises as well as any deviations from recommendations the designer intends to make should be carefully documented for the record.

33.3.2 Notes

The notes in Table 33.2 may refer to other task headings in the table or to other handbook chapters as appropriate. Where some degree of clarification is warranted, notes are made.

33.3.3 Recommended Maintained Illuminance Targets

Values cited are maintained on the area of coverage for the task under consideration. Illuminance is additive. Where practical and without negatively affecting the intended application of light, target values are achieved with any combination of daylighting and/or electric lighting in whatever mix of ambient, task, and accent lighting is deemed appropriate to meet these and the other lighting goals established during design. See 12 | COMPONENTS OF LIGHTING DESIGN and see 10.7.1 Light Loss Factors.

With respect to light loss factors, an accounting must be made of anticipated light losses through the point in time at which lamps will be changed. For residential applications, this may not occur until the lamp fails. Accounting for lamp lumen depreciation (LLD) through end of life may wildly throw off initial costs, energy and sustainability efforts, and illuminances for much of the life of the lamp. Ultimately this is unsustainable and is unacceptable to most homeowners. In most situations, homeowners will understand the consequences of poor LLDs resulting from spot relamping at time of lamp failure. Most homeowners accept the gradual reduction in illuminance over time of operation where illuminance is not tied to safety or the degrees of accuracy and speed required in commercial and institutional settings. Therefore, a default design strategy bases LLDs on group-relamping to avoid what otherwise will be the shock of still-greater initial and operating costs and subpar energy and sustainability performance. This condition of illuminances ultimately falling below criteria, but the ramifications of the alternative should be reviewed with the homeowner. Luminaire dirt depreciation (LDD) can be maintained at an efficient level with periodic cleaning, a concept appreciated by many homeowners.

Targets cited are consensus and recommended for respective functional activity. Footcandle conversions of any values cited in Table 33.2 should be made at 1 fc to 10 lx. This soft conversion avoids a redundant diminishing of illuminance values after multiple



Figure 33.12 | Kitchens
Architectural style and personal taste influence design and operation. The top image illustrates a kitchen and dining area where small downlights concentrate light at the island. Undercabinet task lighting, a mainstay in many kitchens, meets illuminance criteria a the counters. A unique pendant luminaire at the dining table is combined with a wallslot detail with closed shades as the reflecting surface for a dramatic look and spacious effect.

The middle image illustrates undercabinet lighting with traditional-style short-stem pendants to provide general diffuse light.

In the lower image, a simple layout of linear indirect pendants complement the modern architecture and illuminate the work area with no glare. The dimmable T5HO fluorescent lamps exhibit CCT of 3000 K and CRI of 85.

» Top image ©Marc Gerritsen/Lived In Images/ Corbis
» Middle image ©William Geddes Beateworks Corbis
» Bottom image www.jmaconochie.com

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Figure 33.13 | Media Lounges
Two series of steplights are used in the top image to light the perimeter of the theater. One series is located in the traditional position near the floor and lighting downward onto the floor. A second series, separately dimmed from the floor steplights, is located close to the ceiling and oriented to light the ceiling providing indirect lighting. The steplight is specifically UL/NRTL-listed and labeled for such application in the USA. Pinhole downlights provide general light for some reading and conversation. Downlights at screen can be separately dimmed to eliminate screen washout. Floor steplights alone are used during shows.

The middle image illustrates a traditional wall sconce and larger-aperture downlights.

The dark ceiling and the strategic placement of downlights in the bottom image make for a high-contrast screen image even when room lights are brightened.

» Top Image ©Glen Calvin Moon
» Middle Image ©George Gutenberg/Beateworks/Corbis
» Bottom Image ©Scott Van Dyke/Beateworks/Corbis

citations and conversions over time. This also eliminates a false sense of accuracy advanced by an ever-increasing number of decimal places and a false sense of urgency advanced by eccentric fractional values introduced by hard conversions.

A lighting design must meet code and the mechanics of which must be coordinated amongst the design team. The IES recommendations should not, do not, and cannot reflect all of the various code requirements in force in all jurisdictions at any given time.

Targets are intended to apply to the dominant plane of the task, typically, but not always, horizontal or vertical. In some situations, illuminance criteria are cited for one plane, such as the vertical plane for lighting white boards, while the other plane is blank. The blank signifies that illuminance on that plane is unimportant and may be a consequence of the illuminance of other tasks within the vicinity or by whatever illuminance results from meeting the target illuminance for the prescribed plane of interest.

In some situations, no light is anticipated on at least one plane of a task. A 0 indicates no light or zero light is recommended for the task or application.

33.3.3.1 Target Planes

Many, though certainly not all, tasks are performed with the task in roughly a horizontal orientation or vertical orientation. Additionally, most tasks are expected to have both a horizontal illuminance component (E_h) and a vertical illuminance component (E_v). Where these illuminance components are intended at differing planar elevations, such is indicated under "Notes." For example, for bathroom vanities, horizontal illuminances apply to the counter top while vertical illuminances apply to standing-face-plane height of 5' AFF oriented in the direction facing the mirror. In situations where a sit-down vanity is designed the height of the counter top or table and of the seated face must be established and criteria applied to the respective planes of interest.

For planes related to vertical illuminance targets, some guidance is indicated under "Notes." However, the designer may elect to use alternate or multiple vertical planes. In some situations the vertical planes could be oriented in a number of directions and the designer must determine which are most appropriate for the situation. For example, in a kitchen, E_v at preparation surfaces (RESIDENTIAL INTERIORS/Kitchen/Preparation Counters), the number and orientation of vertical planar points assessed depends on the preparation surface. On a counter against a full-height wall, the vertical planes of most interest are the one facing the preparer and the two planes perpendicular to the preparer (one oriented toward the right and one toward the left). The criteria apply to these three planes. On an island or peninsula which may be used from more than one side, there are four planes of interest.

33.3.3.2 Visual Ages of Observers

Illuminance criteria are based on the visual ages of more than half the intended observers. This aspect should be resolved during programming with the homeowner. It may be determined that in a residence where perhaps two people constitute a majority the "design age" is for a different age group to address an elderly relative or accommodate the homeowner's own desire to remain a resident of the house for a long time. However, this may result in over lighting, under lighting, harsh lighting, visual displeasure, or visual discomfort for some residents some of the time. See 12.5.5 Illuminance and 4.12 An Illuminance Determination System for additional information and guidance.

33.3.3.3 Illuminance Categories

Illuminance categories are designated by letters A through Y. These are shown in Table 33.2 for more convenient reference to Table 4.1 | Recommended Illuminance Targets should the designer wish to explore other criteria targets or if applications or tasks on a specific project are not readily correlated to the table citations.

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33.3.3.4 Gauge

The common gauge for determining illuminance target compliance is cited for each application. All gauges presume that point-by-point techniques are used for predictive calculations and presume that uniformity criteria are closely monitored. Where an average illuminance value over the area of coverage can satisfy target compliance, "Avg" is cited. In applications or tasks where a minimum or maximum target is necessary, the gauge for compliance is "Min" or "Max" respectively.

The designer may elect to use other methods to evaluate target compliance, such as criterion rating (CR) or coefficient of variation (C_v). See 4.12.4.5 Tasks at Uncertain Locations Over a Large Area.

In any event, once illuminance targets and uniformities are established, then any calculated deviation from them should be limited. Standard engineering allowance of ±10% might be acceptable for targets gauged as average unless contractual or code obligations demand otherwise. Minima and maxima must be achieved as intended.

Designs should be adjusted until predictions are within allowance for averages and meet minima and maxima. For additional information, see 4.12.4.1 Recommended Illuminances at Design Time, 4.12.5 Illuminance Ratios, 9.15.1.1 Average Illuminance, and 10.8 Assessing Computed Results.

33.3.4 Uniformity Targets

Illuminance uniformity targets work in conjunction with luminance uniformities and surface reflectances all of which must be addressed as part of the design to avoid visual discomfort, glare, and strain. Uniformity ratios are targets that define the widest recommended ranges. In many situations, uniformity ratio criteria are those between average values of an array of points and the minimum value in the same array of points. Uniformity targets apply to both horizontal and vertical illuminances over the area of coverage. Where horizontal uniformity criterion is different from vertical uniformity criterion, two ratios are reported with the first value for horizontal illuminance (E_h). In some situations, notably those with regard to exterior illuminances, two uniformity values are cited. The first value addresses the primary cited application or task. The parenthetical value references the parenthetical application or task, such as a curfew situation associated with nighttime outdoor lighting.

Generally the more important speed and accuracy and the more demanding the visual task, the tighter the ratio. Ratios in many residential applications are relatively broad reflecting the greater diversity in illuminances that are tolerated, even enjoyed, in a residential setting.

33.3.4.1 Maximum-to-average

This is the recommended ratio of maximum illuminance to the average illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations sensitive to even a relatively small degree of overlighting.

33.3.4.2 Average-to-minimum

This is the recommended ratio of average illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where illuminance too far below average conditions is noticeable and detrimental to task performance or inconsistent with normal expectations.

33.3.4.3 Maximum-to-minimum

This is the recommended ratio of maximum illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where too much variation in illuminance is considered undesirable and untenable from a performance or safety perspective.

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33.3.5 Daylighting Advancement

Generally, design strategies should embrace any combination of daylighting and electric lighting to achieve target values during daylight hours. The preference is for daylighting to provide all or most of the recommended illuminance presuming that all aspects of daylighting are properly addressed. A sunburst icon depicts those applications and tasks where daylighting is considered a strategic candidate. Where users are willing to cede to automation, photocells and stepped-dimming or continuous dimming can be used to reduce or eliminate electric lighting during daylight hours. See 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Even for those applications where daylighting is not traditionally a strategic candidate, it may be determined that very careful and coordinated design will offer great sustainability opportunities along with positive influences associated with daylight and views.

33.3.6 Veiling Reflections

Tasks with specular components, like some televisions or computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper or, worse, both, are prone to veiling reflections. The likelihood of particular applications and tasks predisposed to veiling reflections is indicated by a "reflected light" icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood. Veiling reflections are minimized by controlling the overall amount and direction of light with respect to the task locations and orientations. Alternatively, tasks sensitive to veiling reflections can be screened or isolated. Effective strategies include employing indirect soft, diffuse electric lighting or direct electric lighting with multiple low-output luminaires, or positioning tasks and luminaires and luminance patterns to avoid harsh reflections from tasks. Addressing luminance recommendations (see Table 12.4 | Default Luminance and Luminaire Intensity Recommendations for VDT Applications) minimizes veiling reflections. Changing the task will reduce or eliminate veiling reflections, such as use of CSA/ISO Type I or II computer screens and matte paper versus their specular counterparts.

IESH/10e CSA/ISO

> 12.5 Task Factors
- for information on CSA/ISO computer screen qualities

33.3.7 Defining Areas of Coverage

In addition to establishing planes of task orientation, the areas of coverage to which targets apply must be determined. Typical areas of task illuminance coverage are identified here, but these may not be appropriate to specific project situations. One area of coverage is "task proper or task area." Here, the illuminance criteria are applied to the task itself or to a relatively small area to which the task is confined. See 12.5.5.1 Tasks and Applications and Figure 12.22 | Task Coverage Example. In some situations, such as accenting, the "task" area may consist of the entire wall when "feature wall" or "perimeter" accenting is desired. It is important to remember that illuminance is additive, that is, task illuminance can be achieved with some combination of ambient lighting, task lighting, and/or accent lighting, providing that the total illuminance on the task proper or task area meets the illuminance criteria outlined in Table 33.2.

Another area of coverage is "room or designated area." In this situation, illuminance criteria are applied to the room or an area of fairly substantive size representing the zone in which the applications and tasks are expected to occur. The designated area is typically established by the furniture layout, for example, or might be established by the design team or homeowner. The area-of-coverage citations in Table 33.2 are based on traditional notions.

An assessment and determination must be made on which area of coverage best satisfies the lighting goals on a particular project.

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33.4 Designing

Information provided here is specific to residential dwelling units and should be used as part of the design and documentation processes outlined in Chapters 12, 15, and 20. For outdoor applications, lamps and ballasts, transformers, and drivers must be selected for ambient temperature conditions, some of which are extremely hot and others extremely cold. See 22 | LIGHTING FOR COMMON APPLICATIONS and 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY for additional information on respective aspects, particularly as it relates to common areas in residential complexes.

Unlike most other application types, a residence is usually inhabited by a small number of occupants. One or two of these occupants, the homeowner, is typically in charge of voicing needs and desires of the family and of making decisions. Design must accommodate these very specific needs and desires.

Programming should include personal lifestyle information if lighting is to be successful. Which occupants will use which rooms exclusively, mostly, seldom, or collectively may help define or refine tasks and visual age of the user or users. An appreciation of homeowner preferences on color, light levels, brightnesses, manual and automated technologies, and style and design is a must. An understanding of homeowner priorities such as initial and operating costs, leadtime, comfort, sustainability, and project life cycle is also necessary. Details on living range from entertainment needs to how much time and what times are spent at home. Lighting can only be appropriately tailored to an individual's or family's lifestyle where lifestyle detail has been investigated.

Also unlike most other applications, some homeowners have a penchant for leading style or technology movements. Opportunities may exist for unique, even untried techniques, to be implemented. These include siting and building configuration and orientation to optimize daylight and introduction of novel power generation and distribution systems for lighting which may be too exotic or costly for larger-scale commercial applications.

Addressing all code requirements is a must. Energy efficient and sustainable practices are an integral part of all IES recommendations. Key design tenets include, but are not limited to:

- designing for the satisfaction of the observers intended to use the project
- using daylighting that meets luminance and illuminance criteria
- using highest-efficacy lamps that meet color, optical and electrical control, and output criteria
- using highest-efficiency luminaires that meet aesthetic and luminance criteria
- using accenting to provide luminance balancing or improve brightness perceptions where necessary
- using controls liberally, preferably automated varieties such as presets, occupancy and vacancy sensors, astronomical time clocks, and photocells
- establishing IES-recommended illuminance criteria to meet programmed tasks
- establishing layouts that just meet IES-recommended illuminance criteria
- addressing outdoor environmental needs
- using calculations, photometrically-realistic renderings, and operational samples and mockups to prove concepts
- documenting all code-, energy-, sustainability-, and IES-criteria compliance
- documenting criteria and design deviations and rationale and subsequent disposition by team, client, or AHJ
- documenting clearly the layouts, controls, and luminaire and lamp selections

Designing for the satisfaction of the observers is the paramount design tenet and must be kept in perspective during all aspects of design. If the observers' expectations are not fulfilled, then how much energy could be saved is moot, as is how many fewer earth

IESH/10e Economics Resources

> 15.3.3 Budgets
  - for more on budgets and value engineering

> 18 | ECONOMICS
  - for more on estimating costs
  - for more on life cycle costs
  - for more on paybacks and rates of return

IESH/10e Energy Efficiency Resources

> 17.2 New Construction
  - for more on designing for daylighting
  - for more on electric lighting equipment
  - for more on lighting controls

> 17.4 Lighting Codes, Regulations and Standards
  - for more on application standards
  - for more on equipment regulations

IESH/10e Lighting Exteriors Resources

> 12.5.5.6 Nighttime Outdoor Illuminances
  - for more on lamp efficacies under mesopic adaptation

> 26 | LIGHTING FOR EXTERIORS
  - for more on criteria

IESH/10e Sustainability Resources

> 13.11 Sustainability
  - for more on lamps

> 19 | SUSTAINABILITY
  - for more on controls
  - for more on earth resources
  - for more on energy
  - for more on life cycle analyses
  - for more on lighting design
  - for more on recycling

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resources were spared, as is how much the whole affair cost or how much value engineering saved or the photogenic qualities of the project. See sidebar references for additional guidance on the key tenets. The design effort must be undertaken with coordinated and realistic expectations by all involved on initial and life cycle costs. Budgeting should include designer input and dialogue with the team and client at project commencement and design milestones. In other words, and paraphrasing Thomas Edison, genius is, indeed, just 1% inspiration and 99% perspiration.

33.5 References

[1] [DOE] US Department of Energy, Energy Information Administration. 2010. U.S. Residential Electricity Consumption by End Use [Internet]. DOE. [cited September 2010]. Available from: http://tonto.eia.doe.gov/ask/electricity_faqs.asp.

[2] Mark S. Rea, ed. 2000. The IESNA lighting handbook: Reference and application. 9th Edition. New York: IESNA. Ch 18.

[3] [IESNA] Illuminating Engineering Society of North America. Design criteria for lighting interior living spaces ANSI/IESNA RP-11-95. New York: IESNA. 59 p.

[4] [IESNA] Illuminating Engineering Society of North America. Lighting and the visual environment for senior living ANSI/IESNA RP-28-07. New York: IESNA. pp. 8-10.

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34 | LIGHTING FOR RETAIL

I take the family shopping round. The markets of the world.
Edgar A. Guest, 20th Century Poet

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34.1 Project Type and Status. . . . 34.2
34.2 Application Types 34.2
34.3 Illuminance Criteria 34.43
34.4 Designing. 34.47
34.5 References 34.48

Shopping may be a past time for some, but a necessity for many. From food to clothing to electronics to paper and pens to vehicles and their servicing and fueling many purchases are an integral, if not essential, part of people's lives. Most shopping occurs in traditional brick-and-mortar settings where the shoppers' experiences of store, mall, and center affects brand perceptions and loyalty. Exciting store design has been cited as a contributor to brand [1]. Lighting influences, if not creates excitement. This does not diminish lighting's other long-standing retail attributes of rendering goods for visual attraction and inspection. Just like most other applications, the real bottom line should not be in securing quick and cheap commodity lighting at the time of project construction for what amounts to a fleeting gain of perhaps a tenth of a percentage point, if that, in construction costs. Rather, the long-term value is leveraging lighting for its contribution to branding and to overtly or subliminally sell merchandise.

Even online or e-commerce shopping demands attention to lighting. In these situations, retailers rely on employees in stocked warehouses and distribution centers to make accurate selections, careful packing, and timely shipments.

Electric lighting accounts for about 42% of the electricity used in retailing [2]. Figure 34.1 shows the breakdown of electricity use in retail facilities. Proper use of daylight and efficient electric light is unquestionable. What follows is a discussion of the key aspects affecting lighting for people in retail facilities: project status; space types; activities; application-specific design goals, and illuminance criteria.

Comprehensive design efforts must also rely on material in 12 | COMPONENTS OF LIGHTING DESIGN, 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS, 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. The designer should have a thorough understanding of the design tenets outlined in those chapters, must identify those deemed appropriate and develop lighting goals and strategies accordingly. This chapter primarily addresses specifics related to lighting for retail which should influence luminaire optical selections, lamping, and final layouts based on previously developed thought-starters (see 15.2 A Lighting Scheme). Use of the material in this chapter to the exclusion of material in Chapters 12, 13, 14, and 15 will likely lead to unsatisfactory results. Previous and current IES related documents serve as archival and reference sources [3] [4].

Deliberate thought should be given to details beyond the recommended illuminances in this chapter. For example, in a department store setting where daylighting is introduced, the control system to operate electric lighting and any shade treatments could be used for other purposes. The control system could also be used to vary the illuminances on feature displays over time, thereby providing a dynamic visual rotation of feature displays. This is one means of contributing to an exciting store design. These and other techniques can only come from contemplation of the design problem while addressing design priorities outlined in the project's program. Table 34.1 offers a checklist of IES lighting topics and criteria. The design team is responsible for determining and addressing indoor and outdoor lighting and energy criteria set forth by authorities having jurisdiction (AHJ) which may be different from and supersede IES criteria. See also 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

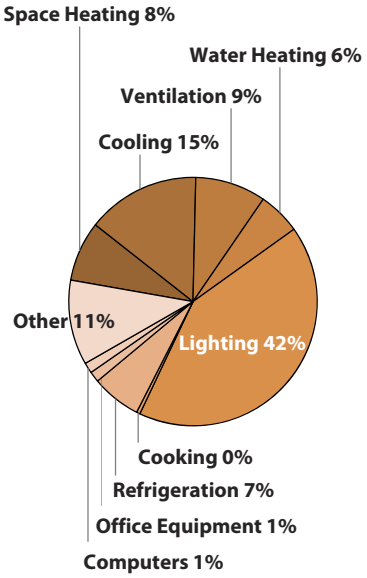


Figure 34.1 | Electricity Use of Retail Facilities
Based on 2003 data from the US DOE's Energy Information Administration, lighting accounts for 42% of electricity use in retail buildings (electricity use for Cooking rounds to 0%). Retail buildings themselves account for about 21% of electricity use by all commercial and institutional buildings.

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Table 34.1 | Retail Lighting Checklist

Topics
✔ **Criteria and Design Resources**
Accenting
15.1.1.3 Accent Lighting
Table 12.2 | Subjective Impressions
Table 15.2 | Accent Illuminance Ratios
Table 22.2 | Common Applications Illuminance Recommendations
Appearance
12.2 Spatial Factors
Color
12.5.6 Color Considerations
Controls
16 | LIGHTING CONTROLS
Daylighting
14 | DESIGNING DAYLIGHTING
Electric Lighting
15 | DESIGNING ELECTRIC LIGHTING
Flicker
4.6 Flicker and Temporal Contrast Sensitivity
Glare
4.10.1 Discomfort Glare
4.10.2 Disability Glare
Illuminance
This Chapter: Table 34.2
12.5.5.1 Applications and Tasks
Table 12.6 | Default Illuminance Ratio Recommendations
Figure 12.22 | Task Coverage Example
Light Distribution
12.3.2 Subjective Impressions
Luminances
12.5.2 Luminance
Table 12.5 | Default Luminance Ratio Recommendations
Maintenance
15.4.4 Installation and Maintenance
Outdoor Sensitivities
26 | LIGHTING FOR EXTERIORS
Systems Integration
12.6 Systems Factors
Veiling Reflections
This Chapter: Section 34.3.6
12.5.4 Veiling Reflections
Visual Tasks
This Chapter: Section 34.2
This Chapter: Table 34.2
Table 11.2 | Programming: Inventory Scope and Specific Examples
12.5.1 Visual Tasks
Table 12.3 | Sample Visual Task Survey

34.1 Project Type and Status

Before any design work, an understanding of the project type and scope is necessary. New, renovation, and restoration projects each offer varying opportunities. See 11.2 Planning, 11.3.1 Pre-design, and 11.3.2 Schematic Design. A clear understanding of the project type and scope will help establish the extent to which daylighting can address most or many or some of the lighting goals. At every opportunity the lighting designer should consider daylighting as a light source. A host of lighting design factors is identified in 12 | COMPONENTS OF LIGHTING DESIGN. Daylight demands determined attention to address glare and balance visible and thermal energy. Since many retail establishments operate during dark hours, electric lighting and controls must be well-integrated.

34.2 Application Types

To develop lighting solutions that meet quality, quantity, and operational criteria, an inventory is made of the retail space types under consideration and the anticipated occupants, functions, and tasks (see Table 11.2 | Programming: Inventory Scope and Specific Examples and Table 12.3 | Sample Visual Task Survey). Otherwise, lighting cannot be best targeted to the users, their expectations, functions and tasks.

Space type definitions are required early in the project design in order to track design efforts that include inventorying the project knowns, anticipated functions, and tasks and calculating lighting, power, and energy compliance. Room and store department names, from which functions can be deduced, and numbers for tracking should be clearly marked on architectural backgrounds. The applications and tasks cited in Table 34.2 | Retail Illuminance Recommendations should be reviewed against the project knowns and correlated with the named space types and functions to establish recommended illuminance criteria. Seek clarification with the client where discrepancies occur between programming information, the list of room and department names, and the available application and task citations in Table 34.2.

The following sections are keyed to the major application and task headings in Table 34.2. These discussions, those identified in Table 34.1, and the material in Table 34.2 offer comprehensive qualitative and quantitative criteria.

34.2.1 Accenting

Accenting affects people's brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. Default accent lighting criteria are discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. Also see 15.1.1.3 Accent Lighting.

34.2.2 Administration

Lighting for administrative areas is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. The architectural scheme and even task specifics may vary based on the associated type of retail facility.

34.2.3 Atria and Courtyards

Lighting for atria and courtyards is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. The design for the store, mall, or retail center may include one or several multi-story covered or open daylighted spaces considered atria or courtyards. The designer must coordinate with the team and the client to determine if programmed activities and style are best served by illuminance criteria for malls or atria and courtyards. Criteria for live plants are outlined in 22 | LIGHTING FOR COMMON APPLICATIONS.

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34.2.4 Building Entries

Lighting for building entries is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. For building entries, variables affecting recommended illuminance criteria include anticipated levels of activity and the nighttime outdoor lighting zone. Nighttime activity levels may vary by type of retail facility, such as automotive dealership versus a mall versus shopping district, by specific schedules, such as which night of the week, and by other events or activities, such as sports. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions. All of this may demand a control system capable of addressing various settings on various evenings through manual intervention, automated time clock, and photocell functions.

The nighttime outdoor lighting zone within which the facility is located establishes the categories of illuminance for outdoor tasks. Nighttime outdoor lighting zones vary by local ordinance, sustainability guides, or the team's own definition of place. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions.

Business- and after-hours security needs, such as on-site or remote monitoring or recording, may require specific luminaire placement and specific illuminances coordinated with security cameras, and, after hours, may require that some luminaires at building entries remain energized through the night or placed on motion sensors or interconnected with camera operations. Control zones and time clock functions must be designed accordingly. Where remote monitoring is done with infrared cameras, lighting may be unnecessary.

Entry lighting must transition between the indoor and outdoor lighting conditions. Entries should be inviting and reflect the indoor setting. Lamp CCTs and CRIs should be based on indoor lamping color criteria rather than on parking or roadway selections.

34.2.5 Centers, Outdoor

Outdoor shopping centers, districts, and malls served by mass transit and where vehicles are restricted to distant parking and service areas should be designed strictly for pedestrian shopping and social experiences. Vertical illuminances are relatively low and uniformity ratios are relatively broad. Attention to lighting of show windows, store fronts, art features, sidewalk cafes, and beverage oases is important. Curbs, ramps, and stairs must be addressed. If curfew occurs after business hours, lighting should be extinguished except as needed for security. Security lighting can be motion-sensor controlled for improved sustainability and detection and deterrence. If curfew occurs prior to businesses closing, lighting should be controlled to allow a set-back to reduce illuminances and broaden uniformities as outlined in Table 34.2. Regardless, all non-commercial accent lighting on plazas, promenades, and town squares, such as that for sculpture and fountains, should be extinguished at curfew. A control system of photocells and astronomical time clock functions can automate much of the lighting. For special events, manual or programmed overrides are appropriate.

As illustrated in Figure 34.2, one approach to lighting large promenades or other pedestrian areas is to transition lighting from peripheral brighter zones (store fronts and their immediately-adjacent pavement) to darker central zones (center of the promenades between opposing store fronts). Vertical and horizontal illuminances drop toward the central zones while meeting uniformity ratios and overall averages. This approach better enables shoppers to adapt as they move between store interiors and central areas of promenades. Finally, a darker central promenade establishes a backdrop for better contrast of accented features such as sculpture or fountains.

The designer must work with team members and the client to define an appropriate level of activity. Although seasonal activity levels might be higher than those expected at other times, this should not necessarily establish the norm for year-round operations. Additionally, seasonal activity is itself identified with seasonal decorations, many with lighting. Overlighting the pedestrian areas will diminish the visual effects of the lighted decorations.



Figure 34.2 | Shopping Promenades
Open air shopping districts and centers offer promenades, plazas and town squares exclusive to shoppers on foot. Lighting is not burdened with interaction between pedestrians and vehicles and should be designed to enhance the retail and social experiences. Lighting of show windows and store fronts is introduced primarily for attention. Decorative lighting effects are introduced secondarily for visual interest. All of these lighting techniques also address subjective impressions of preference and relaxation and mix to create an exciting experience.
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Table 34.2 | Retail Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
ACCENTING	Accenting influences observers' overall brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. See 22 | LIGHTING FOR COMMON APPLICATIONS/ACCENTING for default accenting criteria for consideration in any application.											
ADMINISTRATION	See 22 | LIGHTING FOR COMMON APPLICATIONS											
ATRIA and COURTYARDS	See 22 | LIGHTING FOR COMMON APPLICATIONS											
BUILDING ENTRIES	See 22 | LIGHTING FOR COMMON APPLICATIONS											
CENTERS, OUTDOOR	Vehicular traffic restricted. Open-air malls or centers dedicated to shoppers. See 26 | LIGHTING FOR EXTERIORS for vehicular-adjacent pedestrian walkways..											
• Accents	Extinguish at curfew											
• Art	On artwork plane (typically vertical)						see Table 15.2 (typically "Moderate" or "Soft")					
• Feature	On wall plane or trees						see Table 15.2 (typically "Moderate")					
• Performance Areas	E_h @pavement; E_v @5' AFG	see Table 15.2 (typically "Moderate")					see Table 15.2 (typically "Strong" to "Moderate")					
• Perimeter	On wall plane or trees						see Table 15.2 (typically "Soft")					
• Significant Focal Point	On focal point plane (typically vertical)						see Table 15.2 (typically "Strong" to "Moderate")					
• Plazas and Town Squares	E_h @pavement; E_v @5' AFG in at least the two primary directions of circulation. Coordinate lighting with security cameras.											
• High Activity[i]	Plazas typified by periods of high shopper volume											
• LZ4[j]		E	4	8	16	Avg	C	2	4	8	Avg	
• LZ3[j] (and LZ4 curfew)		D	3	6	12	Avg	B	1	2	4	Avg	
• LZ2[j] (and LZ3 curfew)		C	2	4	8	Avg	B	1	2	4	Avg	
• LZ1[j] (and LZ2 curfew)		B	1	2	4	Avg	A	0.5	1	2	Avg	
• LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	A	0.5	1	2	Avg	-	0	0	0		
• Medium Activity[i]	Plazas typified by periods of medium shopper volume											
• LZ4[j]		D	3	6	12	Avg	B	1	2	4	Avg	
• LZ3[j] (and LZ4 curfew)		C	2	4	8	Avg	B	1	2	4	Avg	
• LZ2[j] (and LZ3 curfew)		B	1	2	4	Avg	A	0.5	1	2	Avg	
• LZ1[j] (and LZ2 curfew)		A	0.5	1	2	Avg	-	0	0	0		
• LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	A	0.5	1	2	Avg	-	0	0	0		
• Low Activity[i]	Plazas typified by periods of low shopper volume											
• LZ4[j]		C	2	4	8	Avg	B	1	2	4	Avg	
• LZ3[j] (and LZ4 curfew)		B	1	2	4	Avg	A	0.5	1	2	Avg	
• LZ2[j] (and LZ3 curfew)		A	0.5	1	2	Avg	-	0	0	0		
• LZ1[j] (and LZ2 curfew)		A	0.5	1	2	Avg	-	0	0	0		
• LZ0[j] (and LZ1 curfew)		-	0	0	0		-	0	0	0		
• Ramps, Stairs, and Steps	E_h @treads/landings; E_v @5' AFG in at least the two primary directions of circulation. Coordinate lighting with security cameras. Lighting should address the area of the ramps, steps, and landings. Alternatively, draw attention to the elevation changes with contrast lighting.											
• High Activity[i]	Ramps, stairs, and steps typified by periods of high shopper volume											
• LZ4[j]		F	5	10	20	Avg	D	3	6	12	Avg	
• LZ3[j] (and LZ4 curfew)		E	4	8	16	Avg	C	2	4	8	Avg	
• LZ2[j] (and LZ3 curfew)		D	3	6	12	Avg	B	1	2	4	Avg	
• LZ1[j] (and LZ2 curfew)		C	2	4	8	Avg	B	1	2	4	Avg	
• LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	B	1	2	4	Avg	A	0.5	1	2	Avg	

Table 34.2 | Retail Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
4:1	5:1					
4:1	5:1 (10:1)					
4:1	5:1 (10:1)					
4:1	5:1 (10:1)					
4:1						
4:1	5:1					
4:1	5:1 (10:1)					
4:1	5:1 (10:1)					
4:1	5:1 (10:1)					
4:1						
4:1	5:1					
4:1	5:1 (10:1)					
4:1	5:1 (10:1)					
4:1	5:1 (10:1)					
4:1	5:1					
4:1	5:1 (10:1)					
4:1	5:1 (10:1)					
4:1	5:1 (10:1)					
4:1						

Notes for Table 34.2

The table column headings are discussed in detail in 34.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 34.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 34.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 34.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some general retail sales, the typical area of coverage is "Room or Designated Area" at the planar elevations noted. For applications where task position is known, such as fixed displays or specific gondola layouts, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area" and which may involve different planar elevations that the designer must accommodate.

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Table 34.2 | Retail Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
CENTERS, OUTDOOR	(Ramps, Stairs, and Steps continued)										
• **Medium Activity**[i]	Ramps, stairs, and steps typified by periods of medium shopper volume										
• **LZ4**[j]		E	4	8	16	Avg	C	2	4	8	Avg
• **LZ3**[j] **(and LZ4 curfew)**		D	3	6	12	Avg	B	1	2	4	Avg
• **LZ2**[j] **(and LZ3 curfew)**		C	2	4	8	Avg	B	1	2	4	Avg
• **LZ1**[j] **(and LZ2 curfew)**		B	1	2	4	Avg	A	0.5	1	2	Avg
• **LZ0**[j] **(and LZ1 curfew)**	Control with motion sensors[k]	A	0.5	1	2	Avg	-	0	0	0	
• **Low Activity**[i]	Ramps, stairs, and steps typified by periods of low shopper volume										
• **LZ4**[j]		D	3	6	12	Avg	B	1	2	4	Avg
• **LZ3**[j] **(and LZ4 curfew)**		C	2	4	8	Avg	B	1	2	4	Avg
• **LZ2**[j] **(and LZ3 curfew)**		B	1	2	4	Avg	A	0.5	1	2	Avg
• **LZ1**[j] **(and LZ2 curfew)**		A	0.5	1	2	Avg	A	0.5	1	2	Avg
• **LZ0**[j] **(and LZ1 curfew)**	Control with motion sensors[k]	A	0.5	1	2	Avg	-	0	0	0	
• **Shopping Promenades**	E_h @grade; E_v @5' AFG in at least the two primary directions of circulation. Coordinate lighting with security cameras.										
• **High Activity**[i]	Shopping promenades typified by periods of high shopper volume										
• **LZ4**[j]		F	5	10	20	Avg	D	3	6	12	Avg
• **LZ3**[j] **(and LZ4 curfew)**		E	4	8	16	Avg	C	2	4	8	Avg
• **LZ2**[j] **(and LZ3 curfew)**		D	3	6	12	Avg	B	1	2	4	Avg
• **LZ1**[j] **(and LZ2 curfew)**		C	2	4	8	Avg	B	1	2	4	Avg
• **LZ0**[j] **(and LZ1 curfew)**	Control with motion sensors[k]	B	1	2	4	Avg	A	0.5	1	2	Avg
• **Medium Activity**[i]	Shopping promenades typified by periods of medium shopper volume										
• **LZ4**[j]		E	4	8	16	Avg	C	2	4	8	Avg
• **LZ3**[j] **(and LZ4 curfew)**		D	3	6	12	Avg	B	1	2	4	Avg
• **LZ2**[j] **(and LZ3 curfew)**		C	2	4	8	Avg	B	1	2	4	Avg
• **LZ1**[j] **(and LZ2 curfew)**		B	1	2	4	Avg	A	0.5	1	2	Avg
• **LZ0**[j] **(and LZ1 curfew)**	Control with motion sensors[k]	A	0.5	1	2	Avg	-	0	0	0	
• **Low Activity**[i]	Shopping promenades typified by periods of low shopper volume										
• **LZ4**[j]		D	3	6	12	Avg	B	1	2	4	Avg
• **LZ3**[j] **(and LZ4 curfew)**		C	2	4	8	Avg	B	1	2	4	Avg
• **LZ2**[j] **(and LZ3 curfew)**		B	1	2	4	Avg	A	0.5	1	2	Avg
• **LZ1**[j] **(and LZ2 curfew)**		A	0.5	1	2	Avg	A	0.5	1	2	Avg
• **LZ0**[j] **(and LZ1 curfew)**	Control with motion sensors[k]	A	0.5	1	2	Avg	-	0	0	0	
FOOD SERVICE	See 22 | LIGHTING FOR COMMON APPLICATIONS										
IT	See 22 | LIGHTING FOR COMMON APPLICATIONS										

Table 34.2 | Retail Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f] [g] Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min	Task Proper or Task Area	Room or Designated Area
4:1	5:1			
4:1	5:1 (10:1)			
4:1	5:1 (10:1)			
4:1	5:1 (10:1)			
4:1				
4:1	5:1			
4:1	5:1 (10:1)			
4:1	5:1 (10:1)			
4:1	5:1 (10:1)			
4:1				
4:1	5:1			
4:1	5:1 (10:1)			
4:1	5:1 (10:1)			
4:1	5:1 (10:1)			
4:1				
4:1	5:1			
4:1	5:1 (10:1)			
4:1	5:1 (10:1)			
4:1	5:1 (10:1)			
4:1				
4:1	5:1			
4:1	5:1 (10:1)			
4:1	5:1 (10:1)			
4:1	5:1 (10:1)			
4:1				

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a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 34.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 34.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some general retail sales, the typical area of coverage is "Room or Designated Area" at the planar elevations noted. For applications where task position is known, such as fixed displays or specific gondola layouts, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area" and which may involve different planar elevations that the designer must accommodate.

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Table 34.2 | Retail Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
MALLS, INDOOR											
• Accenting	Accenting influences observers' overall brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding.										
• Art	On artwork plane (typically vertical). See 21 | LIGHTING FOR ART for preservation-worthy material.						see Table 15.2 (typically "Moderate" or "Soft")				
• Displays	On plane(s) of display	see Table 15.2 (typically "Moderate")					see Table 15.2 (typically "Moderate")				
• Feature Displays	On plane(s) of display	see Table 15.2 (typically "Dramatic")					see Table 15.2 (typically "Dramatic")				
• Feature Wall	On wall plane						see Table 15.2 (typically "Soft" or "Subtle")				
• Services	E_h @floor; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Concourses	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Directories	E_v @3'-5' AFF						P	150	300	600	Avg
• Entertainment Areas	See 24 | LIGHTING FOR EDUCATION/AUDITORIA/Performance										
• Food Courts	See 22 | LIGHTING FOR COMMON APPLICATIONS/FOOD SERVICE										
• Information Desks	E_h @3' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Retail Kiosks											
• Displays											
• Horizontal	E_h @3' AFF	P	150	300	600	Avg					
• Vertical	E_v @3'-5' AFF						P	150	300	600	Avg
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Transaction Counters	E_h @3' AFF	P	150	300	600	Avg					
• Service Corridors	E_h @floor; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
PARKING	See 26 | LIGHTING FOR EXTERIORS										
PEDESTRIAN WAYS	See 26 | LIGHTING FOR EXTERIORS										
RETAILING, INDOOR											
• Display Windows	See RETAILING, INDOOR/Show Windows										
• Feature Displays	E_h and E_v @respective relevant plane(s) on feature display										
• Dazzle	Apply strategically to ≤10% of display	10 times general E_h of adjacent retail area; may affect fading, bleaching, and shelf life				Max					
• Highlight	Apply strategically to ≤25% of display	5 times general E_h of adjacent retail area; may affect fading, bleaching, and shelf life				Max					
• Total Display	Apply to entire display	equal to general E_h of adjacent retail area				Avg					
• Fitting Rooms	Primary plane of interest is vertical oriented toward mirror.										
• Dressing Areas											
• Typical	E_h @floor; E_v @3'-5' AFF	P	150	300	600	Avg	P	150	300	600	Avg
• Upscale	E_h @floor; E_v @3'-5' AFF	P	150	300	600	Avg	R	250	500	1000	Avg
• Fitting Areas	E_h @floor; E_v @3'-5' AFF	P	150	300	600	Avg	R	250	500	1000	Avg

Table 34.2 | Retail Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	see 15.1.1.3					
	see 15.1.1.3					
	see 15.1.1.3					
	see 15.1.1.3					
	2:1					
1.2:1/1.5:1	1.2:1/1.5:1					
	see Table 12.6					
	see Table 12.6					
1.2:1	1.2:1					
1.5:1	1.5:1					
1.2:1/1.5:1	1.2:1/1.5:1					
	2:1					
1.2:1/1.5:1	1.2:1/1.5:1					
2:1						
2:1						
1.2:1	1.2:1					
1.2:1/1.5:1	1.2:1/1.5:1					
1.2:1/1.5:1	1.2:1/1.5:1					
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e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

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k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some general retail sales, the typical area of coverage is "Room or Designated Area" at the planar elevations noted. For applications where task position is known, such as fixed displays or specific gondola layouts, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area" and which may involve different planar elevations that the designer must accommodate.

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Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
RETAILING, INDOOR	(continued)										
• Retail by Classification	Classified by type of store or department. Coordinate lighting with security cameras.										
• Automotive Sales/Service											
◦ Circulation	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
◦ Feature displays	See RETAILING, INDOOR/Feature Displays										
◦ General retail[l]	E_h @2' 6" AFF; E_v @3'-5' AFF	R	250	500	1000	Avg	M	50	100	200	Avg
◦ Perimeter[l]	E_v @5' AFF						P	150	300	600	Avg
◦ Service											
▪ General	E_h @floor; E_v @5' AFF	R	250	500	1000	Avg	P	150	300	600	Avg
▪ Provisional	Provide for portable worklights as needed										
▪ Task at bench and hood	E_h and E_v @3' 6" AFF	T	500	1000	2000	Avg	R	250	500	1000	Avg
▪ Work-order write-up	E_h and E_v @3' 6" AFF	Q	200	400	800	Avg	N	75	150	300	Avg
• Department Store											
◦ Circulation	E_h @floor; E_v @5' AFF	N	75	150	300	Avg	K	25	50	100	Avg
◦ Feature displays	See RETAILING, INDOOR/Feature Displays										
◦ General retail[l]	E_h @2' 6" AFF; E_v @3'-5' AFF	Q	200	400	800	Avg	N	75	150	300	Avg
◦ Perimeter[l]	E_v @5' AFF						S	375	750	1500	Avg
• Designer ShopBoutique											
◦ Circulation	E_h @floor; E_v @5' AFF	L	37.5	75	150	Avg	H	10	20	40	Avg
◦ Feature displays	See RETAILING, INDOOR/Feature Displays										
◦ General retail[l]	E_h @2' 6" AFF; E_v @3'-5' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
◦ Perimeter[l]	E_v @5' AFF						O	100	200	400	Avg
• Discount											
◦ Circulation	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
◦ Feature displays	See RETAILING, INDOOR/Feature Displays										
◦ General retail[l]	E_h @2' 6" AFF; E_v @3'-5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
◦ Perimeter[l]	E_v @5' AFF						R	250	500	1000	Avg
• Drug and Convenience											
◦ Circulation	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
◦ Feature displays	See RETAILING, INDOOR/Feature Displays										
◦ General retail[l]	E_h @2' 6" AFF; E_v @3'-5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
◦ Perimeter[l]	E_v @5' AFF						R	250	500	1000	Avg
• Fine/Precious Jewelry											
◦ Circulation	E_h @floor; E_v @5' AFF	N	75	150	300	Avg	K	25	50	100	Avg
◦ Feature displays	See RETAILING, INDOOR/Feature Displays										
◦ General retail[l]	E_h @2' 6" AFF; E_v @3'-5' AFF	Q	200	400	800	Avg	N	75	150	300	Avg
◦ Perimeter[l]	E_v @5' AFF						Q	200	400	800	Avg
• Furniture											
◦ Circulation	E_h @floor; E_v @5' AFF	L	37.5	75	150	Avg	H	10	20	40	Avg
◦ Feature displays	See RETAILING, INDOOR/Feature Displays										
◦ General retail[l]	E_h @2' 6" AFF; E_v @3'-5' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
◦ Perimeter[l]	E_v @5' AFF						O	100	200	400	Avg

Table 34.2 | Retail Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
1.2:1	1.2:1		☀		■	
3:1/6:1	3:1/6:1		☀		■	■
4:1	4:1		☀		■	■
1.5:1	1.5:1		☀			■
1.5:1	1.5:1		☀		■	
1.5:1	1.5:1		☀		■	
1.2:1	1.2:1		☀		■	
1.5:1/3:1	1.5:1/3:1		☀		■	■
2:1	2:1		☀		■	■
1.2:1	1.2:1		☀		■	
3:1/6:1	3:1/6:1		☀		■	■
4:1	4:1		☀		■	■
1.2:1	1.2:1		☀		■	
1.5:1/3:1	1.5:1/3:1		☀		■	■
2:1	2:1		☀		■	■
1.2:1	1.2:1		☀		■	
1.5:1/3:1	1.5:1/3:1		☀		■	■
2:1	2:1		☀		■	■
1.2:1	1.2:1		☀		■	
				◆		
3:1/6:1	3:1/6:1		☀	◆	■	■
4:1	4:1		☀		■	■
1.2:1	1.2:1		☀		■	
3:1/6:1	3:1/6:1		☀		■	■
4:1	4:1		☀		■	■

Notes for Table 34.2

The table column headings are discussed in detail in 34.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 34.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 34.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 34.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◆ signals high likelihood; gray and white ◆ signals moderate likelihood; pale gray and white ◆ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some general retail sales, the typical area of coverage is "Room or Designated Area" at the planar elevations noted. For applications where task position is known, such as fixed displays or specific gondola layouts, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area" and which may involve different planar elevations that the designer must accommodate.

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Table 34.2 | Retail Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
RETAILING, INDOOR	(Retail by Classification continued)										
• Grocery/Supermarket											
• Circulation	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
• Feature displays	See RETAILING, INDOOR/Feature Displays										
• General retail[l]	E_h @2' 6" AFF; E_v @3'-5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Perimeter[l]	E_v @5' AFF						R	250	500	1000	Avg
• Home/Bath Bedding											
• Circulation	E_h @floor; E_v @5' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• Feature displays	See RETAILING, INDOOR/Feature Displays										
• General retail[l]	E_h @2' 6" AFF; E_v @3'-5' AFF	Q	200	400	800	Avg	N	75	150	300	Avg
• Perimeter[l]	E_v @5' AFF						Q	200	400	800	Avg
• Mass Merchant											
• Circulation	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
• Feature displays	See RETAILING, INDOOR/Feature Displays										
• General retail[l]	E_h @2' 6" AFF; E_v @3'-5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Perimeter[l]	E_v @5' AFF						R	250	500	1000	Avg
• Service Station											
• Service	See RETAILING, INDOOR/Retail by Classification/Automotive Sales/Service/Service										
• Store	Select relevant retailing category from RETAILING, INDOOR/Retail by Classification										
• Specialty Retailer											
• Circulation	E_h @floor; E_v @5' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• Feature displays	See RETAILING, INDOOR/Feature Displays										
• General retail[l]	E_h @2' 6" AFF; E_v @3'-5' AFF	Q	200	400	800	Avg	N	75	150	300	Avg
• Perimeter[l]	E_v @5' AFF						S	375	750	1500	Avg
• Upscale Crystal, China, Silver											
• Circulation	E_h @floor; E_v @5' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• Feature displays	See RETAILING, INDOOR/Feature Displays										
• General retail[l]	E_h @2' 6" AFF; E_v @3'-5' AFF	Q	200	400	800	Avg	N	75	150	300	Avg
• Perimeter[l]	E_v @5' AFF						Q	200	400	800	Avg
• Upscale Department											
• Circulation	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Feature displays	See RETAILING, INDOOR/Feature Displays										
• General retail[l]	E_h @2' 6" AFF; E_v @3'-5' AFF	P	150	300	600	Avg	O	100	200	400	Avg
• Perimeter[l]	E_v @5' AFF						R	250	500	1000	Avg
• Upscale Specialty											
• Circulation	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Feature displays	See RETAILING, INDOOR/Feature Displays										
• General retail[l]	E_h @2' 6" AFF; E_v @3'-5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Perimeter[l]	E_v @5' AFF						P	150	300	600	Avg
• Warehouse Store											
• Circulation	E_h @floor; E_v @5' AFF	O	100	200	400	Avg	L	37.5	75	150	Avg
• Feature displays	See RETAILING, INDOOR/Feature Displays										
• General retail[l]	E_h @2' 6" AFF; E_v @3'-5' AFF	R	250	500	1000	Avg	O	100	200	400	Avg
• Perimeter[l]	E_v @5' AFF						R	250	500	1000	Avg

Table 34.2 | Retail Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
1.2:1	1.2:1					
1.5:1/3:1	1.5:1/3:1					
2:1	2:1					
1.2:1	1.2:1					
3:1/6:1	3:1/6:1					
4:1	4:1					
1.2:1	1.2:1					
1.5:1/3:1	1.5:1/3:1					
2:1	2:1					
1.2:1	1.2:1					
3:1/6:1	3:1/6:1					
4:1	4:1					
1.2:1	1.2:1					
3:1/6:1	3:1/6:1					
4:1	4:1					
1.2:1	1.2:1					
3:1/6:1	3:1/6:1					
4:1	4:1					
1.2:1	1.2:1					
3:1/6:1	3:1/6:1					
4:1	4:1					
1.2:1	1.2:1					
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2:1	2:1					

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d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

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j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some general retail sales, the typical area of coverage is "Room or Designated Area" at the planar elevations noted. For applications where task position is known, such as fixed displays or specific gondola layouts, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area" and which may involve different planar elevations that the designer must accommodate.

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Table 34.2 | Retail Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
RETAILING, INDOOR	(continued)										
• Sales Transaction Areas	E_h @3' 6" AFF; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Show Windows	E_v on relevant areas of displays in windows										
• Exterior Facing Windows											
• Day											
◦ Dazzle	Apply strategically to ≤10% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life						Y	5000	10000	20000	Max
◦ Highlight	Apply strategically to ≤25% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life						X	2500	5000	10000	Max
◦ Total display	Apply to total display or displays visible from primary viewing direction						T	500	1000	2000	Avg
• Night											
◦ High Activity[i]	Show windows in areas typified by high nighttime pedestrian or vehicular activity										
LZ4[j]											
Dazzle	Apply strategically to ≤10% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life						W	1500	3000	6000	Max
Highlight	Apply strategically to ≤25% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life						U	750	1500	3000	Max
Total display	Apply to total display or displays visible from primary viewing direction						P	150	300	600	Avg
LZ3[j] (and LZ4 curfew)											
Dazzle	Apply strategically to ≤10% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life						V	1000	2000	4000	Max
Highlight	Apply strategically to ≤25% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life						T	500	1000	2000	Max
Total display	Apply to total display or displays visible from primary viewing direction						O	100	200	400	Avg
LZ2[j] (and LZ3 curfew)											
Dazzle	Apply strategically to ≤10% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life						T	500	1000	2000	Max
Highlight	Apply strategically to ≤25% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life						R	250	500	1000	Max
Total display	Apply to total display or displays visible from primary viewing direction						M	50	100	200	Avg
LZ1[j] (and LZ2 curfew)											
Dazzle	Apply strategically to ≤10% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life						R	250	500	1000	Max
Highlight	Apply strategically to ≤25% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life						P	150	300	600	Max
Total display	Apply to total display or displays visible from primary viewing direction						K	25	50	100	Avg
LZ0[j] (and LZ1 curfew)		-	0	0	0		-	0	0	0	

Table 34.2 | Retail Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
1.2:1/1.5:1	1.2:1/1.5:1		☀		■	
			☀		■	
			☀		■	
5:1			☀		■	
			☀		■	
			☀		■	
5:1			☀		■	
			☀		■	
			☀		■	
5:1			☀		■	
			☀		■	
			☀		■	
5:1			☀		■	

Notes for Table 34.2

The table column headings are discussed in detail in 34.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 34.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 34.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 34.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◥ signals high likelihood; gray and white ◥ signals moderate likelihood; pale gray and white ◥ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some general retail sales, the typical area of coverage is "Room or Designated Area" at the planar elevations noted. For applications where task position is known, such as fixed displays or specific gondola layouts, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area" and which may involve different planar elevations that the designer must accommodate.

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Table 34.2 | Retail Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d] Horizontal (E_h) Targets — Visual Ages of Observers (years) where **at least half** are <25	25-65	>65	Category	Vertical (E_v) Targets — Visual Ages of Observers (years) where **at least half** are <25	25-65	>65	Gauge
RETAILING, INDOOR	(Show Windows continued)								
° **Medium Activity**[i]	Show windows in areas typified by medium nighttime pedestrian or vehicular activity								
LZ4[j]									
Dazzle	Apply strategically to ≤10% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life				V	1000	2000	4000	Max
Highlight	Apply strategically to ≤25% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life				T	500	1000	2000	Max
Total display	Apply to total display or displays visible from primary viewing direction				O	100	200	400	Avg
LZ3[j] **(and LZ4 curfew)**									
Dazzle	Apply strategically to ≤10% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life				T	500	1000	2000	Max
Highlight	Apply strategically to ≤25% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life				R	250	500	1000	Max
Total display	Apply to total display or displays visible from primary viewing direction				M	50	100	200	Avg
LZ2[j] **(and LZ3 curfew)**									
Dazzle	Apply strategically to ≤10% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life				R	250	500	1000	Max
Highlight	Apply strategically to ≤25% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life				P	150	300	600	Max
Total display	Apply to total display or displays visible from primary viewing direction				K	25	50	100	Avg
LZ1[j] **(and LZ2 curfew)**									
Dazzle	Apply strategically to ≤10% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life				P	150	300	600	Max
Highlight	Apply strategically to ≤25% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life				N	75	150	300	Max
Total display	Apply to total display or displays visible from primary viewing direction				I	15	30	60	Avg
LZ0[j] **(and LZ1 curfew)**		-	0	0	0	-	0	0	0	
° **Low Activity**[i]	Show windows in areas typified by low nighttime pedestrian or vehicular activity								
LZ4[j]									
Dazzle	Apply strategically to ≤10% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life				T	500	1000	2000	Max
Highlight	Apply strategically to ≤25% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life				R	250	500	1000	Max
Total display	Apply to total display or displays visible from primary viewing direction				M	50	100	200	Avg

Table 34.2 | Retail Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
5:1						
5:1						
5:1						
5:1						
5:1						

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h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some general retail sales, the typical area of coverage is "Room or Designated Area" at the planar elevations noted. For applications where task position is known, such as fixed displays or specific gondola layouts, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area" and which may involve different planar elevations that the designer must accommodate.

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Table 34.2 | Retail Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]								
		Horizontal (E_h) Targets				Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are				Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
RETAILING, INDOOR	(Show Windows continued)										
LZ3[j] (and LZ4 curfew)											
Dazzle	Apply strategically to ≤10% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life						R	250	500	1000	Max
Highlight	Apply strategically to ≤25% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life						P	150	300	600	Max
Total display	Apply to total display or displays visible from primary viewing direction						K	25	50	100	Avg
LZ2[j] (and LZ3 curfew)											
Dazzle	Apply strategically to ≤10% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life						P	150	300	600	Max
Highlight	Apply strategically to ≤25% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life						N	75	150	300	Max
Total display	Apply to total display or displays visible from primary viewing direction						I	15	30	60	Avg
LZ1[j] (and LZ2 curfew)											
Dazzle	Apply strategically to ≤10% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life						N	75	150	300	Max
Highlight	Apply strategically to ≤25% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life						L	37.5	75	150	Max
Total display	Apply to total display or displays visible from primary viewing direction						G	7.5	15	30	Avg
LZ0[j] (and LZ1 curfew)		-	0	0	0		-	0	0	0	
• Interior Facing Windows											
• Dazzle	Apply strategically to ≤10% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life						U	750	1500	3000	Max
• Highlight	Apply strategically to ≤25% of total display or displays visible from primary viewing direction; may affect fading, bleaching, and shelf life						S	375	750	1500	Max
• Total display	Apply to total display or displays visible from primary viewing direction						N	75	150	300	Avg
• Wrapping and Packaging	E_h @3' 6" AFF; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg

Table 34.2 | Retail Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
5:1						
5:1						
5:1						
5:1						
1.2:1/1.5:1	1.2:1/1.5:1					

Notes for Table 34.2

The table column headings are discussed in detail in 34.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 34.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 34.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 34.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some general retail sales, the typical area of coverage is "Room or Designated Area" at the planar elevations noted. For applications where task position is known, such as fixed displays or specific gondola layouts, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area" and which may involve different planar elevations that the designer must accommodate.

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Table 34.2 | Retail Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
RETAILING, OUTDOOR											
• Automotive Sales	Coordinate lighting with security cameras.										
• Circulation Drives	E_h @pavement; E_v @5' AFF										
• High Activity[i]											
◦ LZ4[j]		H	10	20	40	Avg	E	4	8	16	Avg
◦ LZ3[j] (and LZ4 curfew)		G	7.5	15	30	Avg	D	3	6	12	Avg
◦ LZ2[j] (and LZ3 curfew)		F	5	10	20	Avg	C	2	4	8	Avg
◦ LZ1[j] (and LZ2 curfew)		E	4	8	16	Avg	B	1	2	4	Avg
◦ LZ0[j] (and LZ1 curfew)		-	0	0	0		-	0	0	0	
• Medium Activity[i]											
◦ LZ4[j]		G	7.5	15	30	Avg	D	3	6	12	Avg
◦ LZ3[j] (and LZ4 curfew)		F	5	10	20	Avg	C	2	4	8	Avg
◦ LZ2[j] (and LZ3 curfew)		E	4	8	16	Avg	B	1	2	4	Avg
◦ LZ1[j] (and LZ2 curfew)		D	3	6	12	Avg	A	0.5	1	2	Avg
◦ LZ0[j] (and LZ1 curfew)		-	0	0	0		-	0	0	0	
• Low Activity[i]											
◦ LZ4[j]		F	5	10	20	Avg	C	2	4	8	Avg
◦ LZ3[j] (and LZ4 curfew)		E	4	8	16	Avg	B	1	2	4	Avg
◦ LZ2[j] (and LZ3 curfew)		D	3	6	12	Avg	A	0.5	1	2	Avg
◦ LZ1[j] (and LZ2 curfew)		C	2	4	8	Avg	-	0	0	0	
◦ LZ0[j] (and LZ1 curfew)		-	0	0	0		-	0	0	0	
• Featured Vehicle	Illuminance @respective relevant plane(s) on feature display										
• Dazzle	Apply strategically to ≤10% of total vehicle visible from primary viewing direction			E_h and E_v on the featured vehicle ≤10 times E_h of Front Row for respective Activity Level and Lighting Zone							Max
• Highlight	Apply strategically to ≤25% of total vehicle visible from primary viewing direction			E_h and E_v on the featured vehicle ≤5 times E_h of Front Row for respective Activity Level and Lighting Zone							Max
• Total vehicle	IESH/10e proposed values: Apply to total vehicle visible from primary viewing direction			equal to E_h of Front Row for respective Activity Level and Lighting Zone							Avg
• Front Row	E_h and E_v @4' AFF										
• High Activity[i]											
◦ LZ4[j]		P	150	300	600	Avg	P	150	300	600	Avg
◦ LZ3[j] (and LZ4 curfew)		O	100	200	400	Avg	O	100	200	400	Avg
◦ LZ2[j] (and LZ3 curfew)		N	75	150	300	Avg	N	75	150	300	Avg
◦ LZ1[j] (and LZ2 curfew)		M	50	100	200	Avg	M	50	100	200	Avg
◦ LZ0[j] (and LZ1 curfew)		-	0	0	0		-	0	0	0	
• Medium Activity[i]											
◦ LZ4[j]		O	100	200	400	Avg	O	100	200	400	Avg
◦ LZ3[j] (and LZ4 curfew)		N	75	150	300	Avg	N	75	150	300	Avg
◦ LZ2[j] (and LZ3 curfew)		M	50	100	200	Avg	M	50	100	200	Avg
◦ LZ1[j] (and LZ2 curfew)		L	37.5	75	150	Avg	L	37.5	75	150	Avg
◦ LZ0[j] (and LZ1 curfew)		-	0	0	0		-	0	0	0	

Table 34.2 | Retail Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f] [g] Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min	Task Proper or Task Area	Room or Designated Area
3:1	3:1			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
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3:1	3:1			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
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3:1	3:1 (6:1)			

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a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 34.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 34.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

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k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some general retail sales, the typical area of coverage is "Room or Designated Area" at the planar elevations noted. For applications where task position is known, such as fixed displays or specific gondola layouts, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area" and which may involve different planar elevations that the designer must accommodate.

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Table 34.2 | Retail Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
RETAILING, OUTDOOR	(Automotive Sales/Front Row continued)										
• Low Activity[i]											
◦ LZ4[j]		N	75	150	300	Avg	N	75	150	300	Avg
◦ LZ3[j] (and LZ4 curfew)		M	50	100	200	Avg	M	50	100	200	Avg
◦ LZ2[j] (and LZ3 curfew)		L	37.5	75	150	Avg	L	37.5	75	150	Avg
◦ LZ1[j] (and LZ2 curfew)		K	25	50	100	Avg	K	25	50	100	Avg
◦ LZ0[j] (and LZ1 curfew)		-	0	0	0		-	0	0	0	
• Parking	E_h @pavement; E_v @5' AFF										
• High Activity[i]											
◦ LZ4[j]		I	15	30	60	Avg	G	7.5	15	30	Avg
◦ LZ3[j] (and LZ4 curfew)		H	10	20	40	Avg	F	5	10	20	Avg
◦ LZ2[j] (and LZ3 curfew)		G	7.5	15	30	Avg	E	4	8	16	Avg
◦ LZ1[j] (and LZ2 curfew)		F	5	10	20	Avg	D	3	6	12	Avg
◦ LZ0[j] (and LZ1 curfew)		-	0	0	0		-	0	0	0	
• Medium Activity[i]											
◦ LZ4[j]		H	10	20	40	Avg	F	5	10	20	Avg
◦ LZ3[j] (and LZ4 curfew)		G	7.5	15	30	Avg	E	4	8	16	Avg
◦ LZ2[j] (and LZ3 curfew)		F	5	10	20	Avg	D	3	6	12	Avg
◦ LZ1[j] (and LZ2 curfew)		E	4	8	16	Avg	C	2	4	8	Avg
◦ LZ0[j] (and LZ1 curfew)		-	0	0	0		-	0	0	0	
• Low Activity[i]											
◦ LZ4[j]		G	7.5	15	30	Avg	E	4	8	16	Avg
◦ LZ3[j] (and LZ4 curfew)		F	5	10	20	Avg	D	3	6	12	Avg
◦ LZ2[j] (and LZ3 curfew)		E	4	8	16	Avg	C	2	4	8	Avg
◦ LZ1[j] (and LZ2 curfew)		D	3	6	12	Avg	B	1	2	4	Avg
◦ LZ0[j] (and LZ1 curfew)		-	0	0	0		-	0	0	0	
• Preparation and Storage	E_h @pavement; E_v @5' AFF										
• High Activity[i]											
◦ LZ4[j]		I	15	30	60	Avg	G	7.5	15	30	Avg
◦ LZ3[j] (and LZ4 curfew)		H	10	20	40	Avg	F	5	10	20	Avg
◦ LZ2[j] (and LZ3 curfew)		G	7.5	15	30	Avg	E	4	8	16	Avg
◦ LZ1[j] (and LZ2 curfew)		F	5	10	20	Avg	D	3	6	12	Avg
◦ LZ0[j] (and LZ1 curfew)		-	0	0	0		-	0	0	0	
• Medium Activity[i]											
◦ LZ4[j]		H	10	20	40	Avg	F	5	10	20	Avg
◦ LZ3[j] (and LZ4 curfew)		G	7.5	15	30	Avg	E	4	8	16	Avg
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◦ LZ1[j] (and LZ2 curfew)		E	4	8	16	Avg	C	2	4	8	Avg
◦ LZ0[j] (and LZ1 curfew)		-	0	0	0		-	0	0	0	

Table 34.2 | Retail Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f] [g] Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min	Task Proper or Task Area	Room or Designated Area
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3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
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3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
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g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

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Table 34.2 | Retail Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d] Horizontal (E_h) Targets: Visual Ages of Observers (years) where **at least half** are <25	25-65	>65	Category	Gauge	Vertical (E_v) Targets: Visual Ages of Observers (years) where **at least half** are <25	25-65	>65	Category	Gauge
RETAILING, OUTDOOR	(Automotive Sales/Preparation and Storage continued)										
• Low Activity[i]											
◦ LZ4[j]		7.5	15	30	G	Avg	4	8	16	E	Avg
◦ LZ3[j] (and LZ4 curfew)		5	10	20	F	Avg	3	6	12	D	Avg
◦ LZ2[j] (and LZ3 curfew)		4	8	16	E	Avg	2	4	8	C	Avg
◦ LZ1[j] (and LZ2 curfew)		3	6	12	D	Avg	1	2	4	B	Avg
◦ LZ0[j] (and LZ1 curfew)		0	0	0	-		0	0	0	-	
• Sales	E_h and E_v @4' AFF										
• High Activity[i]											
◦ LZ4[j]		75	150	300	N	Avg	37.5	75	150	L	Avg
◦ LZ3[j] (and LZ4 curfew)		50	100	200	M	Avg	25	50	100	K	Avg
◦ LZ2[j] (and LZ3 curfew)		37.5	75	150	L	Avg	20	40	80	J	Avg
◦ LZ1[j] (and LZ2 curfew)		25	50	100	K	Avg	15	30	60	I	Avg
◦ LZ0[j] (and LZ1 curfew)		0	0	0	-		0	0	0	-	
• Medium Activity[i]											
◦ LZ4[j]		50	100	200	M	Avg	25	50	100	K	Avg
◦ LZ3[j] (and LZ4 curfew)		37.5	75	150	L	Avg	20	40	80	J	Avg
◦ LZ2[j] (and LZ3 curfew)		25	50	100	K	Avg	15	30	60	I	Avg
◦ LZ1[j] (and LZ2 curfew)		20	40	80	J	Avg	10	20	40	H	Avg
◦ LZ0[j] (and LZ1 curfew)		0	0	0	-		0	0	0	-	
• Low Activity[i]											
◦ LZ4[j]		37.5	75	150	L	Avg	20	40	80	J	Avg
◦ LZ3[j] (and LZ4 curfew)		25	50	100	K	Avg	15	30	60	I	Avg
◦ LZ2[j] (and LZ3 curfew)		20	40	80	J	Avg	10	20	40	H	Avg
◦ LZ1[j] (and LZ2 curfew)		15	30	60	I	Avg	7.5	15	30	G	Avg
◦ LZ0[j] (and LZ1 curfew)		0	0	0	-		0	0	0	-	
• Seasonal Open-air	Examples include farmers markets, Christmas tree sales, arts festivals, and produce stands typified by open-air or partial-cover situations. Coordinate lighting with security cameras.										
• LZ4[j]											
• Circulation	E_h @pavement; E_v @5' AFF	10	20	40	H	Avg	4	8	16	E	Avg
• Feature displays	Apply strategically to ≤25 ft² or 25% of feature whichever covers more area of feature	75	150	300	N	Avg	75	150	300	N	Avg
• Merchandise[l]	E_h @2' 6" AFF; Ev @4' AFF or at actual display elevations and orientations when known	20	40	80	J	Avg	20	40	80	J	Avg
• LZ3[j] (and LZ4 curfew)											
• Circulation	E_h @pavement; E_v @5' AFF	7.5	15	30	G	Avg	3	6	12	D	Avg
• Feature displays	Apply strategically to ≤25 ft² or 25% of feature whichever covers more area of feature	50	100	200	M	Avg	50	100	200	M	Avg
• Merchandise[l]	E_h @2' 6" AFF; Ev @4' AFF or at actual display elevations and orientations when known	15	30	60	I	Avg	15	30	60	I	Avg

Table 34.2 | Retail Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f] [g] Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min	Task Proper or Task Area	Room or Designated Area
3:1	3:1			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
2:1	2:1			
2:1				
2:1	2:1 (4:1)			
2:1	2:1 (4:1)			
2:1				
2:1	2:1 (4:1)			

Notes for Table 34.2

The table column headings are discussed in detail in 34.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 34.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 34.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 34.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some general retail sales, the typical area of coverage is "Room or Designated Area" at the planar elevations noted. For applications where task position is known, such as fixed displays or specific gondola layouts, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area" and which may involve different planar elevations that the designer must accommodate.

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Table 34.2 | Retail Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
RETAILING, OUTDOOR	(Seasonal Open-air continued)										
• LZ2[j] (and LZ3 curfew)											
• Circulation	E_h @pavement; E_v @5' AFF	F	5	10	20	Avg	C	2	4	8	Avg
• Feature displays	Apply strategically to ≤25 ft² or 25% of feature whichever covers more area of feature	K	25	50	100	Avg	K	25	50	100	Avg
• Merchandise[l]	E_h @2' 6" AFF; Ev @4' AFF or at actual display elevations and orientations when known	H	10	20	40	Avg	H	10	20	40	Avg
• LZ1[j] (and LZ2 curfew)											
• Circulation	E_h @pavement; E_v @5' AFF	D	3	6	12	Avg	B	1	2	4	Avg
• Feature displays	Apply strategically to ≤25 ft² or 25% of feature whichever covers more area of feature	J	20	40	80	Avg	J	20	40	80	Avg
• Merchandise[l]	E_h @2' 6" AFF; Ev @4' AFF or at actual display elevations and orientations when known	G	7.5	15	30	Avg	G	7.5	15	30	Avg
• LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]										
• Circulation	E_h @pavement; E_v @5' AFF	C	2	4	8	Avg	A	0.5	1	2	Avg
• Feature displays	Apply strategically to ≤25 ft² or 25% of feature whichever covers more area of feature	I	15	30	60	Avg	I	15	30	60	Avg
• Merchandise[l]	E_h @2' 6" AFF; Ev @4' AFF or at actual display elevations and orientations when known	F	5	10	20	Avg	F	5	10	20	Avg
• Service Stations	Coordinate lighting with security cameras.										
• Approaches/Drives/Parking	Areas not associated with dispensing or service functions.										
• High Activity[i]	E_h @pavement; E_v @5' AFF										
◦ LZ4[j]		H	10	20	40	Avg	F	5	10	20	Avg
◦ LZ3[j] (and LZ4 curfew)		G	7.5	15	30	Avg	E	4	8	16	Avg
◦ LZ2[j] (and LZ3 curfew)		F	5	10	20	Avg	D	3	6	12	Avg
◦ LZ1[j] (and LZ2 curfew)		E	4	8	16	Avg	C	2	4	8	Avg
◦ LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	D	3	6	12	Avg	B	1	2	4	Avg
• Medium Activity[i]	E_h @pavement; E_v @5' AFF										
◦ LZ4[j]		G	7.5	15	30	Avg	E	4	8	16	Avg
◦ LZ3[j] (and LZ4 curfew)		F	5	10	20	Avg	D	3	6	12	Avg
◦ LZ2[j] (and LZ3 curfew)		E	4	8	16	Avg	C	2	4	8	Avg
◦ LZ1[j] (and LZ2 curfew)		D	3	6	12	Avg	B	1	2	4	Avg
◦ LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	C	2	4	8	Avg	A	0.5	1	2	Avg
• Low Activity[i]	E_h @pavement; E_v @5' AFF										
◦ LZ4[j]		F	5	10	20	Avg	D	3	6	12	Avg
◦ LZ3[j] (and LZ4 curfew)		E	4	8	16	Avg	C	2	4	8	Avg
◦ LZ2[j] (and LZ3 curfew)		D	3	6	12	Avg	B	1	2	4	Avg
◦ LZ1[j] (and LZ2 curfew)		C	2	4	8	Avg	A	0.5	1	2	Avg
◦ LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	B	1	2	4	Avg	-	0	0	0	

Table 34.2 | Retail Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f] [g] Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min	Task Proper or Task Area	Room or Designated Area
2:1	2:1 (4:1)			
2:1				
2:1	2:1 (4:1)			
2:1	2:1 (4:1)			
2:1				
2:1	2:1 (4:1)			
2:1				
2:1				
2:1				
2:1	3:1			
2:1	3:1 (6:1)			
2:1	3:1 (6:1)			
2:1	3:1 (6:1)			
2:1				
2:1	3:1			
2:1	3:1 (6:1)			
2:1	3:1 (6:1)			
2:1	3:1 (6:1)			
2:1				
2:1	3:1			
2:1	3:1 (6:1)			
2:1	3:1 (6:1)			
2:1	3:1 (6:1)			
2:1				

Notes for Table 34.2

The table column headings are discussed in detail in 34.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 34.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 34.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 34.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some general retail sales, the typical area of coverage is "Room or Designated Area" at the planar elevations noted. For applications where task position is known, such as fixed displays or specific gondola layouts, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area" and which may involve different planar elevations that the designer must accommodate.

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Table 34.2 | Retail Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
RETAILING, OUTDOOR	(Service Stations continued)										
• Building Facades	Key vertical facade surfaces to define place and attract attention. Apply strategically to ≤25% of area of building facade visible from primary viewing directions										
• High Activity[i]											
◦ LZ4[j]							K	25	50	100	Avg
◦ LZ3[j] (and LZ4 curfew)							J	20	40	80	Avg
◦ LZ2[j] (and LZ3 curfew)							I	15	30	60	Avg
◦ LZ1[j] (and LZ2 curfew)							H	10	20	40	Avg
◦ LZ1[j] curfew							G	7.5	15	30	Avg
◦ LZ0[j]							-	0	0	0	
• Medium Activity[i]											
◦ LZ4[j]							J	20	40	80	Avg
◦ LZ3[j] (and LZ4 curfew)							I	15	30	60	Avg
◦ LZ2[j] (and LZ3 curfew)							H	10	20	40	Avg
◦ LZ1[j] (and LZ2 curfew)							G	7.5	15	30	Avg
◦ LZ1[j] curfew							F	5	10	20	Avg
◦ LZ0[j]							-	0	0	0	
• Low Activity[i]											
◦ LZ4[j]							I	15	30	60	Avg
◦ LZ3[j] (and LZ4 curfew)							H	10	20	40	Avg
◦ LZ2[j] (and LZ3 curfew)							G	7.5	15	30	Avg
◦ LZ1[j] (and LZ2 curfew)							F	5	10	20	Avg
◦ LZ1[j] curfew							E	4	8	16	Avg
◦ LZ0[j]							-	0	0	0	
• Dispensing Islands	Fuel pumps or short-time (Level III) charging stations										
• High Activity[i]	E_h @pavement in area defined by 9' radius from center of each dispensing pump or charging station face; E_v @face of dispensing pump or charging station including transaction device. Control with motion sensors.[k]										
◦ LZ4[j]		O	100	200	400	Avg	O	100	200	400	Avg
◦ LZ3[j] (and LZ4 curfew)		N	75	150	300	Avg	N	75	150	300	Avg
◦ LZ2[j] (and LZ3 curfew)		M	50	100	200	Avg	M	50	100	200	Avg
◦ LZ1[j] (and LZ2 curfew)		L	37.5	75	150	Avg	L	37.5	75	150	Avg
◦ LZ0[j] (and LZ1 curfew)		K	25	50	100	Avg	K	25	50	100	Avg
• Medium Activity[i]	E_h @pavement in area defined by 9' radius from center of each dispensing pump or charging station face; E_v @face of dispensing pump or charging station including transaction device. Control with motion sensors.[k]										
◦ LZ4[j]		N	75	150	300	Avg	N	75	150	300	Avg
◦ LZ3[j] (and LZ4 curfew)		M	50	100	200	Avg	M	50	100	200	Avg
◦ LZ2[j] (and LZ3 curfew)		L	37.5	75	150	Avg	L	37.5	75	150	Avg
◦ LZ1[j] (and LZ2 curfew)		K	25	50	100	Avg	K	25	50	100	Avg
◦ LZ0[j] (and LZ1 curfew)		J	20	40	80	Avg	J	20	40	80	Avg

Table 34.2 | Retail Illuminance Recommendations continued next page

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4:1	4:1			
4:1	4:1 (8:1)			
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		Horizontal (E_h) Targets					Vertical (E_v) Targets				
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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
RETAILING, OUTDOOR	(Service Station Dispensing Islands continued)										
• Low Activity[i]	E_h @pavement in area defined by 9' radius from center of each dispensing pump or charging station face; E_v @face of dispensing pump or charging station including transaction device. Control with motion sensors.[k]										
◦ LZ4[j]		M	50	100	200	Avg	M	50	100	200	Avg
◦ LZ3[j] (and LZ4 curfew)		L	37.5	75	150	Avg	L	37.5	75	150	Avg
◦ LZ2[j] (and LZ3 curfew)		K	25	50	100	Avg	K	25	50	100	Avg
◦ LZ1[j] (and LZ2 curfew)		J	20	40	80	Avg	J	20	40	80	Avg
◦ LZ0[j] (and LZ1 curfew)		I	15	30	60	Avg	I	15	30	60	Avg
• Landscape Highlights	Key vertical foliage surfaces to define place and attract attention. Apply strategically to ≤25% of area of select foliage visible from primary viewing direction.										
• High Activity[i]											
◦ LZ4[j]							J	20	40	80	Avg
◦ LZ3[j] (and LZ4 curfew)							I	15	30	60	Avg
◦ LZ2[j] (and LZ3 curfew)							H	10	20	40	Avg
◦ LZ1[j] (and LZ2 curfew)							G	7.5	15	30	Avg
◦ LZ1[j] curfew							F	5	10	20	Avg
◦ LZ0[j]							-	0	0	0	
• Medium Activity[i]											
◦ LZ4[j]							I	15	30	60	Avg
◦ LZ3[j] (and LZ4 curfew)							H	10	20	40	Avg
◦ LZ2[j] (and LZ3 curfew)							G	7.5	15	30	Avg
◦ LZ1[j] (and LZ2 curfew)							F	5	10	20	Avg
◦ LZ1[j] curfew							E	4	8	16	Avg
◦ LZ0[j]							-	0	0	0	
• Low Activity[i]											
◦ LZ4[j]							H	10	20	40	Avg
◦ LZ3[j] (and LZ4 curfew)							G	7.5	15	30	Avg
◦ LZ2[j] (and LZ3 curfew)							F	5	10	20	Avg
◦ LZ1[j] (and LZ2 curfew)							E	4	8	16	Avg
◦ LZ1[j] curfew							D	3	6	12	Avg
◦ LZ0[j]							-	0	0	0	
• Outdoor Service	For nighttime performance of non-mechanical services such as fluids and air pressure checks and fills or use of long-time (Type II) charging stations.										
• High Activity[i]	E_h @3' 6" AFG at designated service or charging area defined by 9' radius from center of each charging station face; E_v @face of charging station including transaction device.										
◦ LZ4[j]		K	25	50	100	Avg	K	25	50	100	Avg
◦ LZ3[j] (and LZ4 curfew)		J	20	40	80	Avg	J	20	40	80	Avg
◦ LZ2[j] (and LZ3 curfew)		I	15	30	60	Avg	I	15	30	60	Avg
◦ LZ1[j] (and LZ2 curfew)		H	10	20	40	Avg	H	10	20	40	Avg
◦ LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	G	7.5	15	30	Avg	G	7.5	15	30	Avg

Table 34.2 | Retail Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f] [g] Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min	Task Proper or Task Area	Room or Designated Area
2:1	4:1			
2:1	4:1 (8:1)			
2:1	4:1 (8:1)			
2:1	4:1 (8:1)			
2:1				
3:1	3:1			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
3:1	3:1 (6:1)			
2:1	2:1			
2:1	2:1 (4:1)			
2:1	2:1 (4:1)			
2:1	2:1 (4:1)			
2:1				

Notes for Table 34.2

The table column headings are discussed in detail in 34.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 34.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 34.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 34.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some general retail sales, the typical area of coverage is "Room or Designated Area" at the planar elevations noted. For applications where task position is known, such as fixed displays or specific gondola layouts, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area" and which may involve different planar elevations that the designer must accommodate.

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Table 34.2 | Retail Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
RETAILING, OUTDOOR	(Service Station Outdoor Service continued)										
• Medium Activity[i]	E_h @3' 6" AFG at designated service or charging area defined by 9' radius from center of each charging station face; E_v @face of charging station including transaction device.										
◦ LZ4[j]		J	20	40	80	Avg	J	20	40	80	Avg
◦ LZ3[j] (and LZ4 curfew)		I	15	30	60	Avg	I	15	30	60	Avg
◦ LZ2[j] (and LZ3 curfew)		H	10	20	40	Avg	H	10	20	40	Avg
◦ LZ1[j] (and LZ2 curfew)		G	7.5	15	30	Avg	G	7.5	15	30	Avg
◦ LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	F	5	10	20	Avg	F	5	10	20	Avg
• Low Activity[i]	E_h @3' 6" AFG at designated service or charging area defined by 9' radius from center of each charging station face; E_v @face of charging station including transaction device.										
◦ LZ4[j]		I	15	30	60	Avg	I	15	30	60	Avg
◦ LZ3[j] (and LZ4 curfew)		H	10	20	40	Avg	H	10	20	40	Avg
◦ LZ2[j] (and LZ3 curfew)		G	7.5	15	30	Avg	G	7.5	15	30	Avg
◦ LZ1[j] (and LZ2 curfew)		F	5	10	20	Avg	F	5	10	20	Avg
◦ LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	E	4	8	16	Avg	E	4	8	16	Avg
SUPPORT SPACES											
• Alterations Rooms											
• General	E_h @2' 6"; E_v @4' AFF	R	250	500	1000	Avg	N	75	150	300	Avg
• Task Areas	E_h @2' 6"; E_v @4' AFF	T	500	1000	2000	Avg	P	150	300	600	Avg
• Coat Check or Coat Rooms	E_h @3' 0"; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Copy/Print Rooms											
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Machines	E_h and E_v @3' 6" AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Janitor's Closet	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Receiving/Shipping											
• Dock	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Receiving/Staging	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Stock Rooms	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Storage											
• Food	See 22 | LIGHTING FOR COMMON APPLICATIONS/Food Service										
• Frequent Use	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Infrequent Use	E_h @floor; E_v @4' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Valet	E_h @3' 0"; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
TOILETS/ LOCKER ROOMS	See 22 | LIGHTING FOR COMMON APPLICATIONS										

Table 34.2 | Retail Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio E_h/2nd ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
2:1	2:1					
2:1	2:1 (4:1)					
2:1	2:1 (4:1)					
2:1	2:1 (4:1)					
2:1						
2:1	2:1					
2:1	2:1 (4:1)					
2:1	2:1 (4:1)					
2:1	2:1 (4:1)					
2:1						
1.2:1/1.5:1	1.2:1/1.5:1					
1.2:1/1.5:1	1.2:1/1.5:1					
	3:1					
	3:1					
	3:1					
	3:1					
	2:1					
	2:1					
	2:1					
	3:1					
	3:1					
	3:1					

Notes for Table 34.2

The table column headings are discussed in detail in 34.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 34.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 34.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 34.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some general retail sales, the typical area of coverage is "Room or Designated Area" at the planar elevations noted. For applications where task position is known, such as fixed displays or specific gondola layouts, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area" and which may involve different planar elevations that the designer must accommodate.

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Table 34.2 | Retail Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
TRANSITION SPACES												
• Elevators												
• Freight												
◦ Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Threshold												
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Passenger												
◦ Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Threshold												
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Escalators/Moving Walkways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Lobbies												
• Circulation, Elevator Lobbies	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.											
◦ At building entries	Close proximity to exterior. Lighting should assist with adaptation when passing to/from exterior..											
▪ Day	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
▪ Night	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
◦ Distant from entries	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Security Screening	E_h @3' AFF; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Lounges												
• Break		M	50	100	200	Avg	K	25	50	100	Avg
• Reception/Waiting Areas												
• Reception Desk		Q	200	400	800	Avg	N	75	150	300	Avg
• Waiting Areas		O	100	200	400	Avg	M	50	100	200	Avg
• Stairs	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.											
◦ High activity[i]	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
◦ Live-surveillance	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
◦ Typical	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	2:1		☀			
	2:1		☀			
	2:1		☀			
	2:1		☀			
	2:1		☀			
	2:1		☀			
	2:1		☀			
	3:1		☀			
	3:1					
	3:1		☀			
	2:1		☀			
	3:1		☀			
see Table 12.6			☀			
	3:1		☀			
	2:1		☀			
	2:1		☀			
	2:1		☀			

Notes for Table 34.2

The table column headings are discussed in detail in 34.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 34.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 34.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 34.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◥ signals high likelihood; gray and white ◥ signals moderate likelihood; pale gray and white ◥ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

l. For applications where task position is indefinite, such as some general retail sales, the typical area of coverage is "Room or Designated Area" at the planar elevations noted. For applications where task position is known, such as fixed displays or specific gondola layouts, a more efficient approach is likely achieved when target illuminance is applied to the "Task Proper or Task Area" and which may involve different planar elevations that the designer must accommodate.

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Table 34.3 | SI Dimensional Conversions

US Customary	SI
General	**Hard Conversion**
inches	mm [inches × 25.40]
feet	m [feet × 0.30]
Specific	**Convenient Conversions[a]**
2'	610 mm or 0.6 m
2' 6"	760 mm or 0.75 m
3'	915 mm or 0.9 m
3' 6"	1065 mm or 1.1 m
4'	1220 mm or 1.2 m
5'	1525 mm or 1.5 m

a. Hard conversions rounded for reporting convenience. Not to be confused with metric-sized luminaires or other building materials. Not for precision construction.

Where nighttime outdoor lighting zones are not defined by local ordinance, their determination must then be addressed with team members and client. Selecting a higher-than-appropriate nighttime outdoor lighting zone only serves to ratchet illuminances unnecessarily high and will likely result in too much light and glare for the shopper. This can negatively affect the experience and reduce the sense of excitement. Overlighting pedestrian areas may encourage overlighting of stores and show windows as these "compete" for attention relative to the lighting of pedestrian areas. For these same reasons, where nighttime outdoor lighting zones are established by ordinance, it makes little sense to insert higher- or lower-zoned projects, as such variances only serve to encourage others to seek similar exemptions and perpetuate the problem.

34.2.6 Food Service

Lighting for food service is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. Food service lighting can be categorized as that for food preparation and handling, food consumption, and cleanup. These illuminance criteria address the safety of those handling and preparing the food, the safety of the food for consumption, which involves inspection, the presentation of the food for consumption, and cleanliness of food stuffs and facilities. In the U.S., lighting for commercial and institutional food preparation must meet FDA Food Code requirements for minimum illuminance which have basis in the IES guidelines. Apparently due to metrication, code requirements are within 10% of IES recommendations. Regardless, a lighting design must meet code.

To avoid the consequences of violent lamp failure and therefore food contamination, lamps used over food preparation areas must be shielded. New technologies, including LEDs and OLEDs, have not been vetted for this aspect. Consult with current codes or code officials if any question exists.

34.2.7 IT

Lighting for IT tasks is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. Many retail establishments may have few IT tasks. Some establishments, however, rely on computers to operate, track, and perform functions.

34.2.8 Malls, Indoor

Malls are covered facilities. The introduction of daylighting is considered a great benefit to the shopping experience and should be pursued. See Figure 34.3.

Accenting in malls should enhance shopping, not compete with it, and therefore careful application is necessary. Where important art features are planned, accenting can help establish these as iconic references to aid wayfinding. Where architectural feature walls form backdrops or where store fronts consist of limited glazing and impressions of spaciousness and preference are desired, wall lighting is recommended. Accenting of important service areas or concierge stations helps shoppers identify these upon arrival or departure. Services might include coat check, stroller and electric wheelchair pickup, wrapping, and valet.

Concourses typically serve as neutral background for circulation against the visually exciting store fronts, show windows, displays, and features. If malls accommodate kiosks, market stalls, or carts, then lighting should be specific to the task area defined by each kiosk rather than increasing lighting throughout the concourse.

For lighting of relatively straightforward entertainment events, see AUDITORIA/ Performance citations in Table 24.2 | Education Facilities Illuminance Recommendations. For professional theatrical events with lighting cues sequenced to the show, consult with a professional theater lighting designer.

See Food Service citations in Table 22.2 | Common Applications Illuminance Recommendations for lighting criteria related to food courts. For food court dining areas, lighting should relate to the type of eating establishments and the mall's architectural style.

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Maintenance challenges in malls are a result of large-volume and usually high-ceiling architecture and the hours during which maintenance may be performed without affecting the shopping experience. Lighting equipment that can be accessed from above is appropriate, but the cost of access ways and catwalks must be considered. Long-life lamps and disciplined use of controls are helpful to extending in-service life. Reliable and warranted LEDs may be appropriate, depending on throw distances and areas of coverage. Regardless, access to lighting equipment must be coordinated with the design team and client.

34.2.9 Parking

Lighting for parking facilities is discussed in 26 | LIGHTING FOR EXTERIORS.

34.2.10 Pedestrian Ways

Lighting for pedestrian ways is discussed in 26 | LIGHTING FOR EXTERIORS.

34.2.11 Retailing, Indoor

Indoor retailing involves lighting of the shopping area, the sales transaction area, show windows, and wrapping and packaging. Depending on the retailer, some of these aspects are set apart in distinctly different areas or even rooms. The shopping area itself consists of circulation, feature displays, general retail areas, and perimeters. Nevertheless, color qualities of light, equipment styles, and even lighting effects are coordinated for harmony.

Fitting Rooms
In clothing stores and where alterations are a part of the selling strategy, dressing rooms and fitting areas are used. If alterations are not a part of the strategy, then dressing rooms suffice. Both dressing rooms and fitting areas should be lighted to feature the shopper. Vertical illuminance is important. In upscale situations and in the fitting rooms for tailoring, higher vertical illuminances are appropriate. The plane of application is that of the shopper's body oriented toward the mirror. In fitting areas, vertical illuminance may be needed for the plane oriented in the direction opposite the mirror depending on tailoring requirements. These vertical illuminances are best achieved with diffuse frontal lighting, such as wall sconces at the mirror combined with diffuse overhead light to provide some top lighting.

Retailing: Circulation; Feature Displays; General Retail Areas; Perimeters
Retail lighting should be tailored to the type of merchandise and consequently the classification of retailer. There are 16 retail classifications cited in Table 34.2. Each classification includes criteria for circulation, feature displays, general retail areas, and store perimeters. A detailed store plan is necessary so that the designer may best:

- Establish appropriate contrasts between merchandise, displays, and backgrounds
- Use available lighting energy
- Establish accent luminaire locations with optimal aiming angles

If store plans cannot be resolved by time of lighting design or if design direction is for "maximum flexibility," then the resulting lighting layouts may compromise lighting effects and the shopping experience.

Circulation lighting establishes a base condition of uniform and relatively low horizontal and vertical illuminances where circulation is designated. Spill light from feature displays, general retail areas, and perimeters may result in circulation illuminances greater than IES recommendations once these components are designed and their effects included. When general retail and perimeter lighting are achieved from fixed architecturally-integrated lighting systems, their spill light can be calculated and considered as part or all of the circulation lighting system. Figures 34.4 and 34.5 illustrate such an approach.

Feature displays can and should be significant focal points to lead shoppers into and through the store. Typically, these are best illuminated with lighting directed to the surface or surfaces which are most visible from key viewing directions. These usually are

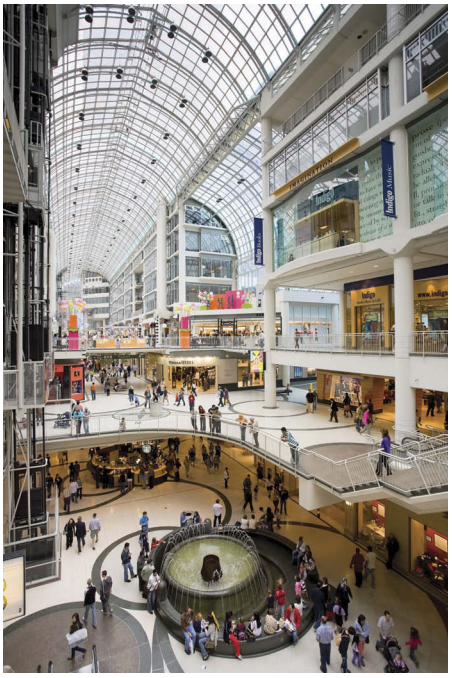


Figure 34.3 | Malls
Even in relatively narrow and tall structures, toplighting daylight strategies can provide sufficient illuminance for circulation and lounge areas.
» Image ©Michele Falzone/JAI/Corbis

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Figure 34.4 | Feature Displays
Feature displays are used to attract shoppers through visual intrigue and excitement. Lighting is a necessary means to that end. Here, a series of mannequins and feature display lighting effects appear to suggest a fashion runway and collectively provide a significant focal feature. A feature display in the middle left background draws attention to that area inviting further exploration.

Perimeter lighting is used here to accentuate an architectural backdrop of wood. Rather than a continuous uniform wash across a large area of the ceiling or the walls, lighting details are used to enhance the juxtaposition of planes (see Table 12.1b | Spatial Factors: Part Two).

Spill light from perimeter architectural lighting can address some or all of the circulation illuminance.

» Image ©WWD/Condé Nast/Corbis

vertical surfaces, but may be horizontal or some combination of vertical and horizontal. In the life of a store, all may be possibilities and the designer should develop a solution accordingly. Primary viewing direction is typically the main approach into a department or area and, if the store area is large, a secondary approach direction may exist. The total display should be lighted to a base illuminance identified in Table 34.2 as "General retail" citation under the various retail classifications of RETAILING, INDOOR. Then, 25% of the feature display should be highlighted to five times the base illuminance. For additional emphasis and visual variety, another 10% of the display can be dazzled to ten times the base illuminance. The dazzle effect may be particularly appropriate on displays of low reflectance. See Figure 34.4. Using such an arrangement creates dramatic contrast across the display, introduces visual intrigue, and avoids washout and sameness of feature displays throughout the store. Nevertheless, to maintain an appropriate degree of intrigue, interest, and attention, feature displays must be limited in number. The general retail illuminance is used to light merchandise for sale. If too much of the merchandise is feature lighted, then no merchandise has the visual interest and excitement that results from a selective approach and an over lighted sales space results. With respect to highlight and dazzle, see discussion below on Merchandise Fading and Bleaching.

Lighting of the general retail area is more dramatic if it can target the merchandise displays, whether they be tables, gondolas, racks, or shelves. This can be accomplished by strategically positioning optically appropriate lighting equipment. This may take a number of trials and errors in virtual modeling for a given situation to balance lighting effects, illuminances, and energy. However, where a high degree of flexibility is necessary or where merchandise displays are tightly arranged or regularly changing significantly in size and position, such as appliances, general uniform layouts of lighting equipment may be appropriate. Figure 34.6 illustrates an approach where merchandise is purposefully targeted.

Perimeter areas should be lighted to attract attention into the store. Although consistent and uniform perimeter lighting can make a small boutique feel more spacious, such an approach in large stores or departments may result in visual monotony unless graphics, signage or color are used, such as illustrated in Figure 34.8. The designer must establish which perimeter surfaces are worthy of lighting. That is, which perimeter surfaces, when lighted, will best attract the eye and shopper to explore. Sometimes this involves illuminating interesting wall or ceiling treatments along the perimeter, such as those in Figure 34.4. At other times, depending on the display of merchandise, this involves lighting merchandise to "general retail" illuminances with some intermittent feature display lighting, such as illustrated in Figures 34.5 and 34.7. With perimeter lighting, visual order is important. Since perimeter surfaces are most often well-organized architectural surfaces, randomly positioned and sized brightness patterns can be disconcerting in a retail setting, though this depends on the merchandising strategy and the architecture.

Sales Transaction Areas

Sales transaction areas should be lighted to meet the demands of shoppers and sales staff visually scanning invoices or credit slips and checking merchandise. Depending on the type and size of store or department, accenting of signage, ceiling elements, backdrops or specific transaction features or surfaces may be employed to attract attention.

Show Windows

A form of advertising, show windows are used to help destination shoppers identify their destination or to attract the impulse shopper. Show window lighting criteria depend on the application of the window: interior facing or exterior facing. Interior facing windows are usually employed in enclosed malls or within a store where little or no daylight is present.

Similar to in-store feature displays, illuminance recommendations for show window displays involve total display lighting, highlighting, and dazzle lighting. During daylight hours for exterior facing window displays, dazzle lighting is necessary. During dark hours of operation or for interior facing windows especially where no daylight is available, the

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Figure 34.5 | Perimeter Lighting
Perimeter lighting here illuminates merchandise and promotes a sense of spaciousness (see Table 12.2 | Subjective Impressions). Sufficient spill light from the perimeter lighting can address circulation illuminance. Centrally positioned slot luminaires house adjustable accent fittings on various control zones to allow for selective feature lighting.
» Image ©Giuseppe Cacace/Getty Images



Figure 34.6 | Retail Display Lighting
Some of the general retail area in a grocery store typically consists of shelving. In addition to ambient lighting, a system of localized accent lighting directed specifically at the retail display can provide more visual interest and offer better glare control and subsequently a more comfortable shopping experience. Here, a valance-like detail at the top of the shelving localizes lighting to the merchandise. Total illuminance on the display results from contribution from the ambient system and from the display accent system. The designer should explore luminaire optics and mounting geometry to maximize illuminances with limited energy use.
» Image ©Chuck Savage/CORBIS



Figure 34.7 | Perimeter Lighting and Feature Displays
Perimeter lighting is used to direct shoppers' attention. In the process of circulating to the brighter perimeter zone, shoppers are encouraged to explore merchandise.

Perimeter lighting in the upper middle is part of a seating zone. In the area to the upper right, feature display lighting and perimeter lighting are one in the same.

A secondary benefit of perimeter lighting when applied uniformly as here, is its promotion of a sense of spaciousness (see Table 12.2 | Subjective Impressions).

Depending on the architectural style or the brand image, portable or decorative lighting is used. For portable lighting, provisions for power and controls must be made. For chandeliers, pendants, and wall sconces, locations must be established that work with the store plan and do not conflict with merchandise or feature display lighting.
» Image ©Todd Williamson/Getty Images



Figure 34.8 | Perimeter Lighting
Perimeter lighting is used here to direct shoppers to deeper interior zones of the store and highlight signage. In mass-merchandise situations, more continuous perimeter lighting can define entire departments and serve as backdrop against which large appliances and televisions are displayed, for example.
» Image ©Rick Friedman/Corbis

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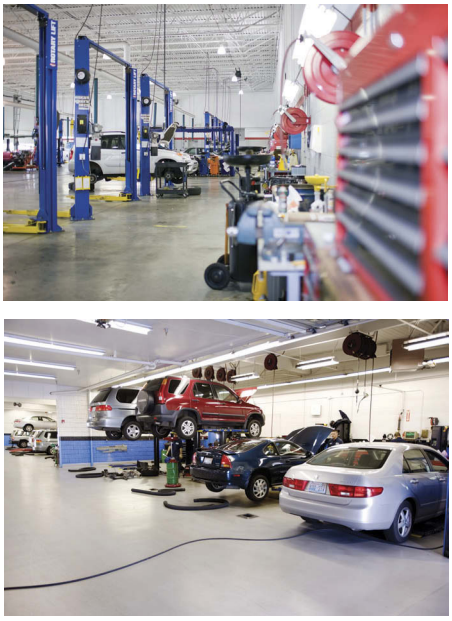


Figure 34.9 | Service Ambient and Task
These service facilities employ ambient and task lighting systems. In the top image, wall-mounted fluorescent luminaires illuminate tasks (the bench and vehicle hood areas). In the bottom image, fluorescent luminaires at the ceiling are strategically located at the tasks (hood areas). White ceilings and walls are necessary to maximize efficiency and diffusion.
» Top Image ©Rick Gomez/Corbis
» Bottom Image ©Don Mason/Corbis

IESH/10e Color Resources

> 6.2.5 Color Temperature and Correlated Color Temperature
- for more on energized lamp appearance

> 6.3 Color Rendition
- for more on energized lamp effect on surfaces

> 6.4 Materials Color Specification
- for more on surface color and reflectance

> 12.5.6 Color Considerations
- for more on the use of color temperature and color rendering

dazzle effect may be unnecessary on all but one or a few window displays. With respect to highlight and dazzle, see discussion below on Merchandise Fading and Bleaching.

During daylight hours, very high illuminances must be used on at least some portion of exterior facing window displays. Accenting is most effective when canopies, awnings, or neighboring architecture limit the available daylight. A confounding element is the glazing T_{vis}. Glass with T_{vis} less than 70% is likely to exhibit veiling reflections severe enough to preclude or greatly limit view of these exterior facing displays (see Figure 12.24). Glazing is available that exhibits a low-glare or non-reflective quality and a T_{vis} of at least 98%.

Lighting of exterior facing show window displays during dark hours of operation relates to the activity level and nighttime outdoor lighting zone of the area. Lighting should be extinguished at curfew or time of business closing, whichever is later. When curfew occurs prior to closing, lighting should be dimmed back according to recommended criteria in Table 34.2.

Wrapping and Packaging
Lighting at wrapping and packaging stations or rooms must accommodate the process of inspecting the merchandise package, selecting wrapping materials, positioning the merchandise and packing materials in a box or other container, sealing, wrapping, and, if necessary, addressing the package. These areas may function much like merchandising spaces, with accent lighting employed on wrapping paper and container displays.

Service
Where stores offer repair services, notably automotive retailers and service stations, lighting must address the respective work areas. Ambient lighting is typically used in combination with architectural and portable task lighting. Figure 34.9 illustrates these concepts and the importance of wall and ceiling surface reflectances in achieving an efficient operation as well as an appearance of cleanliness.

Color Qualities of Light
Color temperature and color rendering qualities of lighting should be carefully reviewed and documented during the design process. Color temperature can be rationalized on many levels: classification of retailer; quality of merchandise; client preference; and designer preference. The whiteness of the light arguably contributes to the overall atmosphere and mood. Where a more residential or less institutional appearance is desired, 2700 K to 3200 K CCTs may be appropriate. Where a neutral-white color of light is desired, 3300 K to 4100 K CCTs should be considered. Where a crisp-white color of light is desired, 4200 K to 6500 K CCTs should be considered. Mockups or at least sample reviews of operable lamps are appropriate prior to final specification.

Color rendering affects visual discrimination of color tones and contrast. Where colorful merchandise and architectural finishes are used a rich, vivid scene results with high color rendering light. For many retail applications, a CRI of 80 should be considered a minimum. Lamps with lower CRIs will render many colors as muted or dulled. Mockups or sample reviews of operable lamps exhibiting the proposed CRIs are appropriate prior to final specification.

Matching CCTs and CRIs for electric lamps is desirable, but often impractical if not impossible. Nevertheless, to limit harsh and readily obvious differences, unless these are desired for effect, attempt should be made to match CCTs and CRIs from one electric source to another. Daylight exhibits a wide range of color temperatures based on time of day and sky condition and the daylight aperture glazing. Matching electric light CCTs to daylighting is usually unwarranted, if not futile, given the fleeting nature of daylight. Daylight exhibits CRI of 100 during most daylight conditions. Many shoppers appreciate access to daylight to review color of many products since these are likely to be seen outdoors or under interior daylight conditions.

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Merchandise Fading and Bleaching

Display lighting, particularly highlight and dazzle, and uncontrolled daylighting can fade and bleach merchandise. The degree of susceptibility is merchandise dependent. Some materials are susceptible to UV, or IR, or visible radiation or some combination. Where the merchandise is a consistent product and universally susceptible to specific radiation, such as chocolate to IR, lamp selection or lamp and glazing filters on daylight media and on display cases can be employed. Where merchandise is moved periodically or simply changes seasonally, it may be impractical to select lamping to address both IR and UV and still provide appropriate illuminance and color quality. Several techniques can be used to limit exposure to fading and bleaching:

- Rotate merchandise
- Display sacrificial items
- Automate controls

Rotating merchandise requires staff intervention to rotate merchandise out of the high-illuminance condition on a 7- to 10-day cycle. Sacrificing items for display purposes and not for resale requires retailer staff concurrence and intervention. Automated controls can incorporate photocell and time clock functions to adjust light levels and simply extinguish lights on a regular basis to minimize exposure. Where merchandise has a high turnover rate or where its packaging is opaque or the merchandise consists of durable materials and finishes, no measures to limit fading and bleaching may be necessary. Programming information or interviews with store owner or merchandise display designers should reveal any need for IR or UV control. Natural fabrics and dyes may be especially susceptible. Table 21.3 | Light Sensitivity Categories identifies some materials and their relative sensitivity to UV. Section 21.2.7.2 Objects discusses UV control for preservation-worthy objects. Packaging or merchandise that is considered more sustainable may be more vulnerable to IR and UV.

34.2.12 Retailing, Outdoor

Outdoor retail lighting involves lighting of the shopping and transaction areas. Unlike indoor retailing, the shoppers' states of adaptation are much lower outdoors. Lighting should be designed for this outdoor seeing condition rather than attempting to impose indoor illuminances. Outdoor retailing has few walls and ceilings to contain and reflect light. Lighting must be designed and controlled to specifically address tasks and surfaces rather than attempting to uniformly floodlight a setting. The night environment is greatly affected by electric lighting. Lighting should be optically appropriate and electrically controlled to place light only where and when needed in the recommended illuminances cited in Table 34.2. In general, illuminance criteria are much lower than for interior situations. Color contrast, typically enhanced with lamps exhibiting CRIs ≥80, can help, to a point, compensate for low illuminances in outdoor situations.

See 26 | LIGHTING FOR EXTERIORS for additional information related to outdoor sensitivities involving light trespass and light pollution.

Automotive Sales

In addition to an indoor showroom and service facility, an automotive sales property is usually comprised of outdoor circulation drives, featured vehicle, parking, preparation and storage, and sales or retail area. Tailor lighting of these properties to the anticipated levels of activity and the nighttime outdoor lighting zones within which they are located.

Outdoor automotive sales generally involve destination shoppers viewing models and buyers taking delivery of vehicles at times of convenience. Visual tasks include gross inspections of vehicle forms, components, trims, and finishes and window stickers. Perhaps the easiest of these tasks is reading window stickers. Standardized simple-style black-ink fonts, with bold and large typefaces outlining key information on generous label sizes offer inherent advantages. Coupled with no real penalties on speed and accuracy of visual performance, this task requires relatively low illuminance.



Figure 34.10 | Automotive Sales
Vehicle luminance is starkly illustrated in the top image. Even under low outdoor illuminances lighter-colored vehicles will elicit significant visual attention.

Straightforward cutoff pole luminaires can provide appropriate illuminances at the retail areas for casual nighttime viewing. Relatively low-wattage luminaires with highly-controlled optics will limit light trespass and upward light. Lamps should be recessed entirely into the luminaire housing with no dropped lens for best glare control of general lighting. LEDs may offer dazzle and glitter reflections from vehicles, but must be well-controlled optically to limit direct glare. Lamps with CRIs ≥80 are appropriate.

Showroom general lighting consists of three techniques: diffuse indirect; linear accent; and direct. The combined effect of these on form, contours, and finish are evident in the bottom image. The auto placed immediately outside the showroom also benefits from the luminances of the indirect and linear accent lighting.

» Images ©Jim R. Bounds/Bloomberg via Getty Images

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Vehicle forms, components, and trims can be tentatively assessed in relatively low illuminances as seen in Figure 34.10. However, complete and detailed assessments are best performed under very high illuminances and luminances, daylight being preferred, or in the indoor showroom conditions where some amount of diffuse indirect lighting, linear accenting, and highlighting should be made available for appraisal of the sheet metal and other formed materials, their contours, surface qualities, gauges, and fit as seen in the bottom image of Figure 34.10.

Vehicle finishes can only be tentatively assessed under relatively low illuminances. Appraising quality of application of the finish, including consistency, depth, coverage, flake content or iridescence, if any, and color is best done in daylight or showroom conditions. Color aspects include appraising color matching, where applicable, between various substrates such as metal, plastic, fiberglass, and composites. Color reviews under electric lighting in mesopic and photopic states are arguably reasonable when lamps exhibit CRIs ≥80.

Controls are used to dim or step-dim lighting at closing or curfew. For best energy savings, extended in-service life, and environmental benefit, lights might be extinguished except as may be necessary for security. Where instant-on lamps are used, motion sensors are appropriate means of control after hours.

Seasonal Open-air

Open-air markets usually consist of produce stands or designated selling zones where seasonal merchandise is displayed for sale. Lighting must be tailored to the anticipated level of activity and the nighttime outdoor lighting zone in which the market is located. General retail lighting must be well-controlled optically to limit light trespass, light pollution, and glare. Traditional *RLM* luminaires using deep reflectors with lamps recessed above the bottom of the reflector can be effective. Contemporary luminaires with optics appropriate to outdoor sensitivities are also available for general and feature display lighting.

Service Stations

Outdoor lighting for service station retailing should, like other outdoor and indoor retailing, target visual tasks with little extraneous light. This minimizes glare and efficiently directs lighting energy for best visual effect and performance. Illuminance criteria are based on level of anticipated activity and the nighttime outdoor lighting zone in which the service station is located. This coordinates with drivers' adaptation states. See Figure 34.12. Dispensing equipment is evolving from gasoline and diesel to alternative fuels, including electricity. At publishing time, standards for two levels of charging equipment have been adopted by the Society of Automotive Engineers (SAE) and a third is under consideration [6]. The Level 2 and Level 3 charging stations are likely to be accessible at parking lots and service stations. Their formats and locations and the nature of the charging task should be monitored as these aspects may require illuminances other than those recommended in Table 34.2.

34.2.13 Support Spaces

These relatively back-of-house citations are self-explanatory.

34.2.14 Toilets/Locker Rooms

Lighting for toilets and locker rooms is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. Addressing the fixture functional areas, such as toilets, urinals, vanities, will provide sufficient light where needed without overlighting the entire toilet room. Vanities are problematic when little or no vertical illuminance is designed to illuminate an imaginary facial plane (roughly a zone of sufficient size to encompass faces) in front of the mirrors. Design treatments vary based on retail classification.

Vertical light on the faces of lockers will assist with locker use.

RLM was originally an acronym for Reflector and Lamp Manufacturers, an association formed by GE and Electrical Testing Laboratories in the early 20th century to develop and promote standards for luminaire reflectors. Some vintage models survive or have been revived today with modern lamping options. Their simple construction and appearance make these arguably timeless [5]. See Figure 34.11.



Figure 34.11 | RLM Luminaires
The series of luminaires in the foreground top are variations of RLMs used to light these market displays.
» Image ©iStockphoto/Natalia Bratslavsky

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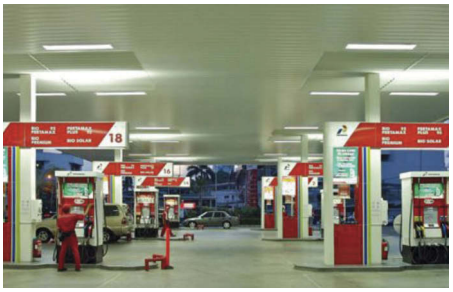






Figure 34.12 | Service Stations
Task-oriented downlighting identifies dispensing equipment from some distance and illuminates the task locally in the top left.

In the top right image, recessed luminaires designed with special asymmetric reflectors with one focal center aimed at each sign and one focal center aimed at the face of each dispenser. Lamps are T5/HO fluorescent exhibiting a CCT of 6500 K.

Direct lighting equipment should use luminaire optics to control light spread and glare. Lenses should be recessed above the bottom of the luminaire or flush with it. Dropped lenses are inappropriate.

An indirect approach in the middle image diffusely illuminates the fueling area with no glare. The vaulted canopy confines the light.

The bottom image illustrates a charging station for electric vehicles.

» From top left clockwise:
» Image ©Klaus Hackenberg/Corbis
» Image ©Abdi Ahsan/Lumina Group
» Image ©iStockphoto/Magdalena Jankowska
» Image ©Rebecca Cook/Reuters/Corbis

34.2.15 Transition Spaces

Most of these spaces are self-explanatory. Codes may demand different illuminances in some circulation areas, including elevators, escalators, and stairs which the designer must address.

Typically, for visual consistency and total store branding as well as for purposes of maintenance convenience, lamp types and color qualities should match those used elsewhere.

34.3 Illuminance Criteria

Illuminance criteria, when fully deployed, are a robust set of quantitative values that influence visibility, visual performance, and visual comfort and attention. Short-circuiting the criteria selection or designing to a single criterion value, such as horizontal illuminance, to address worst-case tasks will surely result in dissatisfaction. Even if clients accept the visual results, not getting the most from the energy expended or, worse, energy waste is a likely result. Following are notes related to various aspects outlined in Table 34.2.

34.3.1 Applications and Tasks

Applications and tasks encountered on any given project may be different from those identified in Table 34.2 and may warrant different illuminance criteria. Cross-referencing closely-associated applications or tasks is appropriate. Sometimes naming trends or conventions for space types or functions change to conform to current practice, client programming, or architectural conventions, but the actual activities and tasks remain the same and this cross-referencing works. Failing this technique, reviewing the list in Table 34.2 may be in order to determine if any applications or tasks exhibit a similar visual-component to the unique applications or tasks. Otherwise, reviewing 4.12 An Illuminance Determination System and Table 4.1 is necessary to establish a task category based on the task characteristics or visual performance descriptions most closely associated with the unique applications or tasks. These exercises as well as any deviations from recommendations the designer intends to make should be carefully documented for the record.

34.3.2 Notes

Notes may refer to other application and task headings in the table or to other handbook chapters as appropriate. Where some degree of clarification is warranted, notes are made.

34.3.3 Recommended Maintained Illuminance Targets

Values cited are maintained on the area of coverage for the task under consideration. Illuminance is additive. Where practical and without negatively affecting the intended application of light, target values are achieved with any combination of daylighting and/or electric lighting in whatever mix of ambient, task, and accent lighting is deemed appropriate to meet these and the other lighting goals established during design. See 12 | COMPONENTS OF LIGHTING DESIGN and see 10.7.1 Light Loss Factors.

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With respect to light loss factors, account for anticipated losses through the point in time at which group relamping and cleaning should occur. Group relamping and cleaning should be standard practice, though these need not occur at the same frequency. Periodic cleaning and group relamping essentially maintain the illuminance at criteria and make the most efficient use of the installed equipment. For purposes of sustainability, cleaning and group relamping can no longer be presumed to be infrequent or unlikely. Maintenance procedures must be part of the design discussions with the client. See the IES document IESNA/NALMCO RP-36 Recommended Practice for Planned Indoor Lighting Maintenance for additional information. Where maintenance is deferred or practiced poorly or not at all, the actual illuminance values will fall below criteria targets. This is inefficient, unsustainable, and may be unsafe while adversely affecting users' quality of life or work. Ratcheting initial illuminances higher is poor practice and not recommended. Maintenance procedures may be especially problematic with LEDs where promises of extraordinarily long life may be offered, but usually with the caveat that lamp lumen depreciation (LLD) at that rated life is 70% or perhaps even as low as 50% of initial rating. If replacement cycles are presumed to be rated life, then LLD alone must be 0.7 or 0.5 or whatever lumen rating is certified by the LED vendor. See 13.3 Life and Lumen Maintenance.

Targets cited are consensus and recommended for respective functional activity. For some applications, IES recommendations are within 10% of code requirements. This apparently is an artifact of metrication. Footcandle conversions of any values cited in Table 34.2 should be made at 1 fc to 10 lx. This soft conversion avoids a redundant diminishing of illuminance values after multiple citations and conversions over time. This also eliminates a false sense of accuracy advanced by an ever-increasing number of decimal places and a false sense of urgency advanced by eccentric fractional values introduced by hard conversions. Nevertheless, a lighting design must meet code and the mechanics of which must be coordinated amongst the design team. The IES recommendations should not, do not, and cannot reflect all of the various code requirements in force in all jurisdictions at any given time.

Targets are intended to apply to the dominant plane of the task, typically, but not always, horizontal or vertical. In some situations, illuminance criteria are cited for one plane, such as the vertical plane for perimeter lighting in indoor retailing situations, while the other plane is blank. The blank signifies that illuminance on that plane is unimportant and may be a consequence of the illuminance of other tasks within the vicinity or by whatever illuminance results from meeting the target illuminance for the prescribed plane of interest.

In some situations, no light is anticipated on one or both planes of a task. A dash indicates no light or zero light is recommended for the task or application, such as exterior facing show windows at night after curfew in LZ1 locales.

34.3.3.1 Target Planes

Many, though certainly not all, tasks are performed with the task in roughly a horizontal orientation or vertical orientation. A dominant orientation must be assigned and the illuminance target determined accordingly. There may be situations where the IES recommended target relating to the typical planar mode of a task must be applied to a different plane. For example, if a home/bath/bedding store general retail area consists primarily of vertically oriented product displays, then a more exciting rendering of those general retail areas will take place if the horizontal illuminance criteria from Table 34.2 are actually assigned as the vertical illuminance criteria and vice versa. This, however, pressures the designer to attend to glare issues associated with higher vertical illuminances.

Nearly all tasks are expected to have both a horizontal illuminance component (E_h) and a vertical illuminance component (E_v). This allows some degree of task flexibility for off-plane viewing and accommodates various aspects of the task. In many retail applications accommodating a variety of merchandise displays, horizontal- and vertical-plane illuminances address the common situation where simultaneously some merchandise or some portion of the merchandise is on horizontal planes while other merchandise or portion is on vertical planes.

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Where illuminance targets are intended at differing planar elevations, this is indicated under "Notes." For example, for outdoor general merchandise displays (RETAILING, OUTDOOR/Seasonal Open-air/Merchandise), E_h illuminance targets are intended for 2' 6" above finished grade while E_v illuminance targets are intended for 4' 0". Establishing and tracking task orientations and addressing both horizontal and vertical illuminance is necessary. If orientations in the project under consideration are programmed to be flipped from what might be considered normal-viewing, then criteria must be adjusted accordingly. If a task is scheduled to be oriented on some plane off axis from horizontal or vertical by more than 10°, say, then the illuminance criteria must be applied to that off-axis orientation. This is an important distinction for luminaire optical selection and aiming capabilities and for layout, calculations, and field measurements.

For planes related to vertical illuminance targets, some guidance is indicated under "Notes" where the directional orientation of the plane is believed straightforward and easily identified. However, the designer may elect to use alternate or multiple vertical planes. In some situations the vertical planes could be oriented in a number of directions and the designer must determine which are most appropriate for the situation. For example, feature displays may have a single direction of view or may have multiple directions of view. Lighting three or four sides where only a single-direction-view is possible for shoppers is a waste of resources. Lighting one or two sides of a display with a 360-degree-view may be a lost opportunity in drawing the attention of a significant number of shoppers. The designer must analyze the situation and determine what best meets the needs of the retailer.

34.3.3.2 Visual Ages of Observers

Illuminance criteria are based on the visual ages of more than half the intended observers. The designer must coordinate with the design team and retailer to establish the age group of the intended observers. The target market may differ from those making the actual purchase, such as parents of shopping children, or from the sales staff. Perhaps transaction areas are illuminated to one age group's criteria while retail areas and feature displays are lighted to another's. The aspects of observers' ages, task sets for age groups, and illuminance targets should be resolved during programming with the client. See 12.5.5 Illuminance and 4.12 An Illuminance Determination System for additional information and guidance.

34.3.3.3 Illuminance Categories

Illuminance categories are designated by letters A through Y. These are shown in Table 34.2 for more convenient reference to Table 4.1 | Recommended Illuminance Targets should the designer wish to explore other criteria targets or if applications or tasks on a specific project are not readily correlated to the table citations.

34.3.3.4 Gauge

The common gauge for determining illuminance target compliance is cited for each application. All gauges presume that point-by-point techniques are used for predictive calculations and presume that uniformity criteria are closely monitored. Where an average illuminance value over the area of coverage can satisfy target compliance, "Avg" is cited. In applications or tasks where a minimum or maximum target is necessary, the gauge for compliance is "Min" or "Max" respectively.

The designer may elect to use other methods to evaluate target compliance, such as criterion rating (CR) or coefficient of variation (C_v). See 4.12.4.5 Tasks at Uncertain Locations Over a Large Area.

In any event, once illuminance targets and uniformities are established, then any calculated deviation from them should be limited. Standard engineering allowance of ±10% might be acceptable for targets gauged as average unless contractual or code obligations demand otherwise. Minima and maxima must be achieved as intended.

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Designs should be adjusted until predictions are within allowance for averages and meet minima and maxima. For additional information, see 4.12.4.1 Recommended Illuminances at Design Time, 4.12.5 Illuminance Ratios, 9.15.1.1 Average Illuminance, and 10.8 Assessing Computed Results.

34.3.4 Uniformity Targets

Illuminance uniformity targets work in conjunction with luminance uniformities and surface reflectances all of which must be addressed as part of the design to avoid visual discomfort, glare, and strain. Uniformity ratios are targets that define the widest recommended ranges. In many situations, uniformity ratio criteria are those between average values of an array of points and the minimum value in the same array of points. Uniformity targets apply to both horizontal and vertical illuminances over the area of coverage. Where horizontal uniformity criterion is different from vertical uniformity criterion, two ratios are reported with the first value for horizontal illuminance (E_h). In some situations, notably those with regard to exterior illuminances, two uniformity values are cited. The first value addresses the primary cited application or task. The parenthetical value references the parenthetical application or task, such as a curfew situation associated with nighttime outdoor lighting.

Generally the more important speed and accuracy and the more demanding the visual task, the tighter the ratio.

34.3.4.1 Maximum-to-average

This is the recommended ratio of maximum illuminance to the average illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations sensitive to even a relatively small degree of overlighting.

34.3.4.2 Average-to-minimum

This is the recommended ratio of average illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where illuminance too far below average conditions is noticeable and detrimental to task performance or inconsistent with normal expectations.

34.3.4.3 Maximum-to-minimum

This is the recommended ratio of maximum illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where too much variation in illuminance is considered undesirable and untenable from a performance or safety perspective.

34.3.5 Daylighting Advancement

Generally, design strategies should embrace any combination of daylighting and electric lighting to achieve target values during daylight hours. The preference is for daylighting to provide all or most of the recommended illuminance presuming that all aspects of daylighting are properly addressed. A sunburst icon depicts those applications and tasks where daylighting is considered a strategic candidate. Use photocells and stepped-dimming or continuous dimming to reduce or eliminate electric lighting during daylight hours. See 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Even for those applications where daylighting is not traditionally a strategic candidate, it may be determined that very careful and coordinated design will offer great sustainability opportunities along with positive influences associated with daylight and views.

Daylight must be controlled to provide illuminances appropriate to the task. Overlighting with daylight can accelerate fading and bleaching of merchandise.

34.3.6 Veiling Reflections

Tasks with specular components, which in retail includes most anything behind glass, are prone to veiling reflections. The likelihood of particular applications and tasks predisposed

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to veiling reflections is indicated by a "reflected light" icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood. In situations where merchandise is behind glass, veiling reflections are minimized by carefully analyzing geometry of luminaire-to-glass-plane-to-shopper. Placing lighting equipment outside the typical viewing orientations can help as can the use of anti-reflective glass for the case. Using lighting within the display case is generally superior, though LEDs or fiber optics are best to avoid excessive heating of the display case and limit UV and IR (see Figure 34.13).

34.3.7 Defining Areas of Coverage

In addition to establishing planes of task orientation, the areas of coverage to which targets apply must be determined. Typical areas of task illuminance coverage are identified here, but these may not be appropriate to specific project situations. One area of coverage is "task proper or task area." Here, the illuminance criteria are applied to the task itself or to a relatively small area to which the task is confined. See 12.5.5.1 Tasks and Applications and Figure 12.22 | Task Coverage Example. In some situations, such as accenting, the "task" area may consist of the entire wall when "feature wall" or "perimeter" accenting is desired. It is important to remember that illuminance is additive, that is, task illuminance can be achieved with some combination of ambient lighting, task lighting, and/or accent lighting, providing that the total illuminance on the task proper or task area meets the illuminance criteria outlined in Table 34.2. With outdoor retail areas it is most effective to target light to task proper or task area. General lighting, unless extremely low level over the important shopper-occupied zones, is inappropriate over large areas of the merchandising property.

Another area of coverage is "room or designated area." In this situation, illuminance criteria are applied to the room or an area of fairly substantive size representing the zone in which the applications and tasks are expected to occur. The designated area is typically established by the department or retail layout, for example, but should be scrutinized by the design team and retailer. If, however, the task will be confined to one portion of the department area or if the room or area in which the task is located is itself relatively small, and if the other design goals and criteria outlined in 12 | COMPONENTS OF LIGHTING DESIGN are addressed, then a strategy of refining area or areas of coverage to the task proper or task area has merit. This can result in reduced energy use, more significant visual emphasis of the merchandise, and a more visually interesting and exciting shopping experience.

An assessment and determination must be made on which area of coverage best satisfies the lighting goals on a particular project.



Figure 34.13 | Display Cases
Veiling reflections can be avoided with displays behind glass by using lighting internal to the case. LED or fiber optic luminaires limit heat in the cases and limit UV and IR.
» Image ©Kenneth Johansson/Corbis

34.4 Designing

Information provided here is specific to retail facilities and should be used as part of the design and documentation processes outlined in Chapters 12, 15, and 20. For outdoor applications, lamps and ballasts, transformers, and drivers must be selected for ambient temperature conditions, some of which are extremely hot and others extremely cold. See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY for additional information on respective aspects. Addressing all code requirements is a must. Energy efficient and sustainable practices are an integral part of all IES recommendations. Key design tenets include, but are not limited to:

- designing for the satisfaction of the observers intended to use the project
- using baseline reflectances of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively) in interior production and work-oriented spaces
- using daylighting that meets luminance and illuminance criteria

IESH/10e Economics Resources

> 15.3.3 Budgets
  - for more on budgets and value engineering

> 18 | ECONOMICS
  - for more on estimating costs
  - for more on life cycle costs
  - for more on paybacks and rates of return

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IESH/10e Energy Efficiency Resources

> 17.2 New Construction
- for more on designing for daylighting
- for more on electric lighting equipment
- for more on lighting controls

> 17.4 Lighting Codes, Regulations and Standards
- for more on application standards
- for more on equipment regulations

IESH/10e Lighting Exteriors Resources

> 12.5.5.6 Nighttime Outdoor Illuminances
- for more on lamp efficacies under mesopic adaptation

> 26 | LIGHTING FOR EXTERIORS
- for more on criteria

IESH/10e Sustainability Resources

> 13.11 Sustainability
- for more on lamps

> 19 | SUSTAINABILITY
- for more on controls
- for more on earth resources
- for more on energy
- for more on life cycle analyses
- for more on lighting design
- for more on recycling

- using highest-efficacy lamps that meet color, optical and electrical control, and output criteria
- using highest-efficiency luminaires that meet aesthetic and luminance criteria
- using accenting to provide luminance balancing or improve brightness perceptions where necessary
- using controls liberally, preferably automated varieties such as presets, occupancy and vacancy sensors, astronomical time clocks, and photocells
- establishing IES-recommended illuminance criteria to meet programmed tasks
- establishing layouts that just meet IES-recommended illuminance criteria
- addressing outdoor environmental needs
- using calculations, photometrically-realistic renderings, and operational samples and mockups to prove concepts
- identifying and designing to code-specific requirements, if any, for ambient, task, and accent lighting
- documenting all code-, energy-, sustainability-, and IES-criteria compliance
- documenting criteria and design deviations and rationale and subsequent disposition by team, client, or AHJ
- documenting clearly the layouts, controls, and luminaire and lamp selections

Designing for the satisfaction of the observers is the paramount design tenet and must be kept in perspective during all aspects of design. If the observers' expectations are not fulfilled, then how much energy could be saved is moot, as is how many fewer earth resources were spared, as is how much the whole affair cost or how much value engineering saved or the photogenic qualities of the project. See sidebar references for additional guidance on the key tenets. The design effort must be undertaken with coordinated and realistic expectations by all involved on initial and life cycle costs. Budgeting should include designer input and dialogue with the team and client at project commencement and design milestones. In other words, and paraphrasing Thomas Edison, genius is, indeed, just 1% inspiration and 99% perspiration.

34.5 References

[1] Discovering "WOW" – A Study of Great Retail Shopping Experiences in North America. In: Wharton School of Business. [Internet]. cited October 2010. Available from: http://www.wharton.upenn.edu/news/news-release-new-retail-study.cfm.

[2] [DOE] US Department of Energy, Energy Information Administration. 2003. Table E5A. In: Electricity Consumption (kWh) by End Use for All Buildings [Internet]. DOE. [cited December 2008]. Available from: http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html#enduse03.

[3] Mark S. Rea, ed. 2000. The IESNA lighting handbook: Reference and application. 9th Edition. New York: IESNA. Ch 17.

[4] [IESNA] Illuminating Engineering Society of North America. Recommended practice for lighting merchandise areas IESNA RP-2-01. New York: IESNA.

[5] DiLaura DL. 2005. A history of light and Lighting. New York: IESNA. 416 p.

[6] Ponticel P. 2010. SAE standard on EV charging connector approved[In ternet]. Automotive Engineering International. [cited October 2010]. Available from: http://www.sae.org/mags/AEI/7479.

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35 | LIGHTING FOR SPORTS AND RECREATION

Do you what my favorite part of the game is? The opportunity to play.
Mike Singletary

Sport has always been a part of civilization, but it is only general economic growth and prosperity that provide leisure time sufficient for recreation and sport. A consequence of this has been growth in the demand for facilities to accommodate the large numbers of people who want to participate in sporting events, seeking desirable leisure time activities that are healthy and fun. Sports have also become an important form of entertainment. Venues for spectators of amateur, collegiate, and professional sports are complex facilities that must provide not only for the spectators, but also the equipment used in modern sports broadcasting. Sports are also an important part of education, with gymnasia, ball fields, and other sports facilities commonly being part of schools and municipal recreation centers.

Comprehensive design efforts involve the information in this chapter combined with material in 12 | COMPONENTS OF LIGHTING DESIGN, 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS, 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Design tenets deemed appropriate from those chapters must be identified and lighting goals and strategies developed accordingly. This chapter primarily addresses illuminance criteria for sports applications which should influence luminaire optical selections, lampings, and final layouts based on design thought-starters (see 15.2 A Lighting Scheme). Use of the material in this chapter to the exclusion of material in Chapters 12, 13, 14, and 15 will likely lead to unsatisfactory results. 21 The IESNA Recommended Practice for Sports and Recreational Area Lighting shows the best locations for luminaires to be placed, and is an invaluable source of information for designing sports facilities [1][2].

Deliberate thought must be given to details beyond the recommended illuminances in this chapter. For example, From Table 35.3, for BASEBALL/Infield, the vertical illuminance citation does not necessarily reveal the demand for light from multiple directions required to minimize shadows and provide good modeling of ball and players. Though a target illuminance can achieved, the manner of bringing it about can be as important as the value itself. Such specific details are not enumerated for all tasks. Table 35.1 offers a checklist of IES lighting topics and criteria. The design team is responsible for determining and addressing indoor and outdoor lighting and energy criteria set forth by authorities having jurisdiction (AHJ) which may be different from and supersede IES criteria. See also 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

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35.1 Project Type and Status

Before any design work, an understanding of the project type and scope is necessary. This will establish the extent to which daylighting can address most or many or some of the lighting goals. New, renovation, and restoration projects each offer varying opportunities. See 11.2 Planning, 11.3.1 Pre-design, and 11.3.2 Schematic Design. At every opportunity the lighting designer should give every consideration to daylighting as a light source. For some applications and tasks, daylighting can be the primary light source. Critically, this means addressing the host of lighting factors identified in 12 | COMPONENTS OF

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Table 35.1 | Sports Lighting Checklist

Topics
✔ **Criteria and Design Resources**
Color
6.3 Color Rendition
6.6 Color Appearance
12.5.6 Color Considerations
Controls
16 | LIGHTING CONTROLS
Daylighting
14 | DESIGNING DAYLIGHTING
Electric Lighting
15 | DESIGNING ELECTRIC LIGHTING
Flicker
4.6 Flicker and Temporal Contrast Sensitivity
Glare
4.10.1 Discomfort Glare
4.10.2 Disability Glare
Illuminance
This Chapter: Table 35.3
12.5.5.1 Applications and Tasks
Table 12.6 | Default Illuminance Ratio Recommendations
Figure 12.22 | Task Coverage Example
Luminaires
8.2 Classifying Luminaires
8.3.3.2 Sports Lighting
Luminances
12.5.2 Luminance
Table 12.5 | Default Luminance Ratio Recommendations
Maintenance
15.4.4 Installation and Maintenance
Nighttime Outdoor Environment
Table 15.6 | Nighttime Operational Strategies for Improved Outdoor
Visual Tasks
This Chapter: Section 35.2
This Chapter: Table 35.3
Table 11.2 | Programming: Inventory Scope and Specific Examples
12.5.1 Visual Tasks
Table 12.3 | Sample Visual Task Survey

LIGHTING DESIGN. Daylight demands attention to moderate or eliminate glare and balance visible and thermal energy.

In general, as the skill level is elevated, players and spectators require a better and more sophisticated luminous environment. A correlation exists between the size of a facility and the level of play, for example, a higher skill level attracts a greater number of spectators. As the number of spectators increases their distance from the playing surface increases and their need for increased illuminance to see players and tasks requires the values to increase. Accordingly, facilities should be designed to satisfy the most talented players and accommodate the greatest potential spectator capacity. It is important to note that in large facilities which seat over 10,000 spectators the lighting criteria are usually governed by the needs of television. Recommendations for such facilities are not included in this chapter. To determine illumination criteria, this chapter groups facilities into four classes based on the skill levels of the players and the anticipated number of spectators. See Table 35.2.

- Class I - Competition play before a large group (5000 or more spectators). However, for the purpose of this Practice, illumination criteria for individual sports are limited to a spectator capacity of 10,000 or less. Lighting criteria for major stadiums and arenas require special design considerations such as vertical and horizontal illuminance values not covered by this Practice, which may be defined by individual sports and/or broadcasting organizations.
- Class II - Competition play with facilities for up to 5000 spectators.
- Class III - Competition play with some spectator facilities.
- Class IV - Competition or recreational play only (no provision for spectators).

To develop lighting solutions that meet quality, quantity, and operational criteria, an assessment must be made of the sport or sports that will be played, the level of play, and the requirements of spectators that the facility to be lighted must accommodate. Sports may be considered either aerial sports or ground level sports. Within each of these two groups, all activities can be further divided into multi-directional sports and unidirectional sports.

35.1.1 Aerial Sports

These sports involve playing with an object (such as a ball) that is in the air at least part of the time. The major subcategories are multi- and uni-directional.

35.1.1.1 Multi-directional

Multi-directional aerial sports are sports where the players and spectators view the playing object from multiple positions and viewing angles. These sports demand critical vertical illuminance over the height of the entire playing area as well as horizontal illuminance at ground level. It is important to control direct glare by locating the luminaires away from the most frequent viewing directions of players and spectators. Typical multi-directional aerial sports include badminton, baseball, basketball, football, handball, jai alai, ski jumping, soccer, squash, tennis, and volleyball.

35.1.1.2 Uni-directional

Uni-directional aerial sports are sports where the playing object is viewed in the air from a fixed position on the ground. General horizontal illuminance is required where the playing object is launched (start) and vertical illuminance is required where the playing object lands or is intercepted (finish). This is normally achieved by aiming some luminaires downward at the start and aiming other luminaires at high angles toward the finish. All luminaires must be shielded from the player's field of view. Typical unidirectional sports include golf at a driving range, skeet shooting, and trap shooting.

35.1.2 Ground Level Sports

These sports are played on the ground or a short distance above the ground. In the normal course of play, players and spectators do not look upward. The major subcategories are muti- and uni-directional.

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Table 35.2 | Class of Play and Facilities

Facility	Class of Play			
	I	II	III	IV
Professional	x			
College	x	x		
Semi-Professional	x	x		
Sport Clubs	x	x	x	
Amateur Leagues		x	x	x
High Schools		x	x	x
Training Facilities			x	x
Elementary Schools				x
Recreational Events				x
Social Events				x
Spectator Capacity	Over 5000	Under 5000	some	none

35.1.2.1 Multi-directional

Multi-directional ground level sports where the players and spectators view playing objects from multiple positions, normally looking downward, horizontally, and occasionally upward. These sports require well-distributed horizontal illuminance, although vertical illuminance should be considered. Typical multi-directional ground level sports include boxing, curling, field hockey, ice hockey, skating, swimming (excluding high board diving), and wrestling.

35.1.2.2 Uni-directional

Uni-directional ground level sports where the playing object is aimed at a fixed target near ground level (usually the target is in a vertical position). Vertical illuminance is critical at the target. It is normally provided by aiming luminaires (shielded from the players and spectators field of view) toward the target. Typical uni-directional ground level sports include archery, bowling, skiing, and target shooting.

35.1.3 Television Broadcasting

In larger facilities, sports events are broadcast or recorded for television. Higher illuminances allow the use of high speed shutters and small apertures that increase image sharpness and depth of field. More light also favors stop action, slow motion, and special effects created with telephoto/zoom lenses. Even simple panned shots of the playing field and spectator stands will show improved quality with higher luminances. : As high definition television (HDTV) replaces standard color television, it is recommended that lighting systems address the lamp's stroboscopic effect associated with low frequency ballasts on HID systems. This can be minimized by ensuring the illumination is provided by multiples of three luminaires, with overlapping beams which are balanced across three electrical phases. It should be noted that the recommended values in Table 35.3 do not necessarily provide sufficient illuminance for broadcast equipment. Many TV broadcast companies and sports leagues have recommended lighting specifications available and should be consulted to determine the appropriate illumination levels. Several aspects of the equipment used for television broadcasting can help define the type of project and lighting system required since they have an effect on illuminance requirements.

35.1.3.1 Position and Distance of the Camera Relative to the Playing Field

Telephoto lenses usually have a smaller optical aperture, and thus, require higher illuminance.

35.1.3.2 Apparent Speed and Size of the Object in Play

The speed of the object in play appears faster for movement across rather than along the direction of view. Smaller objects, such as baseballs or tennis balls, require higher illuminance than larger objects such as basketballs or footballs.

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Table 35.3 | Sports and Recreation Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d, e]								
		Horizontal (E_h) Targets					Vertical (E_v) Targets			
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are			
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
INDOOR SPORTS											
ANIMAL SHOWS	E_h @3' above competition surface. Categorized according to class of competition.										
• III			500	500	500	Avg		150	150	150	Avg
• IV			300	300	300	Avg		100	100	100	Avg
ARCHERY	E_h @3' above competition surface; E_v @vertical plane orientation. Categorized according to class of competition.										
• III											
• Shooting Line			300	300	300	Avg					
• Target distance @60'								500	500	500	Avg
• Target distance @300'								750	750	750	Avg
• IV											
• Shooting Line			200	200	200	Avg					
• Target distance @60'								300	300	300	Avg
• Target distance @300'								500	500	500	Avg
ARENA FOOTBALL	See Indoor/Soccer										
BASKETBALL	E_h @3' above competition surface. Categorized according to class of competition.										
• I			1000	1000	1000	Avg		300	300	300	Avg
• II			750	750	750	Avg		200	200	200	Avg
• III			500	500	500	Avg		150	150	150	Avg
• IV			300	300	300	Avg		100	100	100	Avg
BILLIARDS	@competition surface. Categorized according to class of competition.										
• I and II											
• Ambient			0.1 E_h of adjacent space, but ≥ 50					30	30	30	Avg
• Table and Rails			500	500	500	Min		150	150	150	Avg
• III											
• Ambient			0.1 E_h of adjacent space, but ≥ 50					30	30	30	Avg
• Table and Rails			500	500	500	Avg		150	150	150	Avg
• IV											
• Ambient			0.1 E_h of adjacent space, but ≥ 50					15	15	15	Avg
• Table and Rails		P	150	300	600	Avg	M	50	100	200	Avg
• Exclusively social recreation	E_h @surface of participation; E_v @5' above competition surface	O	100	200	400	Avg	K	25	50	100	Avg

Table 35.3 | Sports and Recreation Illuminance Recommendations continued next page

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Uniformity Targets[f] Over Area of Coverage		[g] [h]	Typical Area of Coverage[i]	
CV_{max}	Max:Min		Task Proper or Task Area	Room or Designated Area
0.25	3:1			
0.3	4:1			
0.21	2.5:1			
0.21	2.5:1			
0.21	2.5:1			
0.25	3:1			
0.25	3:1			
0.25	3:1			
0.13	1.7:1			
0.21	2.5:1			
0.25	3:1			
0.3	4:1			
0.25	3:1			
0.10	1.5:1			
0.25	3:1			
0.21	2.5:1			
0.25	3:1			
0.21	2.5:1			
0.25	3:1			

Notes for Table 35.3

The table column headings are discussed in detail in 35.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 35.4 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 35.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 35.3 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Minimum illuminance shall be set according to the following table:

Recommended Uniformity Ratio	Percentage of Average that Defines Mimimum
1.5:1	80%
1.7:1	74%
2:1	66%
2.5:1	57%
3:1	50%
4:1	40%

f. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

g. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

h. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

i. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

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Table 35.3 | Sports and Recreation Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d, e]								
		Horizontal (E_h) Targets					Vertical (E_v) Targets			
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are			
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
BOWLING	Categorized according to class of competition.										
• I											
• Approach	@competition surface		750	750	750	Avg					
• Lane	@competition surface		1000	1000	1000	Avg					
• Target	On face of head pin							1000	1000	1000	Avg
• II											
• Approach	@competition surface		500	500	500	Avg					
• Lane	@competition surface		750	750	750	Avg					
• Target	On face of head pin							750	750	7500	Avg
• III											
• Approach	@competition surface		300	300	300	Avg					
• Lane	@competition surface		500	500	500	Avg					
• Target	On face of head pin							500	500	500	Avg
• IV											
• Approach	@competition surface	M	50	100	200	Avg					
• Lane	@competition surface	N	75	150	300	Avg					
• Target	On face of head pin						P	150	300	600	Avg
BOXING AND WRESTLING	E_h @3' above competition surface. Categorized according to class of competition.										
• II			1000	1000	1000	Avg		300	300	300	Avg
• III			750	750	750	Avg		200	200	200	Avg
• IV			500	500	500	Avg		150	150	150	Avg
CHEERLEADING	See Gymnastics										
CURLING	@competition surface. Categorized according to class of competition.										
• I											
• Hack to Hog			1500	1500	1500	Avg		400	400	400	Avg
• Hog to Hog			1000	1000	1000	Avg		300	300	300	Avg
• II											
• Hack to Hog			1000	1000	1000	Avg		300	300	300	Avg
• Hog to Hog			750	750	750	Avg		200	200	200	Avg
• III											
• Hack to Hog			500	500	500	Avg		150	150	150	Avg
• Hog to Hog			300	300	300	Avg		100	100	100	Avg
• IV											
• Hack to Hog			200	200	200	Avg		50	50	50	Avg
• Hog to Hog			100	100	100	Avg		30	30	30	Avg
DARTS	E_h @3' above competition surface. Categorized according to class of competition.										
• III			300	300	300	Avg		500	500	500	Avg
• IV			200	200	400	Avg		300	300	600	Avg

Table 35.3 | Sports and Recreation Illuminance Recommendations continued next page

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Uniformity Targets[f] Over Area of Coverage		[g]	[h]	Typical Area of Coverage[i]	
				Task Proper or Task Area	Room or Designated Area
CV_{max}	Max:Min				
0.13	1.7:1				
0.13	1.7:1				
0.13	1.7:1				
0.21	2.5:1				
0.21	2.5:1				
0.21	2.5:1				
0.25	3:1				
0.25	3:1				
0.25	3:1				
0.3	4:1				
0.3	4:1				
0.3	4:1				
0.21	2.5:1				
0.25	3:1				
0.3	4:1				
0.13	1.7:1				
0.13	1.7:1				
0.21	2.5:1				
0.21	2.5:1				
0.25	3:1				
0.25	3:1				
0.3	4:1				
0.3	4:1				
0.17	2:1				
0.25	3:1				

Notes for Table 35.3

The table column headings are discussed in detail in 35.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 35.4 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 35.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 35.3 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Minimum illuminance shall be set according to the following table:

Recommended Uniformity Ratio	Percentage of Average that Defines Mimimum
1.5:1	80%
1.7:1	74%
2:1	66%
2.5:1	57%
3:1	50%
4:1	40%

f. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

g. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

h. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

i. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

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Table 35.3 | Sports and Recreation Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d, e]							
		Horizontal (E_h) Targets				Vertical (E_v) Targets			
		Visual Ages of Observers (years) where **at least half** are				Visual Ages of Observers (years) where **at least half** are			
		<25	25-65	>65		<25	25-65	>65	
		Category			Gauge	Category			Gauge
FENCING	E_h @3' above competition surface. Categorized according to class of competition.								
• III		500	500	500	Avg	150	150	150	Avg
• IV		300	300	300	Avg	100	100	100	Avg
FIGURE SKATING	See Sports/Indoor/Skating/Figure								
FIRING RANGE									
GOLF, INDOOR DRIVING RANGE	E_h @competition surface. Categorized according to class of competition.								
• IV									
• Tee Boxes		300	300	300	Avg				
• Face of 600' distance marker	E_v @face of the marker					200	200	200	Avg
GYMNASTICS	E_h @3' above competition surface. Categorized according to class of competition.								
• II		750	750	750	Avg	200	200	200	Avg
• III		500	500	500	Avg	150	150	150	Avg
• IV		300	300	300	Avg	100	100	100	Avg
GUN RANGE	Categorized according to class of competition.								
• III									
• Shooting Line	E_h @3' above competition surface	300	300	300	Avg				
• Target	On target area					1000	1000	1000	Avg
• IV									
• Shooting Line	E_h @3' above competition surface	200	200	200	Avg				
• Target	On target area					500	500	500	Avg
HANDBALL	E_h @3' above competition surface. Categorized according to class of competition.								
• II		750	750	750	Avg	200	200	200	Avg
• III		500	500	500	Avg	150	150	150	Avg
ICE HOCKEY	E_h @3' above competition surface. Categorized according to class of competition.								
• I		1500	1500	1500	Avg	400	400	400	Avg
• II		1000	1000	1000	Avg	300	300	300	Avg
• III		750	750	750	Avg	200	200	200	Avg
• IV		500	500	500	Avg	150	150	150	Avg

Table 35.3 | Sports and Recreation Illuminance Recommendations continued next page

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Uniformity Targets[f] Over Area of Coverage		[g]	[h]	Typical Area of Coverage[i]	
CV_{max}	Max:Min			Task Proper or Task Area	Room or Designated Area
0.25	3:1	■			■
0.3	4:1	■			■
0.25	3:1	■		■	
0.25	3:1	■			■
0.21	2.5:1	■			■
0.25	3:1	■			■
0.3	4:1	■			■
0.21	2.5:1				■
0.21	2.5:1				
0.25	3:1				■
0.25	3:1				
0.21	2.5:1	■			■
0.25	3:1	■			■
0.13	1.7:1	■			■
0.21	2.5:1	■			■
0.25	3:1	■			■
0.3	4:1	■			■

Notes for Table 35.3

The table column headings are discussed in detail in 35.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 35.4 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 35.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

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d. Targets are intended to apply to the respective plane or planes of the task.

e. Minimum illuminance shall be set according to the following table:

Recommended Uniformity Ratio	Percentage of Average that Defines Mimimum
1.5:1	80%
1.7:1	74%
2:1	66%
2.5:1	57%
3:1	50%
4:1	40%

f. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

g. Applications and tasks cited with sunburst icon ■ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

h. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ■ signals high likelihood; gray and white ■ signals moderate likelihood; pale gray and white ■ signals some likelihood; and all-white signals little-to-no likelihood.

i. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

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Table 35.3 | Sports and Recreation Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d, e]									
		Horizontal (E_h) Targets				Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are				Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
ICE SKATING	See Sports/Indoor/Skating/Ice/Figure										
JAI ALAI	E_h @competition surface; E_v @vertical plane orientation. Categorized according to class of competition.										
• I											
• Floor			750	750	750	Avg					
• Frontis								1000	1000	1000	Avg
JUDO	See Wrestling										
KARATE	See Wrestling										
PING PONG	See Sports/Indoor/Table Tennis										
PISTOL RANGE	See Sports/Indoor/Gun Range										
POOL	See Sports/Indoor/Billiards										
RACQUETBALL	See Sports/Indoor/Handball										
RIFLE RANGE	See Sports/Indoor/Gun Range										
RODEO	E_h @3' above competition surface. Categorized according to class of competition.										
• II			500	500	500	Avg		150	150	150	Avg
• III			300	300	300	Avg		100	100	100	Avg
RUNNING TRACK	E_h @3' above competition surface. Categorized according to class of competition.										
• II			750	750	750	Avg		200	200	200	Avg
• III			500	500	500	Avg		150	150	150	Avg
• IV		P	150	300	600	Avg	M	50	100	200	Avg
SHUFFLEBOARD	E_h @competition surface; E_v @vertical plane orientation. Categorized according to class of competition.										
• III			300	300	300	Avg		75	75	75	Avg
• IV			200	200	200	Avg		50	50	50	Avg
• Exclusively social recreation	E_h @surface of participation; E_v @5' above competition surface	M	50	100	200	Avg	I	15	30	60	Avg

Table 35.3 | Sports and Recreation Illuminance Recommendations continued next page

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Uniformity Targets[f] Over Area of Coverage		[g]	[h]	Typical Area of Coverage[i]	
CV_{max}	Max:Min			Task Proper or Task Area	Room or Designated Area
0.21	2.5:1				
0.21	2.5:1				
0.21	2.5:1				
0.25	3:1				
0.17	1.7:1				
0.17	2:1				
0.25	3:1				
0.21	2.5:1				
0.3	4:1				
0.3	4:1				

Notes for Table 35.3

The table column headings are discussed in detail in 35.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 35.4 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 35.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 35.3 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Minimum illuminance shall be set according to the following table:

Recommended Uniformity Ratio	Percentage of Average that Defines Mimimum
1.5:1	80%
1.7:1	74%
2:1	66%
2.5:1	57%
3:1	50%
4:1	40%

f. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

g. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

h. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

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Table 35.3 | Sports and Recreation Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d, e]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
SKATING	Categorized according to class of competition.										
• Ice											
• Figure Skating	E_h @3' above competition surface. Categorized according to class of competition.										
• I			1500	1500	1500	Avg		500	500	500	Avg
• II			1000	1000	1000	Avg		300	300	300	Avg
• III			750	750	750	Avg		200	200	200	Avg
• IV			500	500	500	Avg		150	150	150	Avg
• Exclusively social recreation	E_h @surface of participation; E_v @5' above competition surface	O	100	200	400	Avg	K	25	50	100	Avg
• Speed Skating	E_h @competition surface. Categorized according to class of competition.										
• II			300	300	300	Avg		100	100	100	Avg
• III			200	200	200	Avg		50	50	50	Avg
• Roller (quad or inline)	E_h @competition surface. Categorized according to class of competition.										
• I			1000	1000	1000	Avg		300	300	300	Avg
• II			500	500	500	Avg		150	150	150	Avg
• III			300	300	300	Avg		100	100	100	Avg
• IV			200	200	200	Avg		50	50	50	Avg
• Exclusively social recreation	E_h @competition surface; E_v @5' above competition surface	M	50	100	200	Avg	I	15	30	60	Avg
SOCCER	E_h @3' above competition surface. Categorized according to class of competition.										
• I			1500	1500	1500	Avg		500	500	500	Avg
• II			1000	1000	1000	Avg		300	300	300	Avg
• III			750	750	750	Avg		100	100	100	Avg
• IV			500	500	500	Avg		50	50	50	Avg
SPEED SKATING	See Sports/Indoor/Skating/Ice/Speed										
SQUASH	See Sports/Indoor/Handball										

Table 35.3 | Sports and Recreation Illuminance Recommendations continued next page

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Uniformity Targets[f] Over Area of Coverage		[g]	[h]	Typical Area of Coverage[i]	
CV_{max}	Max:Min			Task Proper or Task Area	Room or Designated Area
0.13	1.7:1				
0.21	2.5:1				
0.25	3:1				
0.3	4:1				
0.35	5:1				
0.25	3:1				
0.3	4:1				
0.21	2.5:1				
0.21	2.5:1				
0.25	3:1				
0.3	4:1				
0.35	5:1				
0.17	2:1				
0.21	2.5:1				
0.25	3:1				
0.3	4:1				

Notes for Table 35.3

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2.5:1	57%
3:1	50%
4:1	40%

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Table 35.3 | Sports and Recreation Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d, e]							
		Horizontal (E_h) Targets				Vertical (E_v) Targets			
		Visual Ages of Observers (years) where **at least half** are				Visual Ages of Observers (years) where **at least half** are			
		<25	25-65	>65		<25	25-65	>65	
		Category			Gauge	Category			Gauge
SWIMMING AND WATER SPORTS	Categorized according to class of competition.								
• I									
• Water Surface Luminance	cd/m^2 @water surface	376	376	376	Avg				
• Water Surface Illuminance	E_h @water surface	750	750	750	Avg				
• Deck Surface Illuminance	E_h @deck surface	500	500	500	Avg				
• Start/finish and turning lines	E_h @water surface	1000	1000	1000	Avg				
• II									
• Water Surface Luminance	cd/m^2 @water surface	269	269	269	Avg				
• Water Surface Illuminance	E_h @water surface	500	500	500	Avg				
• Deck Surface Illuminance	E_h @deck surface	200	200	200	Avg				
• Start/finish and turning lines	E_h @water surface	750	750	750	Avg				
• III									
• Water Surface Luminance	cd/m^2 @water surface	161	161	161	Avg				
• Water Surface Illuminance	E_h @water surface	300	300	300	Avg				
• Deck Surface Illuminance	E_h @deck surface	100	100	100	Avg				
• Start/finish and turning lines	E_h @water surface	500	500	500	Avg				
• IV									
• Water Surface Luminance	cd/m^2 @water surface	161	161	161	Avg				
• Water Surface Illuminance	E_h @water surface	300	300	300	Avg				
• Deck Surface Illuminance	E_h @deck surface	100	100	100	Avg				
TABLE TENNIS	E_h @3' above floor surface on which table stands. Categorized according to class of competition.								
• II		750	750	750	Avg	200	200	200	Avg
• III		500	500	500	Avg	150	150	150	Avg
• IV		300	300	300	Avg	100	100	100	Avg
• Exclusively social recreational		100	100	200	Avg	30	30	60	Avg
TENNIS	E_h @3' above competition surface. Categorized according to class of competition.								
• I		1500	1500	1500	Avg	400	400	400	Avg
• II		1000	1000	1000	Avg	300	300	300	Avg
• III		750	750	750	Avg	200	200	200	Avg
• IV		500	500	500	Avg	150	150	150	Avg

Table 35.3 | Sports and Recreation Illuminance Recommendations continued next page

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Uniformity Targets[f] Over Area of Coverage		[g]	[h]	Typical Area of Coverage[i]	
CV_{max}	Max:Min			Task Proper or Task Area	Room or Designated Area
0.13	1.7:1				
0.21	2.5:1				
0.25	3:1				
0.21	2.5:1				
0.3	4:1				
0.13	1.7:1				
0.25	3:1				
0.3	4:1				
0.13	1.7:1				
0.3	4:1				
0.3	4:1				
0.21	2.5:1				
0.25	3:1				
0.3	4:1				
0.35	5:1				
0.10	1.5:1				
0.10	1.5:1				
0.13	1.7:1				
0.17	2:1				

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d. Targets are intended to apply to the respective plane or planes of the task.

e. Minimum illuminance shall be set according to the following table:

Recommended Uniformity Ratio	Percentage of Average that Defines Mimimum
1.5:1	80%
1.7:1	74%
2:1	66%
2.5:1	57%
3:1	50%
4:1	40%

f. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

g. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

h. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

i. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

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Table 35.3 | Sports and Recreation Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d, e]								
		Horizontal (E_h) Targets					Vertical (E_v) Targets			
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are			
		<25	25-65	>65			<25	25-65	>65	
	Category				Gauge	Category				Gauge
VOLLEYBALL	E_h @3' above competition surface. Categorized according to class of competition.									
• II		750	750	750	Avg		200	200	200	Avg
• III		500	500	500	Avg		150	150	150	Avg
• IV		300	300	300	Avg		100	100	100	Avg
OUTDOOR SPORTS										
ANIMAL SHOWS	E_h @ 3' above competition surface. Categorized according to class of competition.									
• II		500	500	500	Avg		150	150	150	Avg
• III		300	300	300	Avg		100	100	100	Avg
ARCHERY	E_h @ 3' above competition surface. Categorized according to class of competition.									
• III										
• Shooting Line		100	100	100	Avg					
• Target distance @60'							300	300	300	Avg
• Target distance @300'							500	500	500	Avg
• IV										
• Shooting Line		100	100	100	Avg					
• Target distance @60'							200	200	200	Avg
• Target distance @300'							300	300	300	Avg
BADMINTON	E_h @ 3' above surface of participation									
• Exclusively social recreation	M	50	100	200	Avg	I	15	30	60	Avg
BASEBALL	E_h @ 3' above competition surface. Categorized according to class of competition.									
• I										
• Infield		1500	1500	1500	Avg		400	400	400	Avg
• Outfield		1000	1000	1000	Avg		300	300	300	Avg
• II										
• Infield		1000	1000	1000	Avg		300	300	300	Avg
• Outfield		750	750	750	Avg		200	200	200	Avg
• III										
• Infield		500	500	500	Avg		150	150	150	Avg
• Outfield		300	300	300	Avg		100	100	100	Avg
• IV										
• Infield		300	300	300	Avg		100	100	100	Avg
• Outfield		200	200	200	Avg		50	50	50	Avg

Table 35.3 | Sports and Recreation Illuminance Recommendations continued next page

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Uniformity Targets[f] Over Area of Coverage		[g] [h]	Typical Area of Coverage[i]	
CV_{max}	Max:Min		Task Proper or Task Area	Room or Designated Area
0.21	2.5:1			
0.25	3:1			
0.3	4:1			
0.21	2.5:1			
0.25	3:1			
0.21	2.5:1			
0.21	2.5:1			
0.21	2.5:1			
0.25	3:1			
0.25	3:1			
0.25	3:1			
0.25	3:1			
0.07	1.3:1			
0.13	1.7:1			
0.10	1.5:1			
0.17	2:1			
0.17	2:1			
0.21	2.5:1			
0.21	2.5:1			
0.25	3:1			

Notes for Table 35.3

The table column headings are discussed in detail in 35.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 35.4 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 35.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 35.3 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Minimum illuminance shall be set according to the following table:

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1.7:1	74%
2:1	66%
2.5:1	57%
3:1	50%
4:1	40%

f. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

g. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

h. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

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Table 35.3 | Sports and Recreation Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d, e]							
		Horizontal (E_h) Targets				Vertical (E_v) Targets			
		Visual Ages of Observers (years) where **at least half** are				Visual Ages of Observers (years) where **at least half** are			
		<25	25-65	>65		<25	25-65	>65	
		Category			Gauge	Category			Gauge
BASKETBALL	E_h @ 3' above competition surface. Categorized according to class of competition.								
• III		500	500	500	Avg	150	150	150	Avg
• IV		200	200	200	Avg	50	50	50	Avg
BATMINTON									
• IV		100	100	100	Avg	50	50	100	Avg
BICYCLE RACING	E_h @ competition surface. Categorized according to class of competition.								
• II		500	500	500	Avg	150	150	150	Avg
• III									
• Track		300	300	300	Avg	100	100	100	Avg
• IV									
• Track		200	200	200	Avg	50	50	50	Avg
BMX	Categorized according to class of competition.								
• III		300	300	300	Avg	75	75	75	Avg
• IV		200	200	200	Avg	50	50	50	Avg
BOCCE COURTS	See Sports/Outdoor/Bowling Greens								
BOWLING GREENS	E_h @ 3' above surface of participation								
• Exclusively social recreation		50	50	100	Avg	15	15	30	Avg
BROOMBALL	See Sports/Outdoor/Ice Hockey								
CART RACING	See Horse Racing								
CRICKET	Categorized according to class of competition.								
• I									
• Infield		1000	1000	1000	Avg	300	300	300	Avg
• Outfield		750	750	750	Avg	200	200	200	Avg
• II									
• Infield		750	750	750	Avg	200	200	200	Avg
• Outfield		500	500	500	Avg	150	150	150	Avg

Table 35.3 | Sports and Recreation Illuminance Recommendations continued next page

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Uniformity Targets[f] Over Area of Coverage		[g] [h]	Typical Area of Coverage[i]	
CV_{max}	Max:Min		Task Proper or Task Area	Room or Designated Area
0.25	3:1			
0.3	4:1			
0.25	3:1			
0.21	2.5:1			
0.25	3:1			
0.3	4:1			
0.17	2:1			
0.25	3:1			
0.25	3:1			
0.1	1.5:1			
0.17	1.7:1			
0.1	1.5:1			
0.17	2:1			

Notes for Table 35.3

The table column headings are discussed in detail in 35.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 35.4 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 35.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 35.3 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Minimum illuminance shall be set according to the following table:

Recommended Uniformity Ratio	Percentage of Average that Defines Mimimum
1.5:1	80%
1.7:1	74%
2:1	66%
2.5:1	57%
3:1	50%
4:1	40%

f. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

g. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

h. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

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Table 35.3 | Sports and Recreation Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d, e]							
		Horizontal (E_h) Targets				Vertical (E_v) Targets			
		Visual Ages of Observers (years) where **at least half** are				Visual Ages of Observers (years) where **at least half** are			
		<25	25-65	>65		<25	25-65	>65	
		Category			Gauge	Category			Gauge
CRICKET	(continued)								
• III									
• Infield		500	500	500	Avg	150	150	150	Avg
• Outfield		300	300	300	Avg	100	100	100	Avg
• IV									
• Infield		300	300	300	Avg	100	100	100	Avg
• Outfield		200	200	200	Avg	50	50	50	Avg
CROQUET									
• IV		100	100	200	Avg	30	30	60	Avg
DOG RACING	E_h @ competition surface. Categorized according to class of competition.								
• I		500	500	500	Avg	150	150	150	Avg
DRAG RACING	E_h @ competition surface. Categorized according to class of competition.								
• I									
• Area 1		300	300	300	Avg	100	100	100	Avg
• Area 2		500	500	500	Avg	150	150	150	Avg
• Area 3A		300	300	300	Avg	100	100	100	Avg
• Area 3B		300	300	300	Avg	50	50	50	Avg
• Area 4		200	200	200	Avg	50	50	50	Avg
• II									
• Area 1		200	200	200	Avg	50	50	50	Avg
• Area 2		300	300	300	Avg	100	100	100	Avg
• Area 3A		200	200	200	Avg	50	50	50	Avg
• Area 3B		150	150	150	Avg	50	50	50	Avg
• Area 4		100	100	100	Avg	30	30	30	Avg
• III									
• Area 1		100	100	100	Avg	30	30	30	Avg
• Area 2		200	200	200	Avg	50	50	50	Avg
• Area 3A		150	150	150	Avg	50	50	50	Avg
• Area 3B		100	100	100	Avg	30	30	30	Avg
• Area 4		50	50	50	Avg	15	15	15	Avg
FIELD HOCKEY	E_h @ 3' above competition surface. Categorized according to class of competition.								
• II		500	500	500	Avg	150	150	150	Avg
• III		300	300	300	Avg	100	100	100	Avg
• IV		200	200	200	Avg	50	50	50	Avg
FOOTBALL	E_h @ 3' above competition surface. Categorized according to class of competition.								
• I		1000	1000	1000	Avg	300	300	300	Avg
• II		500	500	500	Avg	150	150	150	Avg
• III		300	300	300	Avg	100	100	100	Avg
• IV		200	200	200	Avg	50	50	50	Avg

Table 35.3 | Sports and Recreation Illuminance Recommendations continued next page

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Uniformity Targets[f] Over Area of Coverage		[g] [h]	Typical Area of Coverage[i]	
CV_{max}	Max:Min		Task Proper or Task Area	Room or Designated Area
0.13	1.7:1			
0.17	2:1			
0.17	2:1			
0.25	3:1			
0.25	3:1			
0.25	3:1			
0.25	3:1			
0.25	3:1			
0.25	3:1			
0.3	4:1			
0.3	4:1			
0.25	3:1			
0.25	3:1			
0.3	4:1			
0.3	4:1			
0.3	4:1			
0.3	4:1			
0.3	4:1			
0.3	4:1			
0.3	4:1			
0.3	4:1			
0.21	2.5:1			
0.25	3:1			
0.3	4:1			
0.13	1.7:1			
0.21	2.5:1			
0.25	3:1			
0.3	4:1			

Notes for Table 35.3

The table column headings are discussed in detail in 35.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 35.4 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 35.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 35.3 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Minimum illuminance shall be set according to the following table:

Recommended Uniformity Ratio	Percentage of Average that Defines Mimimum
1.5:1	80%
1.7:1	74%
2:1	66%
2.5:1	57%
3:1	50%
4:1	40%

f. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

g. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

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Table 35.3 | Sports and Recreation Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d, e]								
		Horizontal (E_h) Targets					Vertical (E_v) Targets			
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are			
		<25	25-65	>65			<25	25-65	>65	
		Category			Gauge	Category				Gauge
FIRING RANGE	See Sports/Outdoor/Gun Range									
GOLF	E_h @ competition surface									
• Course										
• IV										
• Tee Boxes		50	50	50	Avg					
• Fairways		30	30	30	Avg		10	10	10	Avg
• Greens		50	50	50	Avg		15	15	15	Avg
• Driving Range										
• IV										
• Tee Boxes		200	200	200	Avg					
• At 600' distance	On vertical face of marker						100	100	100	Avg
• Miniature	E_h @3' above surface of participation	100	100	200	Avg					
GUN RANGE	Categorized according to class of competition.									
• IV										
• Shooting Line	E_h @3' above competition surface	100	100	100	Avg					
• Target	On target area					R	500	500	500	Avg
HACKEY SACK	Categorized according to class of competition.									
• IV		100	100	100	Avg		30	30	30	Avg
HANDBALL	E_h @ 3' above competition surface. Categorized according to class of competition.									
• III		300	300	300	Avg		100	100	100	Avg
• IV		200	200	400	Avg		50	50	100	Avg
HORSE RACING	E_h @ 3' above competition surface. Categorized according to class of competition.									
• I										
• Track		500	500	500	Avg		150	150	150	Avg
HORSESHOES - GENERAL AREA	E_h @ 3' above surface of participation									
• Exclusively social recreation		K 25	50	100	Avg	G	7.5	15	30	Avg
ICE HOCKEY	E_h @ competition surface. Categorized according to class of competition.									
• II		500	500	500	Avg		150	150	150	Avg
• III		300	300	300	Avg		100	100	100	Avg
• IV		200	200	200	Avg		50	50	50	Avg

Table 35.3 | Sports and Recreation Illuminance Recommendations continued next page

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Uniformity Targets[f] Over Area of Coverage		[g] [h]	Typical Area of Coverage[i]	
CV_{max}	Max:Min		Task Proper or Task Area	Room or Designated Area
0.25	3:1			
0.35	6:1			
0.25	3:1			
0.25	3:1			
0.25	3:1			
0.25	3:1			
0.17	2:1			
0.17	2:1			
0.25	3:1			
0.25	3:1			
0.3	4:1			
0.25	3:1			
0.3	4:1			
0.21	2.5:1			
0.25	3:1			
0.3	4:1			

Notes for Table 35.3

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Table 35.3 | Sports and Recreation Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d, e]								
		Horizontal (E_h) Targets				Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are				Visual Ages of Observers (years) where **at least half** are				
		<25	25-65	>65		<25	25-65	>65		
		Category			Gauge	Category			Gauge	
LACROSSE	E_h @ 3' above competition surface. Categorized according to class of competition.									
• II		500	500	500	Avg	150	150	150	Avg	
• III		300	300	300	Avg	100	100	100	Avg	
• IV		200	200	200	Avg	50	50	50	Avg	
MINIATURE GOLF	See Sports/Outdoor/Golf/Miniature									
MOTOR RACING	E_h @ 3' above competition surface. Categorized according to class of competition.									
• I										
• Track		500	500	500	Avg	150	150	150	Avg	
• II										
• Track		300	300	300	Avg	100	100	100	Avg	
• III										
• Track		200	200	200	Avg	50	50	50	Avg	
NIGHT FISHING	E_h on dock									
• Exclusively social recreation	M	50	100	200	Avg	I	15	30	60	Avg
PISTOL RANGE	See Sports/Outdoor/Gun Range									
PLATFORM TENNIS	E_h @3' above competition surface. Categorized according to class of competition.									
• II		500	500	500	Avg	150	150	150	Avg	
• III		300	300	300	Avg	75	75	75	Avg	
• IV		200	200	200	Avg	50	50	50	Avg	
QUOITS - GENERAL AREA	E_h @ 3' above surface of participation									
• Exclusively social recreation		50	50	100	Avg	15	15	30	Avg	
RACQUETBALL	See Sports/Outdoor/Handball									
RIFLE RANGE	See Sports/Outdoor/Gun Range									

Table 35.3 | Sports and Recreation Illuminance Recommendations continued next page

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Uniformity Targets[f] Over Area of Coverage		[g] [h]	Typical Area of Coverage[i]	
CV_{max}	Max:Min		Task Proper or Task Area	Room or Designated Area
0.21	2.5:1			
0.25	3:1			
0.3	4:1			
0.21	2.5:1			
0.21	2.5:1			
0.25	3:1			
0.3	4:1			
0.17	2:1			
0.17	2:1			
0.17	2:1			
0.3	4:1			

Notes for Table 35.3

The table column headings are discussed in detail in 35.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 35.4 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 35.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 35.3 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Minimum illuminance shall be set according to the following table:

Recommended Uniformity Ratio	Percentage of Average that Defines Mimimum
1.5:1	80%
1.7:1	74%
2:1	66%
2.5:1	57%
3:1	50%
4:1	40%

f. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

g. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

h. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

i. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

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Table 35.3 | Sports and Recreation Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d, e]							
		Horizontal (E_h) Targets				Vertical (E_v) Targets			
		Visual Ages of Observers (years) where **at least half** are				Visual Ages of Observers (years) where **at least half** are			
		<25	25-65	>65		<25	25-65	>65	
		Category			Gauge	Category			Gauge
RODEO	E_h @ 3' above competition surface. Categorized according to class of competition.								
• II		500	500	500	Avg	150	150	150	Avg
• III		300	300	300	Avg	100	100	100	Avg
• IV		200	200	200	Avg	50	50	50	Avg
ROLLER HOCKEY	See Sports/Outdoor/Ice Hockey								
SHUFFLEBOARD	E_h @ surface of participation; E_v @ vertical plane orientation								
• Exclusively social recreation		50	50	100	Avg	15	15	30	Avg
SKATEBOARDING	Categorized according to class of competition.								
• III		300	300	300	Avg	100	100	100	Avg
• IV		100	200	200	Avg	25	50	50	Avg
SKATING									
• Ice									
• Outdoor Ice Skating	E_h @ 3' above surface of participation								
• Exclusively social recreation		30	30	30	Avg	8	8	8	Avg
• Speed	E_h @ competition surface. Categorized according to class of competition.								
• III		300	300	300	Avg	100	100	100	Avg
• IV		200	200	200	Avg	50	50	50	Avg
SKEET AND TRAP SHOOTING	E_h @ 3' above competition surface. Categorized according to class of competition.								
• III									
• Shooting Line		100	100	100	Avg				
• Target distance @60'	On target area					300	300	300	Avg
• Target distance @100'	On target area					400	400	400	Avg
• IV									
• Shooting Line		100	100	100	Avg				
• Target distance @60'	On target area					200	200	200	Avg
• Target distance @100'	On target area					200	200	200	Avg
SKIING	E_v @ 3' above competition surface								
• IV						50	50	50	Avg

Table 35.3 | Sports and Recreation Illuminance Recommendations continued next page

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Uniformity Targets[f] Over Area of Coverage		[g] [h]	Typical Area of Coverage[i]	
CV_{max}	Max:Min		Task Proper or Task Area	Room or Designated Area
0.21	2.5:1			
0.25	3:1			
0.3	4:1			
0.25	3:1			
0.17	2:1			
0.25	3:1			
0.35	5:1			
0.25	3:1			
0.3	4:1			
0.21	2.5:1			
0.21	2.5:1			
0.21	2.5:1			
0.25	3:1			
0.25	3:1			
0.25	3:1			

Notes for Table 35.3

The table column headings are discussed in detail in 35.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 35.4 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 35.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 35.3 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Minimum illuminance shall be set according to the following table:

Recommended Uniformity Ratio	Percentage of Average that Defines Mimimum
1.5:1	80%
1.7:1	74%
2:1	66%
2.5:1	57%
3:1	50%
4:1	40%

f. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

g. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

h. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

i. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

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Table 35.3 | Sports and Recreation Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d, e]							
		Horizontal (E_h) Targets				Vertical (E_v) Targets			
		Visual Ages of Observers (years) where **at least half** are				Visual Ages of Observers (years) where **at least half** are			
		<25	25-65	>65		<25	25-65	>65	
		Category			Gauge	Category			Gauge
SOCCER	Eh@3' above competition surface. Categorized according to class of competition.								
• I		750	750	750	Avg	200	200	200	Avg
• II		500	500	500	Avg	150	150	150	Avg
• III		300	300	300	Avg	100	100	100	Avg
• IV		200	200	200	Avg	50	50	50	Avg
SOFTBALL	See Sports/Outdoor/Baseball								
SQUASH	See Sports/Outdoor/Handball								
SWIMMING AND WATER SPORTS	Categorized according to class of competition.								
• II									
• Water Surface Luminance	cd/m^2 @water surface	161	161	161	Avg				
• Water Surface Illuminance	E_h @ water surface	300	300	300	Avg				
• Deck Surface Illuminance	E_h @ deck surface	200	200	200	Avg				
• Start/finish and turning lines	E_h @ water surface	500	500	500	Avg				
• III									
• Water Surface Luminance	cd/m^2 @water surface	108	108	108	Avg				
• Water Surface Illuminance	E_h @ water surface	300	300	300	Avg				
• Deck Surface Illuminance	E_h @ deck surface	100	100	100	Avg				
• Start/finish and turning lines	E_h @ water surface	500	500	500	Avg				
• IV									
• Water Surface Luminance	cd/m^2 @water surface	54	54	54	Avg				
• Water Surface Illuminance	E_h @ water surface	100	100	100	Avg				
• Deck Surface Illuminance	E_h @ deck surface	100	100	100	Avg				
• Start/finish and turning lines	E_h @ water surface	200	200	200	Avg				
TENNIS	E_h @3' above competition surface. Categorized according to class of competition.								
• I		1000	1000	1000	Avg	300	300	300	Avg
• II		750	750	750	Avg	200	200	200	Avg
• III		500	500	500	Avg	150	150	150	Avg
• IV		300	300	300	Avg	100	100	100	Avg
TRACK AND FIELD	E_h @ 3' above competition surface. Categorized according to class of competition.								
• II									
• Field		500	500	500	Avg	150	150	150	Avg
• Track		300	300	300	Avg	100	100	100	Avg
• III									
• Field		300	300	300	Avg	100	100	100	Avg
• Track		200	200	200	Avg	50	50	50	Avg

Table 35.3 | Sports and Recreation Illuminance Recommendations continued next page

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Uniformity Targets[f] Over Area of Coverage		[g]	[h]	Typical Area of Coverage[i]	
CV_{max}	Max:Min			Task Proper or Task Area	Room or Designated Area
0.13	1.7:1				
0.21	2.5:1				
0.25	3:1				
0.3	4:1				
0.21	2.5:1				
0.3	4:1				
0.21	2.5:1				
0.25	3:1				
0.3	4:1				
0.25	3:1				
0.3	4:1				
0.3	4:1				
0.3	4.:1				
0.10	1.5:1				
0.13	1.7:1				
0.17	2:1				
0.21	2.5:1				
0.25	3:1				
0.25	3:1				
0.3	4:1				
0.3	4:1				

Notes for Table 35.3

The table column headings are discussed in detail in 35.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 35.4 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 35.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 35.3 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Minimum illuminance shall be set according to the following table:

Recommended Uniformity Ratio	Percentage of Average that Defines Mimimum
1.5:1	80%
1.7:1	74%
2:1	66%
2.5:1	57%
3:1	50%
4:1	40%

f. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

g. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

h. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

i. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

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Table 35.3 | Sports and Recreation Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d, e]							
		Horizontal (E_h) Targets				Vertical (E_v) Targets			
		Visual Ages of Observers (years) where **at least half** are				Visual Ages of Observers (years) where **at least half** are			
		<25	25-65	>65		<25	25-65	>65	
		Category			Gauge	Category			Gauge
TRACK AND FIELD	(continued)								
• IV									
• Field		200	200	200	Avg	50	50	50	Avg
• Track		200	200	200	Avg	50	50	50	Avg
ULTIMATE FRISBEE	See Soccer								
VOLLEYBALL	E_h @3' above competition surface. Categorized according to class of competition.								
• III		300	300	300	Avg	100	100	100	Avg
• IV		200	200	200	Avg	50	50	50	Avg
WASHER PITCHING	E_h @ surface of participation								
• Exclusively social recreation		50	50	100	Avg	15	15	30	Avg

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Uniformity Targets[f] Over Area of Coverage		[g] [h]	Typical Area of Coverage[i]	
CV_{max}	Max:Min		Task Proper or Task Area	Room or Designated Area
0.3	4:1			
0.3	4:1			
0.25	3:1			
0.3	4:1			
0.3	4:1			

Notes for Table 35.3

The table column headings are discussed in detail in 35.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 35.4 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 35.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 35.3 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Minimum illuminance shall be set according to the following table:

Recommended Uniformity Ratio	Percentage of Average that Defines Mimimum
1.5:1	80%
1.7:1	74%
2:1	66%
2.5:1	57%
3:1	50%
4:1	40%

f. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

g. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

h. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

i. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

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Figure 35.1 | Multiple Luminaires on a Single Pole
Athletic field lighting involves determining the minimum number of poles and their height and placement, the correct choice of luminaire optics, and careful luminaire aiming in the field. All these aspects can produce an illuminated playing field with the necessary horizontal and vertical illuminances, control of spill and light trespass, and good visibility for players and spectators.
» Image ©Peter Bohler/Corbis

35.1.3.3 Color Temperature of Light Sources

One of the most difficult effects to overcome in television broadcasting is differences in color temperature and color rendering in an installation from imperfect mixing of light sources. The television camera can be balanced for a wide range of light source color temperatures (typically 3000 K to 6000 K). Abrupt color changes should be avoided (abrupt change can come from optical systems projecting beams that include source color separation or from non-uniform coverage of the facility by two different sources). Similarly, in facilities where daylight is present (from windows, skylights, clerestories) or in outdoor facilities with roof shadows, any abrupt color change at a shadow line produces poor picture quality. Daylight color light sources should be chosen to supplement the available daylighting to minimize these problems. Daylight sources also improve the transition from daylight to dark in outdoor facilities. No lighting system, however, will overcome the "shadow edge" problem where direct sunlight produces shadows on playing surfaces.

35.1.3.4 Viewing Direction

From the perspective of players, spectators, or television and film cameras there are a large number of vertical planes. Lighting software permits calculation of the illuminance normal to the camera's or spectator's plane of view. These values should be identified and calculated whenever possible to ensure that the lighting installation will meet all specified requirements.

35.1.3.5 Elevation

Elevations will vary with the sport and the skill level of play. Generally, if only one elevation is selected, it should coincide with that of the horizontal plane to be measured. Horizontal illuminance values are normally in a plane one meter (3 ft) above a playing surface. Vertical illuminance values, except when on a specific object such as an archery target or a bowling pin are also in a plane one meter (3 ft) above the playing surface.

35.1.3.6 Vertical Luminance

Although horizontal illuminance is important for television and film cameras, the average luminance in the direction of the camera establishes the f-stop criteria of a camera lens and the resultant depth of field of the picture. Generally, the greater the camera-to-subject distance, the more luminance is needed to obtain satisfactory pictures.

Objects seen by individuals or cameras are not cubes with only four values of illuminance on four vertical surfaces. Television and film have a contrast latitude (black to white) that is limited, especially when compared to the visual system. The greatest amount of light reaching a plane that is perpendicular to the axis of the viewing direction of a camera (that is, within 90 degrees of the incident camera axis) establishes the white value or most intense area seen by the camera. The axis of primary illumination onto the object, therefore, need not be along the camera, player, or spectator viewing axis.

35.1.3.7 Color and Color Quality

The method used to specify light source color quality is the General Color Rendering Index (CRI). For acceptable color rendering, the CRI should not be less than 65. See 6.3 Color Rendition.

35.2 Application Types

To develop lighting solutions that meet quality, quantity, and operational criteria, an inventory is made of the sports or recreation activities that will be performed in the spaces under consideration, the anticipated players and spectators, and broadcast media requirements. Otherwise, lighting cannot be best targeted to the users, their expectations, functions and tasks.

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These definitions are required early in project design in order to track design efforts that include inventorying project knowns, anticipated sports and recreation functions, and calculating lighting, power, and energy compliance. Sports and recreation functions cited in Table 35.3 | Sports and Recreation Illuminance Recommendations should be reviewed against the project knowns and correlated with the sports and functions to establish recommended illuminance criteria. Seek clarification with the client where discrepancies occur between programming information and the available application and task citations in Table 35.3.

High reflectance ceilings, walls, and floors increase the amount of light delivered to the playing surface. However, if they exhibit a high component of specular reflectance they may also cause reflected glare and may exhibit poor contrast for visual targets as, for example, when the polished finish basketball floor of an arena reflects an image of the bright luminaires to spectators on the opposite side. This issue can be minimized with the use of matte playing surfaces, however to properly address the issue, the luminaires must be carefully located. For new construction it is important that catwalks where the luminaires are located be in the proper position to optimize the sports lighting design.

The following sections describe identifiable facilities in which sports and recreation functions are commonly found. These discussions, those identified in Table 35.1, and the available sports and recreation functions identified in Table 35.3 offer comprehensive qualitative and quantitative criteria.

35.2.1 Arenas

Typically large, multipurpose facilities, arena floors often include playing areas for basketball, hockey and indoor soccer, and are capable of handling rodeos, circuses, animal shows, concert events, and trade shows. Portable seating is often used to make full use of the facility. Lighting installations should be flexible to accommodate this variety of uses.

The size, height, and use of general purpose sports facilities vary widely. Table 35.3 provides recommendations to meet the horizontal, vertical and uniformity illuminance requirements of such facilities, depending on the sports involved. In addition, direct and reflected glare control, direction of light, and modeling must be considered. Electric lighting systems are often capable of a wide area of coverage and usually controlled to provide for illuminance requirements of different sports and activities.

The use of daylight can conserve energy and provide visual attraction. However, it also creates glare and presents blackout control difficulty for visual presentations. In all indoor

Table 35.4 | SI Dimensional Conversions

US Customary	SI
General	**Hard Conversion**
inches	mm [inches × 25.40]
feet	m [feet × 0.30]
Specific	**Convenient Conversions[a]**
2'	610 mm or 0.6 m
2' 6"	760 mm or 0.75 m
3'	915 mm or 0.9 m
3' 6"	1065 mm or 1.1 m
4'	1220 mm or 1.2 m
5'	1525 mm or 1.5 m

a. Hard conversions rounded for reporting convenience. Not to be confused with metric-sized luminaires or other building materials. Not for precision construction.

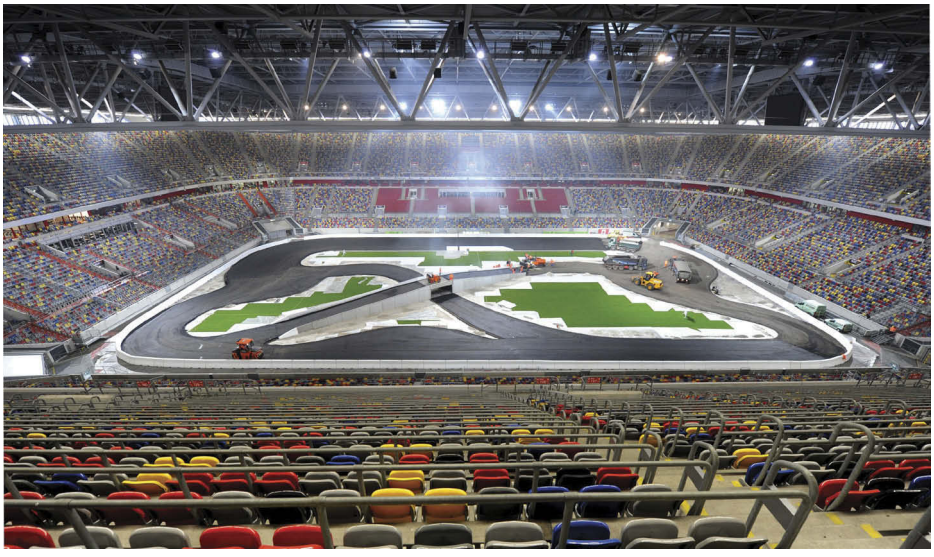


Figure 35.2 | General Arena Lighting
Arenas usually require the ability to light many types of sports and recreational functions. Arena structure provides opportunities for luminaire mounting. Overhead to produce the necessary horizontal illumance and at the sides to augment the vertical illuminance. Controls are usually required to provide the flexibility required to light different events.
» Image ©Julian Stratenschulte/dpa/Corbi

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Figure 35.3 | Collegiate Ice Arena
A series of luminaires mounted to catwalks positioned near the ice-seating juncture and another series mounted to catwalks over the first section of seating provide horizontal and vertical illuminance. Orienting most lights perpendicular to players' primary lines of sight and appropriate luminaire optics and careful aiming are required to limit direct glare.
» Image ©Sports Illustrated/Getty Images

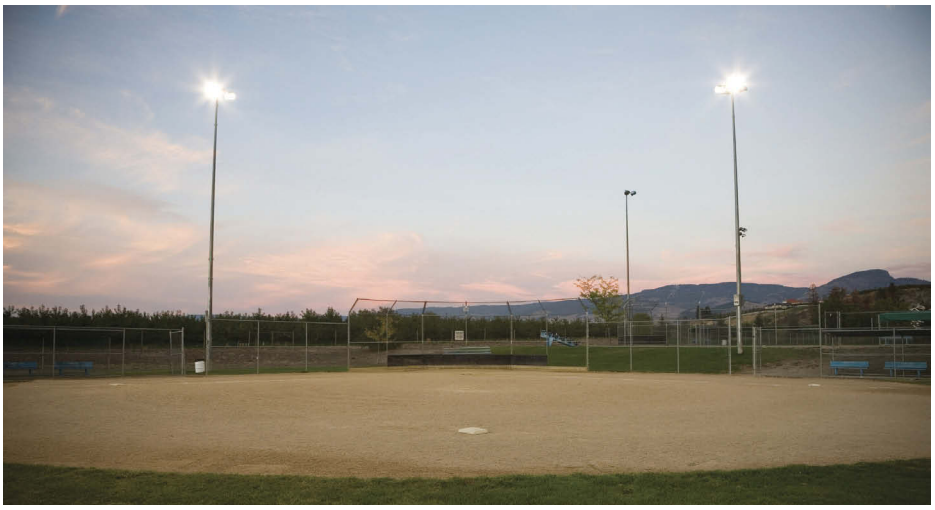


Figure 35.4 | Municipal Baseball Field
Municipal and school baseball fields are usually lighted with clusters of luminaires mounted on poles. Luminaire beam shape and aiming are used to produce the different illuminances required of the infield and outfield. Shielding is often required to prevent light trespass.
» Image ©Radius Images/Corbis



Figure 35.5 | School Football Field
High poles supporting clusters of narrow-beam luminaires put sources sufficiently above spectators' lines of sight to prevent discomfort glare, while providing sufficient reach to light the field uniformly.
» Imageg ©Skip Nall/Corbis

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Figure 35.6 | Gymnasium
Ceiling-mounted wide-spread luminaires produce sufficient horizontal and vertial illuminance on the playing floor. The same luminaires adequatley light the basketball backstops. If HID sources are used, provision must usually be made for instant restrike or supplemental lighting to provide for power outage or emergency situations.
» Image ©John Connell/Corbis

sports facilities, windows and skylights should be evaluated for their impact on construction cost, energy savings, and visual comfort for players and spectators. See 14 | DESIGNING DAYLIGHTING.

Also, many arenas with professional sports teams require the HID lighting to have shutters so the illumination on the floor can be reduced for introductions and other theatrical events without extinguishing the lamps.

35.2.2 Athletic Fields

Athletic fields for high schools and colleges typically serve several different sports. Lighting of such a multipurpose or combination field may not be as satisfactory as when the field lighting can be dedicated to an individual sport. Lighting a multipurpose field requires special attention to the lighting requirements of several sports. The final design is affected by the relative location of the various fields and the limits which each specific arrangement may impose upon lighting equipment locations. Pole mounting height should account for luminaire beam spread and location limitations. Ideally, most of the beam is directed onto the playing field while minimizing light trespass. Also there are locations where luminaires should not be located to eliminate glare for players such as behind the end zone of a sports field or behind home plate in ball fields.

The uncontrolled direct component from luminaires shining beyond the sports facility is called spill light. Sometimes referred to as light trespass, spill light may cause annoyance to the adjacent property or neighborhood. Spill light may be controlled by a number of design considerations:

- Selecting a luminaire with an optical system (and proper orientation) such that the defined beam does not extend beyond the sports facility.
- Checking to ensure that proper mounting heights have been selected. Low luminaire mounting heights increase glare and negatively impact the illumination on the sports field. Occasionally it is possible to add landscaping materials (shrubs, trees) that will partially shield adjacent properties from direct glare.
- Using internal and external shielding louvers or baffles on the luminaires. Note, however that these devices may not be effective and they may reduce optical system efficiency. If shields or baffles are employed, then photometric data that includes the shielding devices must be utilized in the computer calculations to obtain accurate results.



Figure 35.7 | Daylighting a Gymnasium
Daylighting and dimmable/switchable fluroescent electric lighting can effectively and efficinetly light a general purpose gymnasium and multi-function recreation room.
» Image ©Peter Durant/Arcaid/Corbis

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Figure 352.8 | Underwater Pool Lighting
Underwater luminaires can addequately light a pool and augment daylighting. Luminaire placement is to the sides of the principal swimming lanes, if they are present..
» Image ©cultura/Corbis



- Using low reflectance colors on critical surfaces so that reflected light from surrounding surfaces within the facility can be minimized.
- The hours of use are often an issue for spill light and it is good practice to install a timer to automatically turn off the playing field lights at a designated closure or curfew hour.

This combination of design factors must be evaluated as a whole to control spill light or reduce light trespass. Issues related to spill light, like glare, frequently create emotional and political tempests. Review of local ordinances, proper documentation, and early public input to the design process can help minimize this problem.

35.2.3 Field Houses

Many uses are common to both field houses and gymnasiums. However, field houses are generally larger and serve a wider range of sports, including indoor track and field events. Field houses can also accommodate outdoor sports brought indoors during inclement weather. Portable floors and ceiling facilities are commonly used to increase flexibility. Consideration should be given to versatile control schemes, individual lighting systems for aerial and ground level sports, and the needs of participants and spectators. See 35.2.1 Arenas.

35.2.4 Gymnasiums

Generally implemented as part of an educational facility, gymnasiums frequently host school programs during the day and community functions at night. A wide choice of lighting levels may be desirable because diverse visual tasks can be encountered. General lighting control can be achieved through dimming or split switching. See 35.2.1 Arenas.

35.2.5 Pools

Swimming pools come in a wide variety of shapes and sizes and may be used day or night. However, competitive events occurring after dark are generally held at indoor facilities. Swimming is a multi-directional ground level sport. It is a popular recreational activity as well as a competitive sport. Lighting design criteria are similar for both indoor and

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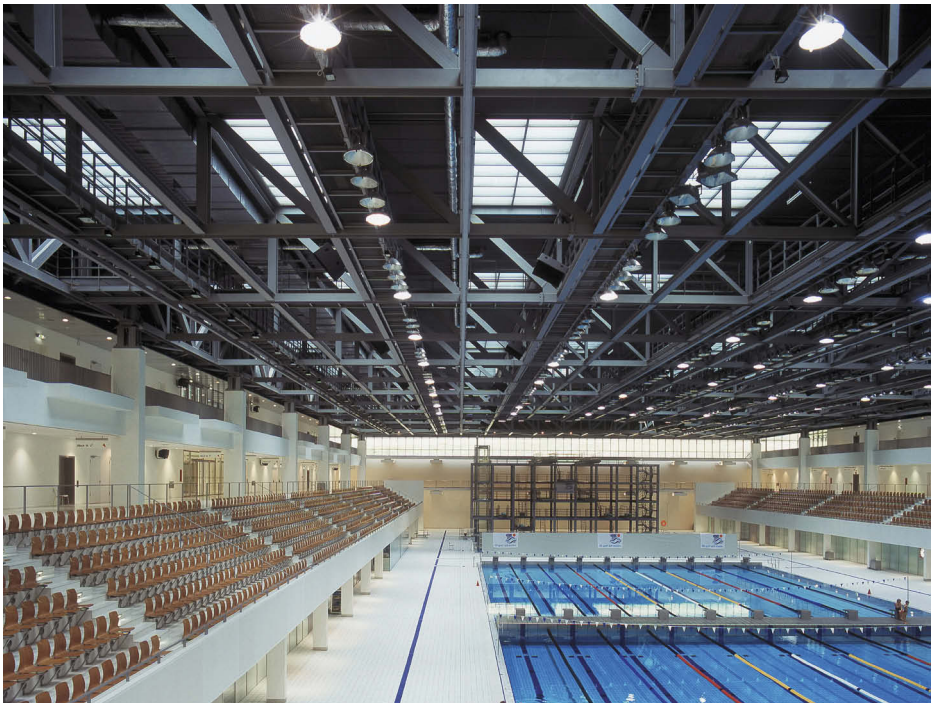


Figure 35.9 | Daylighting a Pool
Daylighting can provide much of the general lighting required for indoor pools. Overhead luminaires provide addition light and illuminate areas adjacent to the pool. Switching allows electric lighting levels to chance with the use and functions in the pool.
» Image ©Construction Photography/Corbis

outdoor swimming pools. The illumination criteria cited in Table 35.3 are for both indoor and outdoor facilities with the emphasis placed on commercial, public, and institutional swimming pools. However, the illumination criteria are also applicable to private and recreational pools.

Water is a good transmitter and diffuser of light. However, the surface of water also acts as a reflector of incident light. The degree of reflection depends on the angle of incidence. Moreover, swimming action causes surface turbulence which produces scattered reflections. In practice, at any one moment, a major part of the water surface is not disturbed by more than 20 degrees from the horizontal.

35.2.5.1 Luminaire locations

As the light strikes the water at shallower angles, the reflected component increases until virtually no light penetrates the water surface. This reflection of light causes veiling reflections, making it difficult to see into the water to observe swimmers and divers. It is, therefore, necessary to control reflections from luminaires or daylight through windows on the water surface to ensure a good penetration of light into the water. As a general rule, it is desirable to locate all overhead light sources so the angle of incidence of the main light beam is less than 50 degrees from vertical. Light from above is required to illuminate pool deck areas, diving platforms, sport action occurring above the water surface (for example, water polo), and to provide light penetration into the water basin.

For improved safety and observation of swimmers in water, illuminances within the pool basin should exceed the luminance of reflected light from the water surface. Underwater luminaires are used to minimize veiling reflections on the surface of the water and enhance visibility for swimmers in the water. For maximum effectiveness, pool basin finishes below the water line preferably should be white or a color with a reflectance of not less than 50 percent.

Luminaires should be placed at locations that permit an adequate portion of the incident light to penetrate the water and not be reflected into the eyes of observers. Luminaires located near the pool edges are easy to maintain and can still provide good light penetration. Luminaires should not be placed inside a 20-degree cone extending above the diving platform.

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Figure 35.10 | Soccer Stadium
Highly-controlled optics and aiming produce illuminances on the field with little glare and spill light.
» Image ©2010 LatinContent/Getty Images



35.2.5.2 Daylight

Daylight presents problems in terms of glare and reflection control. Daylight admitted from directly above the pool is desirable. But light from windows along the sides or ends of the pool can cause excess glare. The total intensity of the viewed scene (including reflections on the water) should be less than the illuminance in the pool basins. The illuminance from skylights can be calculated using any of the generally accepted algorithms. The skylights should be diffuse with splayed matte finished wells to prevent shafts of direct sunlight from entering the pool area. See 14 | DESIGNING DAYLIGHTING.

35.2.5.3 Underwater Luminaires

There are two types of underwater lighting: dry and wet niche mounting. For wet niches, special watertight luminaires are recessed into the pool walls. For dry niches, the luminaires are placed behind watertight portholes or windows. Wet niche designs, if defective, can produce electric shock. Thus the hardware, wiring installation, and ground fault detection methods used must strictly conform to the National Electric Code.

Underwater lights should be placed about 0.61 to 0.91 meters (2.0 to 3.0 feet) below the water surface on the long sides of the pool with another row of luminaires at the 2.4- to 3.0-meter (8.0- to 10.0-foot) level for deep pools. Aiming should be approximately ten degrees above the horizontal so that light from the underwater luminaires reflects off the water surface and back into the pool.

Underwater luminaires should not face swimmers competing in parallel lanes. If the pool is too wide for luminaires with the recommended spacing on the long sides of the pool to provide proper coverage, narrow beam distribution and closer luminaire spacing should be considered.

35.2.5.4 Luminance Requirements

Some of the recommendations in Table 35.3 involve water sports and give required water surface luminances. For design purposes, the following empirical equation can be used to determine the number of total lumens required on a pool surface:

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$$\Phi_{required} = \frac{A \pi L_{required}}{0.8 \rho}$$

Where

$\Phi_{required}$ = Lumens required to achieve required luminance
A = Area of water surface in m^2
$L_{required}$ = Required water surface luminance in cd/m^2
0.8 = Water turbity factor
ρ = Reflectance of pool basin surfaces

35.2.6 Stadiums, Indoor

Large arenas for major league baseball and football that accommodate up to 100,000 spectators are called stadiums. Stadium lighting design should be similar to that for arenas. Some stadiums feature translucent air- or cable-supported soft roofs. During the day these roofs can have the appearance of an overcast sky. This causes direct glare for players looking up and poor contrast between the roof and the visual target (white base ball). To mitigate this problem, the translucent roof and other interior surfaces should have a color and/or finish that increases contrast with the visual target. See 35.2.1 Arenas.

35.2.7 Stadiums, Outdoor

Stadiums are facilities with large seating capacities used for individual or multiple sports and public events. Stadium lighting should be specially designed with proper orientations, locations, illuminances, and controls that will satisfy the needs of any contingency. Typical designs are not recommended here because of the wide variation in stadium configurations. See 35.2.2 Athletic Fields.

35.3 Illuminance Criteria

Illuminance criteria, when fully deployed, are a robust set of quantitative values that influence visibility, visual performance, and visual comfort and attention. Following are notes related to various topics outlined in Table 35.3.

35.3.1 Applications and Tasks

Sports encountered on any given project may be different from those identified in Table 35.3 and may warrant different illuminance criteria. Cross referencing closely associated sports is appropriate. Failing this technique, reviewing the list in Table 35.3 may be in order to determine if any sports exhibit a similar visual component to the unique application's sport. This involves similar aerial or ground sports having similar objects, speed of play, and important surfaces. Otherwise, reviewing 4.12 An Illuminance Determination System and Table 4.1 is necessary to establish a task category based on the sport characteristics most closely associated with the unique sports of the application. These exercises as well as any deviations from recommendations the designer intends to make should be carefully documented for the record.

35.3.2 Notes

The notes in Table 35.3 may refer to other task headings in the table or to other handbook chapters as appropriate. Where some degree of clarification is warranted, notes are made.

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35.3.3 Recommended Maintained Illuminance Targets

Values cited are maintained on the area of coverage for the task under consideration. Illuminance is additive. Where practical and without negatively affecting the intended application of light, target values are achieved with any combination of daylighting and/or electric lighting in whatever mix of ambient, task, and accent lighting is deemed appropriate to meet these and the other lighting goals established during design. See 12 | COMPONENTS OF LIGHTING DESIGN and see 10.7.1 Light Loss Factors.

With respect to light loss factors, account for anticipated losses through the point in time at which group relamping and cleaning should occur. Group relamping and cleaning should be standard practice and for purposes of sustainability can no longer be presumed to be infrequent or unlikely. Maintenance procedures must be part of the design discussions with the client. See the IES document IESNA/NALMCO RP-36 Recommended Practice for Planned Indoor Lighting Maintenance for additional information. Where maintenance is deferred or practiced poorly or not at all, the actual illuminance values will fall below criteria targets. This is inefficient, unsustainable, and may be unsafe while adversely affecting users' quality of life or work. Ratcheting initial illuminances higher is poor practice and not recommended. Maintenance procedures may be especially problematic with LEDs where promises of extraordinarily long life may be offered, but usually with the caveat that lamp lumen depreciation (LLD) at that rated life is 70% or perhaps even as low as 50% of initial rating. If replacement cycles are presumed to be rated life, then LLD alone must be 0.7 or 0.5 or whatever lumen rating is certified by the LED vendor. See 13.3 Life and Lumen Maintenance.

Targets cited are consensus and recommended for respective functional activity. For some applications, IES recommendations are within 10% of code requirements. This apparently is an artifact of metrication. Footcandle conversions of any values cited in Table 35.3 should be made at 1 fc to 10 lx. This soft conversion avoids a redundant diminishing of illuminance values after multiple citations and conversions over time. This also eliminates a false sense of accuracy advanced by an ever-increasing number of decimal places and a false sense of urgency advanced by eccentric fractional values introduced by hard conversions. Nevertheless, a lighting design must meet code and the mechanics of which must be coordinated amongst the design team. The IES recommendations should not, do not, and cannot reflect all of the various code requirements in force in all jurisdictions at any given time.

Targets are intended to apply to the dominant plane of the task, typically, but not always, horizontal or vertical. In some situations, illuminance criteria are cited for one plane, such as the vertical plane for lighting driving range distance markers, while the other plane is blank. The blank signifies that illuminance on that plane is unimportant and may be a consequence of the illuminance of other tasks within the vicinity or by whatever illuminance results from meeting the target illuminance for the prescribed plane of interest.

35.3.3.1 Target Planes

Many, though certainly not all, tasks are performed with the task in roughly a horizontal orientation or vertical orientation. A dominant orientation must be assigned and the illuminance target determined accordingly. There may be situations where the IES recommended target relating to the typical planar mode of a task must be applied to a different plane. In sports facilities, this is sometimes the case for vertical illuminance. For example, the principal axis of play of a uni-directional sport in an arena may not align with the main axes of the arena.

Nearly all tasks have both a horizontal illuminance component (E_h) and a vertical illuminance component (E_v). This allows some degree of task flexibility for off-plane viewing and accommodates various aspects of the task.

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Where illuminance targets are intended at differing planar elevations, this is indicated under "Notes." For example, in some cases the illuminance requirement is on the competitive surface, while it others it is 3' AFF. The height at which vertical illuminances are recommended may not be the same as that for horizontal illuminance recommendations.

Note the implication for observers' visual ages. Establishing and tracking task orientations and addressing both horizontal and vertical illuminance is necessary. If orientations in the project under consideration are programmed to be flipped from what might be considered normal-viewing, then criteria must be adjusted accordingly. If a task is scheduled to be oriented on some plane off axis from horizontal or vertical by more than 10°, say, then the illuminance criteria must be applied to that off-axis orientation. This is an important distinction for luminaire optical selection and aiming capabilities and for layout, calculations, and field measurements.

For planes related to vertical illuminance targets, some guidance is indicated under "Notes." However, the designer must determine the orientation of multiple vertical planes. In some situations the vertical planes could be oriented in a number of directions and the designer must determine which are most appropriate for the situation. Unless otherwise noted, vertical illuminances should be calculated or measured in four cardinal or perpendicular vertical planes at each point of interest. The average of the values at all points in at least one of these planes should meet or exceed the specified vertical illuminance.

35.3.3.2 Visual Ages of Observers

Illuminance criteria are based on the visual ages of more than half the intended observers. This aspect should be resolved during programming with the client. It may be determined that illuminance criteria for an age group other than that representing the majority of the intended observers is appropriate. However, this may result in overlighting, underlighting, harsh lighting, visual displeasure, or visual discomfort for many of the observers. See 12.5.5 Illuminance and 4.12 An Illuminance Determination System for additional information and guidance. In some situations, such as video conferencing, lighting must meet the requirements of the camera technology and, therefore, is not tied to ages of observers.

35.3.3.3 Illuminance Categories

Illuminance categories are designated by letters A through Y. These are shown in Table 35.2 for more convenient reference to Table 4.1 | Recommended Illuminance Targets should the designer wish to explore other criteria targets or if applications or tasks on a specific project are not readily correlated to the table citations.

35.3.3.4 Gauge

The common gauge for determining illuminance target compliance is cited for each application. All gauges presume that point-by-point techniques are used for predictive calculations and presume that uniformity criteria are closely monitored. Where an average illuminance value over the area of coverage can satisfy target compliance, "Avg" is cited. In applications or tasks where a minimum or maximum target is necessary, the gauge for compliance is "Min" or "Max" respectively.

The designer may elect to use other methods to evaluate target compliance, such as criterion rating (CR) or coefficient of variation (C_v). See 4.12.4.5 Tasks at Uncertain Locations Over a Large Area.

In any event, once illuminance targets and uniformities are established, then any calculated deviation from them should be limited. Standard engineering allowance of ±10% might be acceptable for targets gauged as average unless contractual or code obligations demand otherwise. Minima and maxima must be achieved as intended.

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Designs should be adjusted until predictions are within allowance for averages and meet minima and maxima. For additional information, see 4.12.4.1 Recommended Illuminances at Design Time, 4.12.5 Illuminance Ratios, 9.15.1.1 Average Illuminance, and 10.8 Assessing Computed Results.

35.3.3.4 Defining the Minimum Illuminance

For personal safety of the players, a minimum illuminance over the entire playing surface must be maintained. It is recommended that this minimum be a fraction of the average illuminance, where the fraction is a function of the uniformity target. See the values of fractions listed in note e in Table 35.3 | Sports and Recreation Illuminance Recommendations. For example, a sports application with a recommended illuminance of 300 lux and maximum--to-minimum uniformity target of 2:1, 66% of the average recommended illuminance defines the recommended minimum illuminance to be 200 lux.

35.3.4 Uniformity Targets

Illuminance uniformity targets work in conjunction with luminance uniformities and surface reflectances all of which must be addressed as part of the design to avoid visual discomfort, glare, and strain. Uniformity ratios are targets that define the widest recommended ranges. In many situations, uniformity ratio criteria are those between average values of an array of points and the minimum value in the same array of points. The uniformity ratios listed in the table are for the horizontal illuminance only. Generally, the more important speed and accuracy are, and the more demanding the visual task, the tighter the ratio should be.

35.3.4.1 Coefficient of Variance

This method (commonly used in statistics) is a measure of the weighted average of all relevant illuminance values, where the variance of a set of values (CV) is calculated as the ratio of the standard deviation for all illuminance values to the mean illuminance value. CV has been shown to be related to the uniformity ratios common in the lighting industry. It does not consider just 2 points within an array, but includes in the formula every reading point. It is the preferred method for use when referring to uniformity of a sports lighting installation. See 4.12.4.5 Tasks at Uncertain Locations Over a Large Area.

35.3.4.2 Maximum-to-minimum

This is the recommended ratio of maximum illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where too much variation in illuminance is considered undesirable and untenable from a performance or safety perspective.

35.3.5 Daylighting Advancement

Generally, design strategies should embrace any combination of daylighting and electric lighting to achieve target values during daylight hours. The preference is for daylighting to provide all or most of the recommended illuminance presuming that all aspects of daylighting are properly addressed. A sunburst icon depicts those applications and tasks where daylighting is considered a strategic candidate. Use photocells and stepped-dimming or continuous dimming to reduce or eliminate electric lighting during daylight hours. See 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Even for those applications where daylighting is not traditionally a strategic candidate, it may be determined that very careful and coordinated design will offer great sustainability opportunities along with positive influences associated with daylight and views. For outdoor applications, lamps and ballasts, transformers, and drivers must be selected for ambient temperature conditions, some of which are extremely hot and others extremely cold.

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35.3.6 Veiling Reflections

Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper or, worse, both, are prone to veiling reflections. The likelihood of particular applications and tasks predisposed to veiling reflections is indicated by a "reflected light" icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood. Veiling reflections are minimized by controlling the overall amount and direction of light with respect to the task locations and orientations. Alternatively, tasks sensitive to veiling reflections can be screened or isolated. Effective strategies include employing indirect soft, diffuse electric lighting or direct electric lighting with multiple low-output luminaires, or positioning tasks and luminaires and luminance patterns to avoid harsh reflections from tasks. Addressing luminance recommendations (see Table 12.4 | Default Luminance and Luminaire Intensity Recommendations for VDT Applications) minimizes veiling reflections. Changing the task will reduce or eliminate veiling reflections, such as use of CSA/ISO Type I or II computer screens and matte paper versus their specular counterparts.

35.3.7 Defining Areas of Coverage

In addition to establishing planes of task orientation, the areas of coverage to which targets apply must be determined. Typical areas of task illuminance coverage are identified in RP-6 [2]. One area of coverage is "task proper or task area." Here, the illuminance criteria are applied to the task itself or to a relatively small area to which the task is confined. Examples are the head pin in bowling, or the target on an archery course.

Another area of coverage is "room or designated area." In this situation, illuminance criteria are applied to an entire area of play and is usually of fairly substantive size representing the zone in which the sport is played. The designated area is typically established by the games rules or the practical limits of a playing field. The area-of-coverage citations in Table 35.3 are based on standard playing fields defined for individual sports and are described in [2].

An assessment and determination must be made on which area of coverage best satisfies the lighting goals on a particular project. This is particularly true when multiple sports are to be accommodated on a single field and by a single lighting system.

35.4 Designing

Information provided here is specific to sports and recreation facilities and should be used as part of the design and documentation processes outlined in Chapters 12, 15, and 20. For outdoor applications, lamps and ballasts, transformers, and drivers must be selected for ambient temperature conditions, some of which are extremely hot and others extremely cold. See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY for additional information on respective aspects. Addressing all code requirements is a must. Energy efficient and sustainable practices are an integral part of all IES recommendations. Key design tenets include, but are not limited to:

- designing for the satisfaction of the observers intended to use the project
- using baseline reflectances of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively) in interior production and work-oriented spaces
- using daylighting that meets luminance and illuminance criteria

IESH/10e Economics Resources

> 15.3.3 Budgets
  - for more on budgets and value engineering

> 18 | ECONOMICS
  - for more on estimating costs
  - for more on life cycle costs
  - for more on paybacks and rates of return

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IESH/10e Energy Efficiency Resources

> 17.2 New Construction
- for more on designing for daylighting
- for more on electric lighting equipment
- for more on lighting controls

> 17.4 Lighting Codes, Regulations and Standards
- for more on application standards
- for more on equipment regulations

IESH/10e Lighting Exteriors Resources

> 12.5.5.6 Nighttime Outdoor Illuminances
- for more on lamp efficacies under mesopic adaptation

> 26 | LIGHTING FOR EXTERIORS
- for more on criteria

IESH/10e Sustainability Resources

> 13.11 Sustainability
- for more on lamps

> 19 | SUSTAINABILITY
- for more on controls
- for more on earth resources
- for more on energy
- for more on life cycle analyses
- for more on lighting design
- for more on recycling

- using highest-efficacy lamps that meet color, optical and electrical control, and output criteria
- using highest-efficiency luminaires that meet aesthetic and luminance criteria
- using controls liberally, preferably automated varieties such as presets, occupancy and vacancy sensors, astronomical timeclocks, and photocells
- establishing IES-recommended illuminance criteria to meet programmed tasks
- establishing layouts that just meet IES-recommended illuminance criteria
- addressing outdoor environmental needs
- using calculations, photometrically-realistic renderings, and operational samples and mockups to prove concepts
- identifying and designing to code-specific requirements, if any, for ambient, task, and accent lighting
- documenting all code-, energy-, sustainability-, and IES-criteria compliance
- documenting criteria and design deviations and rationale and subsequent disposition by team, client, or AHJ
- documenting clearly the layouts, controls, and luminaire and lamp selections

Designing for the satisfaction of the players and spectators is the paramount design tenet and must be kept in perspective during all aspects of design. If the players' and spectators' expectations are not fulfilled, then how much energy could be saved is moot, as is how many fewer earth resources were spared. See sidebar references for additional guidance on the key tenets. The design effort must be undertaken with coordinated and realistic expectations by all involved on initial and life cycle costs. Budgeting should include designer input and dialogue with the team and client at project commencement and design milestones. In other words, and paraphrasing Thomas Edison, genius is, indeed, just 1% inspiration and 99% perspiration.

35.5 References

[1] Mark S. Rea, ed. The IESNA Lighting Handbook: Reference and Application, Ninth Edition (New York: Illuminating Engineering Society of North America, 2000), Chapters 5, 10, and 13.

[2] [IESNA] Illuminating Engineering Society of North America. 2001. RP-6-01(R2009), Recommended Practice for Sports and Recreational Area Lighting. 92 p.

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36 | LIGHTING FOR TRANSPORT

Travel is fatal to prejudice, bigotry, and narrow-mindedness, and many of our people need it sorely on these accounts. Broad, wholesome, charitable views of men and things cannot be acquired by vegetating in one little corner of the earth all one's lifetime.
Mark Twain

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36.2 Application Types 36.2
36.3 Illuminance Criteria 36.13
36.4 Designing. 36.18
36.5 References 36.19

General economic growth and prosperity are both provided for and based on modern transportation. Communication and cargo, trade and tourism, all depend on modern transportation systems. This chapter gives recommendations for the ground-based facilities used by air, rail, and bus travelers. They are often complex environments that must accommodate large numbers of people, queues for checking in and security, food service and retail, and waiting areas that are comfortable and provide for a certain amount of visual work. A consequence of this is typically very large spaces that must provide lighting for a variety of tasks and functions. Urban areas of even modest size have airports and bus terminals that are important for local trade, transportation, and economic growth. Major cities have large airports with multiple terminals. These complexes must provide for not only the practical mechanics of traveling for thousands of travelers, such as checking in, security, baggage handing, and waiting, but also venues for food service, retail, and comfortable and attractive spaces for business travelers and tourists.

Comprehensive design efforts involve the information in this chapter combined with material in 12 | COMPONENTS OF LIGHTING DESIGN, 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS, 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Design tenets deemed appropriate from those chapters must be identified and lighting goals and strategies developed accordingly. This chapter primarily addresses illuminance criteria for applications in transportation facilities which should influence luminaire optical selections, lampings, and final layouts based on design thought-starters (see 15.2 A Lighting Scheme). Use of the material in this chapter to the exclusion of material in Chapters 12, 13, 14, and 15 will likely lead to unsatisfactory results. Previous IES related documents serve as archival reference sources [1].

Deliberate thought must be given to details beyond the recommended illuminances in this chapter. For example, in Table 36.2 for FLIGHT INFORMATION SCREENS, the illuminance citations alone do not guarantee successful lighting of this important task. The precise nature of the digital displays, wide and multiple angle of view, potential veiling reflections, and glare from distant but visually adjacent sources must be considered. Such specific details are not enumerated for all tasks. Table 36.1 offers a checklist of IES lighting topics and criteria. The design team is responsible for determining and addressing indoor and outdoor lighting and energy criteria set forth by authorities having jurisdiction (AHJ) which may be different from and supersede IES criteria. See also 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

36.1 Project Type and Status

Before any design work, an understanding of the project type and scope is necessary. This will establish the extent to which daylighting can address most or many or some of the lighting goals. New, renovation, and restoration projects each offer varying opportunities.

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Table 36.1 | Transport Lighting Checklist

Topics
✔ **Criteria and Design Resources**
Accenting
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Table 12.2 | Subjective Impressions
Table 15.2 | Accent Illuminance Ratios
Table 22.2 | Common Applications Illuminance Recommendations
Appearance
12.2 Spatial Factors
Color
12.5.6 Color Considerations
Controls
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Daylighting
14 | DESIGNING DAYLIGHTING
Electric Lighting
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12.5.5.1 Applications and Tasks
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Veiling Reflections
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Visual Tasks
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Table 11.2 | Programming: Inventory Scope and Specific Examples
12.5.1 Visual Tasks
Table 12.3 | Sample Visual Task Survey

See 11.2 Planning, 11.3.1 Pre-design, and 11.3.2 Schematic Design. At every opportunity the lighting designer should give every consideration to daylighting as a light source. For some applications and tasks, daylighting can be the primary light source. Critically, this means addressing the host of lighting factors identified in 12 | COMPONENTS OF LIGHTING DESIGN. Daylight demands attention to moderate or eliminate glare and balance visible and thermal energy.

36.2 Application Types

To develop lighting solutions that meet quality, quantity, and operational criteria, an inventory is made of the common applications space types, under consideration and the anticipated occupants, functions, and tasks (see Table 11.2 | Programming: Inventory Scope and Specific Examples and Table 12.3 | Sample Visual Task Survey). Otherwise, lighting cannot be best targeted to the users, their expectations, functions and tasks.

Space type definitions are required early in the project design in order to track design efforts that include inventorying the project knowns, anticipated functions, and tasks and calculating lighting, power, and energy compliance. Room names, from which functions can be deduced, and numbers for tracking should be clearly marked on architectural backgrounds. The applications and tasks cited in Table 36.2 | Transport Illuminance Recommendations should be reviewed against the project knowns and correlated with the named space types and functions to establish recommended illuminance criteria. Seek clarification with the client where discrepancies occur between programming information, the list of room names, and the available application and task citations in Table 36.2.

The following discussion is keyed to major application headings in Table 36.2. Couple this with topics in Table 36.1 for comprehensive qualitative and quantitative criteria.

36.2.1 Administration

Most transportation facilities must provide for administrative functions and typically include circulation, conferencing, lounges, filing or records, and officing. Each of these in turn may involve a number of specifics including some form or degree of acknowledgment, conversation, reading, periods of respite or relaxation, and writing—all tasks within applications. Acknowledgement of other people and conversation, for example, require some vertical illuminance at face height (seating or standing depending on the nature of the application). Vertical illuminance criteria are cited for such applications.

Administrative areas may be dispersed throughout a facility or complex or may be centralized into a single area or building. Depending on client wishes and architectural desires, this centralization or decentralization may affect the degree to which the lighting design in administrative areas is sympathetic to or different from that of other applications.

See also 32 | LIGHTING FOR OFFICES.

36.2.2 Baggage Claim and Service Office

Baggage claim areas house equipment that moves baggage in front of waiting passengers. Carousels with slanted moving surfaces present inclined surfaces for reading and identification. Horizontal belt carousels present more arbitrarily oriented surfaces. In both cases, passengers are usually crowded close the moving surfaces, so illumination must come from above and in front to avoid shadows. Baggage is usually recognized, in part, by its color or the color of an attached tag or flag; good color rendering is therefore a requirement. See Figures 36.1 and 36.2.

In addition to baggage recognition and retrieval, baggage claim areas at airports are places where arriving passengers are met. Vertical illuminance and modeling for good facial

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Figure 36.1 | Slanted Baggage Carousel
❶ Linear fluorescent cove lighting produces general lighting. ❷ Slots are added to light the main runs of the carousel's moving surface. High surface reflectances help increase the interreflected component of illuminance and the vertical illuminances at face height.
» Image ©Jon Feingersh Photography/Super-Stock/Corbis



Figure 36.2 | Horizontal Belt Baggage Carousel
❶ Indirectly lighted shallow vaulted coffer provides general illumination. ❷ Additional downlights illuminate the horizontal moving belt.
» Image ©Scott Barrow/Corbis

recognition are important. For this reason, baggage claim areas also are transition spaces to outdoor walkways, platforms, waiting areas such as taxi stands, and other exterior functions. See 22 | LIGHTING FOR COMMON APPLICATIONS.

For Baggage Claim Service Offices, see also 32 | LIGHTING FOR OFFICES.

36.2.3 Bus and Shuttle Pick-up and Drop-off

Buses and shuttle vans to rental car areas, parking, and other areas of an airport are usually waited for at curb-side areas just outside a terminal or at islands separated from the terminal building by walkways. Several conditions in these areas influence lighting:

- Degree to which they are covered from the elements
- Proximity of vehicular traffic to pedestrian traffic
- Anticipated nighttime activity levels

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Table 36.2 | Transport Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]										
		Horizontal (E_h) Targets					Vertical (E_v) Targets					
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
ACCENTING	Accenting influences observers' overall brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. See 15.1.1.3 Accent Lighting. These are criteria for consideration in any application.											
• Art	On artwork plane (typically vertical). See 21 | LIGHTING FOR ART for preservation-worthy materials.	see Table 15.2										
• Feature Wall	On wall plane	see Table 15.2										
• Important Focal Point	On focal point plane	see Table 15.2										
• Perimeter	On wall plane	see Table 15.2										
ADMINISTRATION	See 22 | LIGHTING FOR COMMON APPLICATIONS											
AVIATION TERMINALS												
• ATMs	E_h @3' AFF; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg	
• Baggage												
• Claim												
• Belt	E_h @3' AFF; Ev @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg	
• Carts	E_h @3' AFF; Ev @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg	
• Carousel	E_h @3' AFF; Ev @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg	
• General	E_h @floor; Ev @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg	
• Hotel Information Kiosk	E_h @3' AFF; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg	
• Racks	E_h @3' AFF; Ev @5' AFF	M	50	100	200	Avg	O	100	200	400	Avg	
• Handling	Coordinate lighting with image sensing equipment requirements and/or security cameras.											
• Automated	E_h and E_v @1' above conveyance	N	75	150	300	Avg	K	25	50	100	Avg	
• Manual	E_h and E_v @1' above conveyance	P	150	300	600	Avg	N	75	150	300	Avg	
• Service Office												
• Agent Counter	E_h @3' AFF; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg	
• Baggage Storage	E_h @3' AFF; E_v @5' AFF	Q	200	400	800	Avg	O	100	200	400	Avg	
• General	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg	
• Bus and Shuttle Pick-up/Drop-off												
• Covered	At dropoff curbs and area under cover for intended queuing and drop-off and pick-up.											
• High Activity[i]	Curbs typified by periods of high pedestrian and vehicular traffic; E_h @grade; E_v @5' AFG in direction of building ingress/egress.											
◦ LZ4[j]		J	20	40	80	Avg	H	10	20	40	Avg	
◦ LZ3[j] (and LZ4 curfew)		I	15	30	60	Avg	G	7.5	15	30	Avg	
◦ LZ2[j] (and LZ3 curfew)		H	10	20	40	Avg	F	5	10	20	Avg	
◦ LZ1[j] (and LZ2 curfew)		G	7.5	15	30	Avg	E	4	8	16	Avg	
◦ LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	F	5	10	20	Avg	D	3	6	12	Avg	
• Medium Activity[i]	Curbs typified by periods of medium pedestrian and vehicular traffic; E_h @grade; E_v @5' AFG in direction of building ingress/egress.											
◦ LZ4[j]		H	10	20	40	Avg	F	5	10	20	Avg	
◦ LZ3[j] (and LZ4 curfew)		G	7.5	15	30	Avg	E	4	8	16	Avg	
◦ LZ2[j] (and LZ3 curfew)		F	5	10	20	Avg	D	3	6	12	Avg	
◦ LZ1[j] (and LZ2 curfew)		E	4	8	16	Avg	C	2	4	8	Avg	
◦ LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	D	3	6	12	Avg	B	1	2	4	Avg	

Table 36.2 | Transport Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	see 15.1.1.3					
	see 15.1.1.3					
	see 15.1.1.3					
	see 15.1.1.3					
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	3:1					
	1.5:1					
	1.5:1					
	3:1					
	3:1					
	3:1					
4:1	2:1					
4:1	2:1 (4:1)					
3:1	2:1 (4:1)					
3:1	2:1 (4:1)					
2:1						
4:1	2:1					
4:1	2:1 (4:1)					
3:1	2:1 (4:1)					
3:1	2:1 (4:1)					
2:1						

Notes for Table 36.2

The table column headings are discussed in detail in 36.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 36.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 36.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 36.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

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		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
AVIATION TERMINALS	(Bus and Shuttle Pick-up/Drop-off continued)										
• Low Activity[i]	Curbs typified by periods of low pedestrian and vehicular traffic; E_h @grade; E_v @5' AFG in direction of building ingress/egress.										
◦ LZ4[j]		F	5	10	20	Avg	D	3	6	12	Avg
◦ LZ3[j] (and LZ4 curfew)		E	4	8	16	Avg	C	2	4	8	Avg
◦ LZ2[j] (and LZ3 curfew)		D	3	6	12	Avg	B	1	2	4	Avg
◦ LZ1[j] (and LZ2 curfew)		C	2	4	8	Avg	A	0.5	1	2	Avg
◦ LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	B	1	2	4	Avg	-	0	0	0	
• Uncovered	At dropoff curbs and area of platform for intended queuing and drop-off and pick-up.										
• High Activity[i]	Curbs typified by periods of high pedestrian and vehicular traffic; E_h @grade; E_v @5' AFG in direction of building ingress/egress.										
◦ LZ4[j]		G	7.5	15	30	Avg	E	4	8	16	Avg
◦ LZ3[j] (and LZ4 curfew)		F	5	10	20	Avg	D	3	6	12	Avg
◦ LZ2[j] (and LZ3 curfew)		E	4	8	16	Avg	C	2	4	8	Avg
◦ LZ1[j] (and LZ2 curfew)		D	3	6	12	Avg	B	1	2	4	Avg
◦ LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	C	2	4	8	Avg	A	0.5	1	2	Avg
• Medium Activity[i]	Curbs typified by periods of medium pedestrian and vehicular traffic; E_h @grade; E_v @5' AFG in direction of building ingress/egress.										
◦ LZ4[j]		E	4	8	16	Avg	C	2	4	8	Avg
◦ LZ3[j] (and LZ4 curfew)		D	3	6	12	Avg	B	1	2	4	Avg
◦ LZ2[j] (and LZ3 curfew)		C	2	4	8	Avg	A	0.5	1	2	Avg
◦ LZ1[j] (and LZ2 curfew)		B	1	2	4	Avg	-	0	0	0	
◦ LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	A	0.5	1	2	Avg	-	0	0	0	
• Low Activity[i]	Curbs typified by periods of low pedestrian and vehicular traffic; E_h @grade; E_v @5' AFG in direction of building ingress/egress.										
◦ LZ4[j]		C	2	4	8	Avg	C	2	4	8	Avg
◦ LZ3[j] (and LZ4 curfew)		B	1	2	4	Avg	B	1	2	4	Avg
◦ LZ2[j] (and LZ3 curfew)		A	0.5	1	2	Avg	A	0.5	1	2	Avg
◦ LZ1[j] (and LZ2 curfew)		A	0.5	1	2	Avg	-	0	0	0	
◦ LZ0[j] (and LZ1 curfew)	Control with motion sensors[k]	A	0.5	1	2	Avg	-	0	0	0	
• Concourses											
• General	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Seating	E_h and E_v @ 2' 6" at sitting area	N	75	150	300	Avg	K	25	50	100	Avg
• Customs											
• Check-point Station	E_h @3' AFF; E_v @5' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Queuing	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Screening	E_h @3' AFF; E_v @5' AFF	Q	200	400	800	Avg	O	100	200	400	Avg
• Elevators	See 22 | LIGHTING FOR COMMON APPLICATIONS										
• Escalators	See 22 | LIGHTING FOR COMMON APPLICATIONS										

Table 36.2 | Transport Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage			[f] [g] Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min	Task Proper or Task Area	Room or Designated Area
4:1	2:1			
4:1	2:1 (4:1)			
3:1	2:1 (4:1)			
3:1	2:1 (4:1)			
2:1				
4:1	2:1			
4:1	2:1 (4:1)			
3:1	2:1 (4:1)			
3:1	2:1 (4:1)			
2:1				
4:1	2:1			
4:1	2:1 (4:1)			
3:1	2:1 (4:1)			
3:1	2:1 (4:1)			
2:1				
4:1	2:1			
4:1	2:1 (4:1)			
3:1	2:1 (4:1)			
3:1	2:1 (4:1)			
2:1				
	3:1			
	3:1			
	2:1			
	3:1			
	2:1			

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d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

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Table 36.2 | Transport Illuminance Recommendations

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		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
AVIATION TERMINALS	(continued)										
• Flight Information Screens	See 22 | LIGHTING FOR COMMON APPLICATIONS										
• VDT Screen and Keyboard											
◦ CSA/ISO Types I and II	See Figure 12.16 | CSA/ISO Computer Screen Qualities										
▪ Positive polarity	E_v over screen surface						N	75	150	300	Avg
▪ Negative polarity	E_v over screen surface						K	25	50	100	Avg
◦ CSA/ISO Type III	See Figure 12.16 | CSA/ISO Computer Screen Qualities										
▪ Positive polarity	E_v over screen surface						K	25	50	100	Avg
▪ Negative polarity	E_v over screen surface						I	15	30	60	Avg
• Food Courts	See 22 | LIGHTING FOR COMMON APPLICATIONS										
• Gate Areas	See 22 | LIGHTING FOR COMMON APPLICATIONS										
◦ Agent Counter and Check-in	E_h @3' AFF; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
◦ Boarding Credentialing	E_h @3' AFF; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
◦ Jetway	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
◦ Seating	E_h and Ev @ 2' 6" at sitting areas	N	75	150	300	Avg	K	25	50	100	Avg
• Immigration	See AVIATION TERMINALS/Customs										
• Information Desks	E_h @3' 6" AFF; E_v @5' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• Lounges	See 22 | LIGHTING FOR COMMON APPLICATIONS										
• Moving Walkways	See 22 | LIGHTING FOR COMMON APPLICATIONS										
• Passenger Pick-up/Drop-off											
◦ Baggage Check Curbside	E_h @3' AFF; E_v @5' AFF	O	100	200	400	Avg	K	25	50	100	Avg
◦ Covered	See Bus and Shuttle Pick-up/Drop-off/Covered										
◦ Uncovered	See Bus and Shuttle Pick-up/Drop-off/Uncovered										
• Security Screening											
◦ Credentialing Area	E_h @3' AFF; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
◦ Queuing	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
◦ Screening											
▪ Private Rooms	E_h @3' AFF; E_v @5' AFF	Q	200	400	800	Avg	M	50	100	200	Avg
▪ Public	E_h @3' AFF; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg
• Signage	See Accenting										
• Stairs	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
◦ High Activity[i]	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
◦ Live Surveillance	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
◦ Typical	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Ticketing											
◦ Agent Counter	E_h @3' AFF; E_v @5' AFF	P	150	300	600	Avg	N	75	150	300	Avg
◦ Queuing	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
◦ Service Kiosks	E_h @3' AFF; E_v @4' AFF	O	100	200	400	Avg	M	50	100	200	Avg
PARKING	See 26 | LIGHTING FOR EXTERIORS										
RETAIL	See 34 | LIGHTING FOR RETAIL										

Table 36.2 | Transport Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1		☀	◔	■	
	3:1			◔	■	
	2:1			◔	■	
	2:1			◕	■	
	3:1		☀		■	
	3:1		☀		■	
	3:1		☀		■	
	3:1		☀			■
	3:1		☀		■	
	3:1		☀		■	
	2:1		☀		■	
	3:1		☀			■
	2:1		☀		■	
	2:1		☀		■	
	2:1		☀			■
	2:1		☀			■
	2:1		☀			■
	3:1		☀		■	
	3:1		☀			■
	3:1		☀	◔	■	

Notes for Table 36.2

The table column headings are discussed in detail in 36.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 36.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 36.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 36.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◕ signals high likelihood; gray and white ◔ signals moderate likelihood; pale gray and white ◔ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

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Table 36.2 | Transport Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
TOILETS											
• Fixtures	E_h @top of plumbing fixture; E_v @3'-5' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• General	E_h @floor; E_v @3'-5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Lockers	E_h @floor; E_v @locker faces	K	25	50	100	Avg	K	25	50	100	Avg
• Showers	E_h @floor; E_v @3'-5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Vanities	E_h @3' AFF; E_v @3'-5' AFF	N	75	150	300	Avg	O	100	200	400	Avg
TRAIN STATIONS											
• Baggage Claim	See AVIATION TERMINALS										
• Bus and Shuttle Pick-up/Drop-off	See AVIATION TERMINALS										
• Concourses	See AVIATION TERMINALS										
• Embark/Disembark	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• Platform/Car Threshold	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Platform/Queuing	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg
• Security Screening	See AVIATION TERMINALS										
• Signage	See AVIATION TERMINALS/Accenting										
• Ticketing	See AVIATION TERMINALS										
WAITING SHELTERS	See AVIATION TERMINALS/Bus and Shuttle Pick-up/Drop-off/Covered. Control with motion sensors.[k]										

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Uniformity Targets[e] Over Area of Coverage			[f]	[g] Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min		Task Proper or Task Area	Room or Designated Area
	2:1				
	2:1				
	2:1				
	2:1				
	2:1				
	2:1				
	3:1				

Notes for Table 36.2

The table column headings are discussed in detail in 36.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 36.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 36.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria. Outdoor tasks are so noted.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 36.2 should be made at 1 fc to 10 lx. Regardless, codes, ordinances, or mandates may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

j. See Table 26.4 | Nighttime Outdoor Lighting Zone Definitions. Nighttime illuminance targets are intended for application during dark hours of operation where lighting is deemed necessary or desirable. At curfew (client- or jurisdiction-defined), if lighting is still deemed necessary or desirable, then reduce lighting as indicated. See Table 26.5 | Recommended Light Trespass Illuminance Limits for recommended light trespass illuminance limits.

k. Use motion-sensing control to toggle lighting from on/off/dimmed state to recommended curfew state or from recommended curfew state to pre-curfew state as designer and client deem necessary to meet functional needs. Use instant-on lighting equipment.

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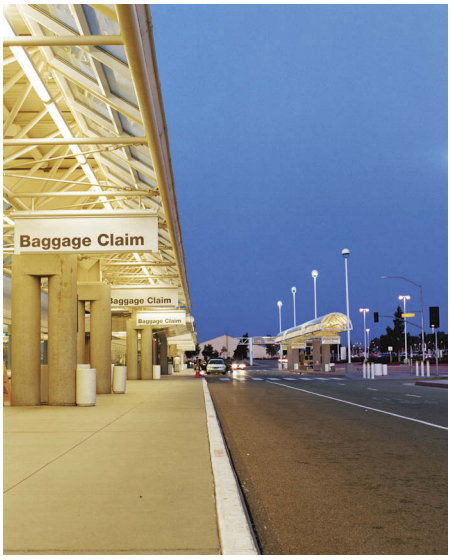


Figure 36.3 | Airport Pick-up/Drop-off
Pick-up and drop-off areas outside of transportation terminals are typically covered to the curb, providing mounting locations for luminaires. Lighting must provide for the safe interaction of pedestrian and vehicular traffic. Here, diffuse light addresses horizontal and vertical illuminances.
» Image ©Mike Powell/Getty Images

Table 36.3 | SI Dimensional Conversions

US Customary	SI
General	**Hard Conversion**
inches	mm [inches × 25.40]
feet	m [feet × 0.30]
Specific	**Convenient Conversions[a]**
2'	610 mm or 0.6 m
2' 6"	760 mm or 0.75 m
3'	915 mm or 0.9 m
3' 6"	1065 mm or 1.1 m
4'	1220 mm or 1.2 m
5'	1525 mm or 1.5 m

a. Hard conversions rounded for reporting convenience. Not to be confused with metric-sized luminaires or other building materials. Not for precision construction.

Table 22.2 in 22 | LIGHTING FOR COMMON APPLICATIONS outlines an extensive list of entry types and situations that give recommendations for these areas where vehicular and pedestrian traffic mix. See Figure 36.3.

These bus and shuttle pick-up and drop-off areas are can be uncovered or canopied. The canopied areas are covered either as an extension of the terminal building, or separately in the case of islands. For such areas under cover where there is expectation for some passing conversation and acknowledgement and for a larger crowd of people, somewhat higher illuminances are appropriate than those for open or uncovered waiting areas, such as out in parking lots. Covered waiting areas near curbside by their nature involve a mix of vehicular and pedestrian traffic and in these situations, still higher illuminances are appropriate.

36.2.4 Concourses

Concourses are usually the largest spaces at airports and provide seating areas for travelers waiting for flights. They also usually contain or are connected by moving and fixed walkways, and house not only gate areas but adjacent retail and food service areas and often areas for temporary or permanent display of art.

Lighting in waiting and seating areas must support conversation, face recognition, and some tasks usually associated with offices, such as reading and working on a laptop computer. As such, vertical illuminance is as important as horizontal.

If the architecture permits, daylighting can be the principal source of illuminance in concourses, particularly in areas with high ceilings. Control of surface finishes and the use of some supplemental electric lighting may be necessary to balance luminances in large spaces. See Figures 36.4 and 36.5.

See 34 | LIGHTING FOR RETAIL, 21 | lighting FOR ART, and 22 | LIGHTING FOR COMMON APPLICATIONS.

36.2.5 Gate Areas

Gate areas provide seating and waiting areas for travelers about to board aircraft and a service counter for gate agents. Work at this counter involves not only printed tasks, but also computer work, ID and document checking, and facial recognition. For these reasons, illuminance in gate areas is usually higher than in other areas of a concourse.

See also 36.2.4 Concourses

36.2.6 Flight Information Screens

Flight information screens are a critical component of the system that delivers flight status information to travelers. They are usually mounted at or above head-height, tipped down, in large open areas to permit access by a large number of travelers, and are self-illuminated. They must be visible from a wide range of viewing positions and angles, and care must be taken to prevent veiling reflections. The designer needs to know the type of VDTs that are used, where they mounted, and their orientation. Electric lighting and daylighting must not generate veiling glare, and surfaces in the passenger's field of view that immediately surround the VDTs, should not produce high luminance ratios with them.

36.2.6 Passenger Pick-up and Drop-off

See 36.2.3 Bus and Shuttle Pick-up and Drop-off

36.2.7 Security

Security at most of the world's airports now includes passenger screening. This involves ID and document checking, X-ray of baggage, and visual observation of all passengers en-

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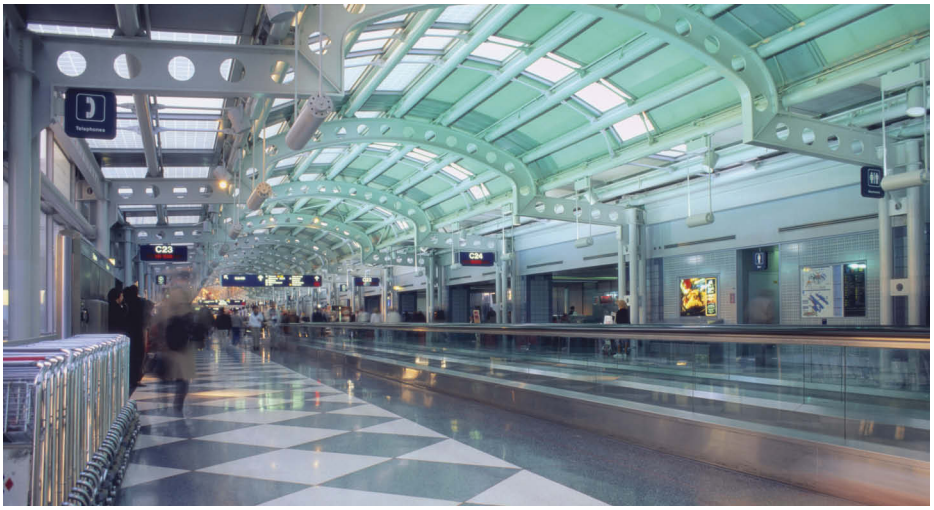


Figure 36.4 | Concourse Walkways
Fixed and moving walkways move passengers between gates and concourses. Integrated daylighting and electric lighting can provide the necessary general illumination. Fritted glass, louvers, and screens may be necessary to control direct sunlight.

Retail and food service areas may need additional lighting to highlight their position along long walkways.

» Image ©Mark E. Gibson/CORBIS

tering an airport's secured areas. Document check stands must provide for reading printed text in both horizontal and vertical orientations. Passenger face recognition by the security officer must be provided by sufficient vertical illuminance on and modeling of faces of passengers standing at the document check stand. See Figure 36.5

36.2.8 Ticketing

Ticket counters at airports and bus and train stations present a wide range of visual tasks that must be performed efficiently and quickly.. These include

- ID and document checking
- VDT reading and keyboard work
- Baggage claim check printing and reading
- Face recognition

Self-service check-in kiosks are located near ticket counters and adjacent to baggage checking stations. These kiosks present VDT tasks that must be viewed from a wide range of viewing angles and are subject to veiling reflections.

Since the task planes are many and varied, illumination at ticket counters should come from multiple directions. See Figure 36.6.

36.2.9 Waiting Shelters

Waiting shelters are popular along routes of mass transit. Lighting responding to photocells and motion sensors minimizes energy use while assuring electric light is available when these facilities are occupied.

36.3 Illuminance Criteria

Illuminance criteria, when fully deployed, are a robust set of quantitative values that influence visibility, visual performance, and visual comfort and attention. Short-circuiting the criteria selection or designing to a single criterion value, such as horizontal illuminance, to address worst-case tasks will surely result in dissatisfaction. Even if clients accept the visual results, not getting the most from the energy expended or, worse, energy waste is a likely result. Following are notes related to various topics outlined in Table 36.2.

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Figure 36.5 | Document Check Stand
General, multidirectional lighting is required at security document check stands in order to provide sufficient horizontal and vertical illuminance.
» Image ©Joshua Sudock/ZUMA Press/Corbis

36.3.1 Applications and Tasks

Applications and tasks encountered on any given project may be different from those identified in Table 36.2 and may warrant different illuminance criteria. Cross-referencing closely-associated applications or tasks is appropriate. Sometimes naming trends or conventions for space types or functions change to conform to current practice, client programming, or architectural conventions, but the actual activities and tasks remain the same and this cross-referencing works. Failing this technique, reviewing the list in Table 36.2 may be in order to determine if any applications or tasks exhibit a similar visual-component to the unique applications or tasks. Otherwise, reviewing 4.12 An Illuminance Determination System and Table 4.1 is necessary to establish a task category based on the task characteristics or visual performance descriptions most closely associated with the unique applications or tasks. These exercises as well as any deviations from recommendations the designer intends to make should be carefully documented for the record.

36.3.2 Notes

The notes in Table 36.2 may refer to other task headings in the table or to other handbook chapters as appropriate. Where some degree of clarification is warranted, notes are made.

36.3.3 Recommended Maintained Illuminance Targets

Values cited are maintained on the area of coverage for the task under consideration. Illuminance is additive. Where practical and without negatively affecting the intended application of light, target values are achieved with any combination of daylighting and/or electric lighting in whatever mix of ambient, task, and accent lighting is deemed appropriate to meet these and the other lighting goals established during design. See 12 | COMPONENTS OF LIGHTING DESIGN and see 10.7.1 Light Loss Factors.

With respect to light loss factors, account for anticipated losses through the point in time at which group relamping and cleaning should occur. Group relamping and cleaning should be standard practice and for purposes of sustainability can no longer be presumed to be infrequent or unlikely. Maintenance procedures must be part of the design discussions with the client. See the IES document IESNA/NALMCO RP-36 Recommended Practice for Planned Indoor Lighting Maintenance for additional information. Where maintenance is deferred or practiced poorly or not at all, the actual illuminance values will fall below criteria targets. This is inefficient, unsustainable, and may be unsafe while adversely affecting users' quality of life or work. Ratcheting initial illuminances higher is poor practice and not recommended. Maintenance procedures may be especially problematic with LEDs where promises of extraordinarily long life may be offered, but usually with

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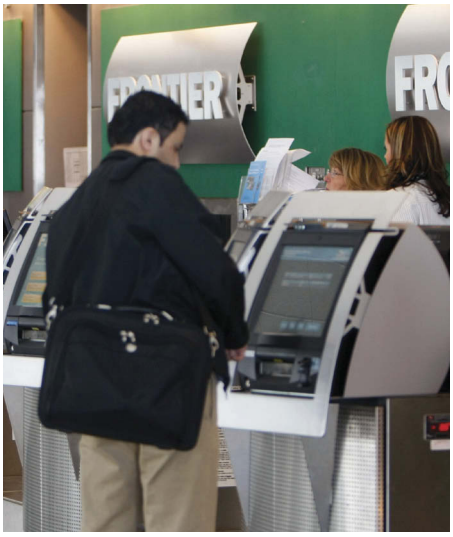


Figure 36.6 | Ticket Counter and Kiosk
The several tasks performed at ticket and customer service counters (left) usually require additional lighting beyond what is provided in the concourse. Walls behind counters are opportunities for wallwahing, highlighting the area and providing additional vertical illuminance on passenger faces.

Self-service ticketing and baggage check-in kiosks (right) can be subject to veiling reflections.

» Left image © DreamPictures/Blend Images/Corbis
» Right image ©RICK WILKING/Reuters/Corbis

the caveat that lamp lumen depreciation (LLD) at that rated life is 70% or perhaps even as low as 50% of initial rating. If replacement cycles are presumed to be rated life, then LLD alone must be 0.7 or 0.5 or whatever lumen rating is certified by the LED vendor. See 13.3 Life and Lumen Maintenance.

Targets cited are consensus and recommended for respective functional activity. For some applications, IES recommendations are within 10% of code requirements. This apparently is an artifact of metrication. Footcandle conversions of any values cited in Table 36.2 should be made at 1 fc to 10 lx. This soft conversion avoids a redundant diminishing of illuminance values after multiple citations and conversions over time. This also eliminates a false sense of accuracy advanced by an ever-increasing number of decimal places and a false sense of urgency advanced by eccentric fractional values introduced by hard conversions. Nevertheless, a lighting design must meet code and the mechanics of which must be coordinated amongst the design team. The IES recommendations should not, do not, and cannot reflect all of the various code requirements in force in all jurisdictions at any given time.

Targets are intended to apply to the dominant plane of the task, typically, but not always, horizontal or vertical. In some situations, illuminance criteria are cited for one plane, such as the vertical plane for lighting white boards, while the other plane is blank. The blank signifies that illuminance on that plane is unimportant and may be a consequence of the illuminance of other tasks within the vicinity or by whatever illuminance results from meeting the target illuminance for the prescribed plane of interest.

In some situations, no light is anticipated on at least one plane of a task. A 0 indicates no light or zero light is recommended for the task or application.

36.3.3.1 Target Planes

Many, though certainly not all, tasks are performed with the task in roughly a horizontal orientation or vertical orientation. A dominant orientation must be assigned and the illuminance target determined accordingly. There may be situations where the IES recommended target relating to the typical planar mode of a task must be applied to a different plane. For example, if ID and document checking at a security stand involves vertically-held documents, then the illuminance target cited in Table 36.2 (SECURITY/ID Check Stand/ID reading), which is for a dominant horizontal orientation, must be applied to the vertical plane at eye-height above the check stand.

Nearly all tasks are expected to have both a horizontal illuminance component (E_h) and a vertical illuminance component (E_v). This allows some degree of task flexibility for off-plane viewing and accommodates various aspects of the task. Where illuminance targets are intended at differing planar elevations, this is indicated under “Notes.”

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Note the implication for observers' visual ages. Establishing and tracking task orientations and addressing both horizontal and vertical illuminance is necessary. If orientations in the project under consideration are programmed to be flipped from what might be considered normal-viewing, then criteria must be adjusted accordingly. If a task is scheduled to be oriented on some plane off axis from horizontal or vertical by more than 10°, say, then the illuminance criteria must be applied to that off-axis orientation. This is an important distinction for luminaire optical selection and aiming capabilities and for layout, calculations, and field measurements.

For planes related to vertical illuminance targets, some guidance is indicated under "Notes." However, the designer may elect to use alternate or multiple vertical planes. In some situations the vertical planes could be oriented in a number of directions and the designer must determine which are most appropriate for the situation.

36.3.3.2 Visual Ages of Observers

Illuminance criteria are based on the visual ages of more than half the intended observers. This aspect should be resolved during programming with the client. It may be determined that illuminance criteria for an age group other than that representing the majority of the intended observers is appropriate. However, this may result in overlighting, underlighting, harsh lighting, visual displeasure, or visual discomfort for many of the observers. See 12.5.5 Illuminance and 4.12 An Illuminance Determination System for additional information and guidance. In some situations, such as video conferencing, lighting must meet the requirements of the camera technology and, therefore, is not tied to ages of observers.

36.3.3.3 Illuminance Categories

Illuminance categories are designated by letters A through Y. These are shown in the table for more convenient reference to Table 4.1 | Recommended Illuminance Targets should the designer wish to explore other criteria targets or if applications or tasks on a specific project are not readily correlated to the table citations.

36.3.3.4 Gauge

The common gauge for determining illuminance target compliance is cited for each application. All gauges presume that point-by-point techniques are used for predictive calculations and presume that uniformity criteria are closely monitored. Where an average illuminance value over the area of coverage can satisfy target compliance, "Avg" is cited. In applications or tasks where a minimum or maximum target is necessary, the gauge for compliance is "Min" or "Max" respectively.

The designer may elect to use other methods to evaluate target compliance, such as criterion rating (CR) or coefficient of variation (C_v). See 4.12.4.5 Tasks at Uncertain Locations Over a Large Area.

In any event, once illuminance targets and uniformities are established, then any calculated deviation from them should be limited. Standard engineering allowance of ±10% might be acceptable for targets gauged as average unless contractual or code obligations demand otherwise. Minima and maxima must be achieved as intended.

Designs should be adjusted until predictions are within allowance for averages and meet minima and maxima. For additional information, see 4.12.4.1 Recommended Illuminances at Design Time, 4.12.5 Illuminance Ratios, 9.15.1.1 Average Illuminance, and 10.8 Assessing Computed Results.

36.3.4 Uniformity Targets

Illuminance uniformity targets work in conjunction with luminance uniformities and surface reflectances all of which must be addressed as part of the design to avoid visual discomfort, glare, and strain. Uniformity ratios are targets that define the widest recommended ranges. In many situations, uniformity ratio criteria are those between average values of an

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array of points and the minimum value in the same array of points. Uniformity targets apply to both horizontal and vertical illuminances over the area of coverage. Where horizontal uniformity criterion is different from vertical uniformity criterion, two ratios are reported with the first value for horizontal illuminance (E_h). In some situations, notably those with regard to exterior illuminances, two uniformity values are cited. The first value addresses the primary cited application or task. The parenthetical value references the parenthetical application or task, such as a curfew situation associated with nighttime outdoor lighting.

Generally the more important speed and accuracy and the more demanding the visual task, the tighter the ratio.

36.3.4.1 Maximum-to-average

This is the recommended ratio of maximum illuminance to the average illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations sensitive to even a relatively small degree of overlighting.

36.3.4.2 Average-to-minimum

This is the recommended ratio of average illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where illuminance too far below average conditions is noticeable and detrimental to task performance or inconsistent with normal expectations.

36.3.4.3 Maximum-to-minimum

This is the recommended ratio of maximum illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where too much variation in illuminance is considered undesirable and untenable from a performance or safety perspective.

36.3.5 Daylighting Advancement

Generally, design strategies should embrace any combination of daylighting and electric lighting to achieve target values during daylight hours. The preference is for daylighting to provide all or most of the recommended illuminance presuming that all aspects of daylighting are properly addressed. A sunburst icon depicts those applications and tasks where daylighting is considered a strategic candidate. Use photocells and stepped-dimming or continuous dimming to reduce or eliminate electric lighting during daylight hours. See 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Even for those applications where daylighting is not traditionally a strategic candidate, it may be determined that very careful and coordinated design will offer great sustainability opportunities along with positive influences associated with daylight and views. For outdoor applications, lamps and ballasts, transformers, and drivers must be selected for ambient temperature conditions, some of which are extremely hot and others extremely cold.

36.3.6 Veiling Reflections

Tasks with specular components, like computers with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper or, worse, both, are prone to veiling reflections. The likelihood of particular applications and tasks predisposed to veiling reflections is indicated by a “reflected light” icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood. Veiling reflections are minimized by controlling the overall amount and direction of light with respect to the task locations and orientations. Alternatively, tasks sensitive to veiling reflections can be screened or isolated. Effective strategies include employing indirect soft, diffuse electric lighting or direct electric lighting with multiple low-output luminaires, or positioning tasks and luminaires and luminance patterns to avoid harsh reflections from tasks. Addressing luminance recommendations (see Table 12.4 | Default Luminance and Luminaire

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Intensity Recommendations for VDT Applications) minimizes veiling reflections. Changing the task will reduce or eliminate veiling reflections, such as use of CSA/ISO Type I or II computer screens and matte paper versus their specular counterparts.

36.3.7 Defining Areas of Coverage

In addition to establishing planes of task orientation, the areas of coverage to which targets apply must be determined. Typical areas of task illuminance coverage are identified here, but these may not be appropriate to specific project situations. One area of coverage is "task proper or task area." Here, the illuminance criteria are applied to the task itself or to a relatively small area to which the task is confined. See 12.5.5.1 Applications and Tasks and Figure 12.22 | Task Coverage Example.

Another area of coverage is "room or designated area." In this situation, illuminance criteria are applied to the room or an area of fairly substantive size representing the zone in which the applications and tasks are expected to occur. The designated area is typically established by the furniture layout, for example, or might be established by the design team or client. The area-of-coverage citations in Table 36.2 are based on traditional notions. So, for example, it may be determined that a "task proper or task area" coverage would result in some amount of LPD reduction when compared to "room or designated area" coverage. If the task can be confined to one area rather then multiple areas, if the room or area in which the task is located is itself relatively small, such as a single-occupant office, and if the other design goals and criteria outlined in 12 | COMPONENTS OF LIGHTING DESIGN are addressed, then this strategy of redefining area of coverage has merit.

An assessment and determination must be made on which area of coverage best satisfies the lighting goals on a particular project.

36.4 Designing

Information provided here is specific to transportation facilities and should be used as part of the design and documentation processes outlined in Chapters 12, 15, and 20. Equipment selection and location strategies may need to address the possibility of lighting equipment abuse. For outdoor applications, lamps and ballasts, transformers, and drivers must be selected for ambient temperature conditions, some of which are extremely hot and others extremely cold. Dimming response to daylight may be impractical. See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY for additional information on respective aspects. Addressing all code requirements is a must. Energy efficient and sustainable practices are an integral part of all IES recommendations. Key design tenets include, but are not limited to:

- designing for the comfort and convenience of travelers intended to use the project
- using baseline reflectances of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively) in interior production, holding, and work-oriented spaces
- using daylighting that meets luminance and illuminance criteria
- using highest-efficacy lamps that meet color, optical and electrical control, and output criteria
- using highest-efficiency luminaires that meet aesthetic, abuse, and luminance criteria
- using accenting to provide luminance balancing
- using controls liberally, preferably automated varieties such as presets, occupancy and vacancy sensors, astronomical timeclocks, and photocells
- establishing IES-recommended illuminance criteria to meet programmed tasks
- establishing layouts that just meet IES-recommended illuminance criteria

IESH/10e Economics Resources

> 15.3.3 Budgets
- for more on budgets and value engineering

> 18 | ECONOMICS
- for more on estimating costs
- for more on life cycle costs
- for more on paybacks and rates of return

IESH/10e Energy Efficiency Resources

> 17.2 New Construction
- for more on designing for daylighting
- for more on electric lighting equipment
- for more on lighting controls

> 17.4 Lighting Codes, Regulations and Standards
- for more on application standards
- for more on equipment regulations

IESH/10e Lighting Exteriors Resources

> 12.5.5.6 Nighttime Outdoor Illuminances
- for more on lamp efficacies under mesopic adaptation

> 26 | LIGHTING FOR EXTERIORS
- for more on criteria

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- addressing outdoor environmental needs
- using calculations, photometrically-realistic renderings, and operational samples and mockups to prove concepts
- identifying and designing to code-specific requirements, if any, for ambient, task, and accent lighting
- documenting all code-, energy-, sustainability-, and IES-criteria compliance
- documenting criteria and design deviations and rationale and subsequent disposition by team, client, or AHJ
- documenting clearly the layouts, controls, and luminaire and lamp selections

Designing for the comfort and convenience of travelers is the paramount design tenet and must be kept in perspective during all aspects of design. If the workers' expectations are not fulfilled, then how much energy could be saved is moot, as is how many fewer earth resources were spared, as is how much the whole affair cost or how much value engineering saved or the photogenic qualities of the project. See sidebar references for additional guidance on the key tenets. The design effort must be undertaken with coordinated and realistic expectations by all involved on initial and life cycle costs. Budgeting should include designer input and dialogue with the team and client at project commencement and design milestones. In other words, and paraphrasing Thomas Edison, genius is, indeed, just 1% inspiration and 99% perspiration.

IESH/10e Sustainability Resources

> 13.11 Sustainability
- for more on lamps

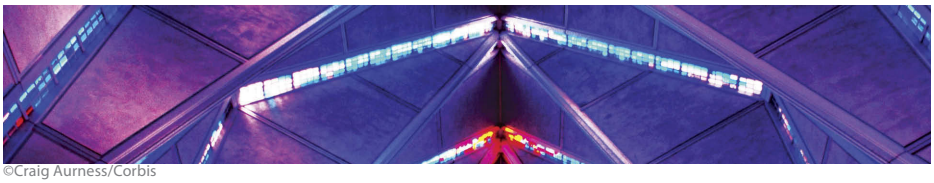
> 19 | SUSTAINABILITY
- for more on controls
- for more on earth resources
- for more on energy
- for more on life cycle analyses
- for more on lighting design
- for more on recycling

36.5 References

[1] Mark S. Rea, ed. The IESNA Lighting Handbook: Reference and Application, Ninth Edition (New York: Illuminating Engineering Society of North America, 2000)

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37 | LIGHTING FOR WORSHIP

The real voyage of discovery consists not in seeking new landscapes, but in having new eyes.
Marcel Proust 20th Century French Novelist

Contents

37.1 Project Type and Status. . . 37.1
37.2 Application Types 37.2
37.3 Illuminance Criteria 37.19
37.4 Designing. 37.23
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Worship is an intensely personal endeavor that may or may not involve a community of participants. Lighting should acknowledge and enhance this deeply personal act, regardless of the setting or number of participants. Focal elements play a significant if not profound role in developing a visual scene conducive to ceremony or meditative state or both. Whether these focal elements are icons relating to a particular ceremony of worship or are visually-arresting elements that evoke introspection and ethereal contemplation, their lighting should create dramatic attention or soothing backdrop. Tasks that involve reading or acknowledgement or interaction require appropriate amounts of light. Appropriate lighting solutions will address occupants' needs within the context of the architecture and not preconceived notions of worship lighting hardware and architecture. Electric lighting accounts for about 28% of the electricity used in worship facilities (see Figure 37.1) [1] What follows is a discussion of the key aspects affecting lighting for people in settings for worship: project status; space types; activities; application-specific design goals, and illuminance criteria.

Comprehensive design efforts must also rely on material in 12 | COMPONENTS OF LIGHTING DESIGN, 13 | LIGHT SOURCES: APPLICATION CONSIDERATIONS, 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. The designer should have a thorough understanding of the design tenets outlined in those chapters, must identify those deemed appropriate and develop lighting goals and strategies accordingly. This chapter primarily addresses specifics related to lighting for worship which should influence luminaire optical selections, lamping, and final layouts based on previously developed thought-starters (see 15.2 A Lighting Scheme). Use of the material in this chapter to the exclusion of material in Chapters 12, 13, 14, and 15 will likely lead to unsatisfactory results. Previous IES related documentation serves as archival and reference source [2].

Deliberate thought must be given to details beyond the citations in this chapter. For example, in monumental cathedrals with unattended access, automated controls responding to occupancy are critical to minimizing energy use and maximizing in-service system life. See 16.3.4 Occupancy/Vacancy Sensors. Challenges include determining areas of coverage and equipment appropriate to the scale of the spaces involved. Such specific details are not enumerated for all applications and tasks. Table 37.1 offers a checklist of IES lighting topics and criteria. The design team is responsible for determining and addressing indoor and outdoor lighting and energy criteria set forth by authorities having jurisdiction (AHJ) which may be different from and supersede IES criteria. See also 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY.

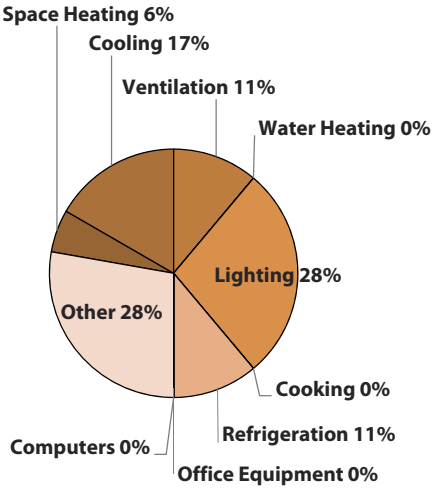


Figure 37.1 | Worship Electricity Use
Based on 2003 data from the US DOE's Energy Information Administration, lighting accounts for 28% of electricity use in worship buildings (electricity use for Computers, Cooking, Office Equipment, and Water Heating rounds to 0%). Worship buildings themselves account for about 2% of electricity use by all commercial and institutional buildings.

37.1 Project Type and Status

An understanding of the project type and scope is necessary before any design work commences. New, renovation, and restoration projects each offer varying opportunities. See 11.2 Planning, 11.3.1 Pre-design, and 11.3.2 Schematic Design. A clear understanding

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Table 37.1 | Lighting for Worship Checklist

Topics
✔ **Criteria and Design Resources**
Accenting
15.1.1.3 Accent Lighting
Table 12.2 | Subjective Impressions
Table 15.2 | Accent Illuminance Ratios
Table 22.2 | Common Applications Illuminance Recommendations
Appearance
12.2 Spatial Factors
Color
12.5.6 Color Considerations
Controls
16 | LIGHTING CONTROLS
Daylighting
14 | DESIGNING DAYLIGHTING
Electric Lighting
15 | DESIGNING ELECTRIC LIGHTING
Flicker
4.6 Flicker and Temporal Contrast Sensitivity
Glare
4.10.1 Discomfort Glare
4.10.2 Disability Glare
Illuminance
This Chapter: Table 37.2
12.5.5.1 Applications and Tasks
Table 12.6 | Default Illuminance Ratio Recommendations
Figure 12.22 | Task Coverage Example
Light Distribution
12.3.2 Subjective Impressions
Luminances
12.5.2 Luminance
Table 12.5 | Default Luminance Ratio Recommendations
Maintenance
15.4.4 Installation and Maintenance
Systems Integration
12.6 Systems Factors
Veiling Reflections
This Chapter: Section 37.3.6
12.5.4 Veiling Reflections
Visual Tasks
This Chapter: Section 37.2
This Chapter: Table 37.2
Table 11.2 | Programming: Inventory Scope and Specific Examples
12.5.1 Visual Tasks
Table 12.3 | Sample Visual Task Survey

of the project type and scope helps establish the extent to which daylighting will address most or many or some of the lighting goals. At every opportunity daylighting should be considered as a light source. Dappled and colored light through stained glass is a tried-and-true application of daylighting for worship. However this generally yields relatively low illuminances that are only appropriate for certain aspects of worship ceremonies in the traditional sense. Attempts have been made to introduce daylight harvesting into the worship environment. If daylight harvesting is not carefully designed, then discomfort glare and sometimes disability glare result. Daylighting requires attention to address glare and manage visible and thermal energy. Critically, this means addressing the host of lighting design factors identified in 12 | COMPONENTS OF LIGHTING DESIGN and in 14 | DESIGNING DAYLIGHTING.

37.2 Application Types

To develop lighting solutions that meet quality, quantity, and operational criteria, an inventory is made of the worship space types under consideration and the anticipated occupants, functions, and tasks (see Table 11.2 | Programming: Inventory Scope and Specific Examples and Table 12.3 | Sample Visual Task Survey). Otherwise, lighting cannot be best targeted to the users, their expectations, functions and tasks.

Space type definitions are required early in the project design in order to track design efforts that include inventorying the project knowns, anticipated functions, and tasks and calculating lighting, power, and energy compliance. Room names and celebratory or liturgical areas, from which functions can be deduced, and numbers for tracking should be clearly marked on architectural backgrounds. The applications and tasks cited in Table 37.2 | Worship Facilities Illuminance Recommendations should be reviewed against the project knowns and correlated with the named space types and functions to establish recommended illuminance criteria. Seek clarification with the client where discrepancies occur between programming information, the list of room names, and the available application and task citations in Table 37.2.

Some worship facilities are relatively diverse activity or cultural centers with a need to accommodate functions other than conventional worship in the main worship space. These other activities should be outlined in the program or might become obvious during a task survey, but might include communal suppers, socializing and learning in the form of prayer and study groups, lectures, music performances, and skits, and movie and book reviews. To accommodate these additional activities, lighting different from that necessary to achieve the goals of worship will be necessary along with controls offering a greater range of flexibility. Some criteria related to performance lighting is cited at CONTEMPORARY FORM/Performance in Table 37.2. The designer should reference other application chapters for further guidance and illuminance criteria depending on the additional tasks involved. This might include referencing 22 | LIGHTING FOR COMMON APPLICATIONS, 24 | LIGHTING FOR EDUCATION, and 28 | LIGHTING FOR HOSPITALITY AND ENTERTAINMENT.

Worship applications are quite personal. The client might be a religious leader, a committee of worshipers, or both. It is possible that criteria cited here may not align with programmed applications and functions or with a client's expressed desires, which may range from "I want it to be mysterious" to "I want my parishioners to be able to read the hymnal." The designer must be interpreter and assess what illuminance criteria are appropriate to meet the needs in the context of a specific project's architecture and finish scheme and the prioritized lighting criteria discussed in 12 | COMPONENTS OF LIGHTING DESIGN. A review of Table 4.1 | Recommended Target Illuminances may be in order to establish criteria suited to the specifics of the client. Accenting greatly assists in brightness perceptions. Dark and high contrast help create a sense of mystery. Design

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reviews, including criteria implications, and design resolution and agreement between the designer and client are important.

The following sections are keyed to the major application and task headings in Table 37.2. These discussions, those highlighted in Table 37.1, and material in Table 37.2 offer comprehensive qualitative and quantitative criteria.

37.2.1 Accenting

Accenting affects people's brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. Default accent lighting criteria are discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. Also see 15.1.1.3 Accent Lighting.

37.2.2 Administration

Lighting for administrative areas is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. The architectural scheme and even task specifics may vary based on the associated worship facility and its size and outreach programs, if any. These distinctions may affect lighting design—from kinds of lighting effects to lighting equipment styling to luminances and illuminances.

The administrative areas may be dispersed throughout a worship facility or complex or may be centralized into a single area, wing, or building. Depending on client wishes and architectural desires, this centralization or decentralization may affect the degree to which the lighting design in administrative areas is sympathetic to or different from that of the other applications and tasks at the worship facility in question.

37.2.3 Building Entries

Lighting for building entries is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. For building entries of worship facilities two distinct variables are time and duration of need. Other variables demanding attention prior to recommending illuminance criteria include anticipated levels of activity and the nighttime outdoor lighting zone. Nighttime activity levels may vary by type of worship facility and the extent and type of outreach programs. Worship may be primarily a day-time activity, a nighttime activity, or both and may fluctuate seasonally. Outreach programs may include community-activity centers, soup kitchens, bible schools, and fund-rasing activities, to name a few. All of this may demand a control system capable of addressing various settings on various evenings through manual intervention, automated time clock, and photocell functions.

The nighttime outdoor lighting zone within which the facility is located establishes the illuminance categories for outdoor tasks. Nighttime outdoor lighting zones vary by local ordinance, sustainability guides, or the team's own definition of place.

After-hours security needs, such as on-site or remote monitoring or recording, may require that some luminaires at building entries remain energized through the night or placed on motion sensors or interconnected with camera operations. Control zones and time clock functions must be designed accordingly. Where remote monitoring is done with infrared cameras, lighting may be unnecessary.

37.2.4 Classrooms

Lighting for classrooms is discussed in 24 | LIGHTING FOR EDUCATION. Relatively simple lighting and controls may be appropriate for religious education classes that occur once a week and for an hour or so and where no multi-technology-presentation is used frequently, if at all. However, where worship facilities encompass faith-based education, lighting needs to address the demands of a pedagogy, formal schedule, testing, and curriculum, including various presentation technologies.

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Table 37.2 | Worship Facilities Illuminance Recommendations

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b,c,d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
ACCENTING	Accenting influences observers' overall brightness perceptions and provides visual relief. Accenting is also used for visual attraction and wayfinding. See 22 | LIGHTING FOR COMMON APPLICATIONS/ACCENTING for default accenting criteria for consideration in any application.										
ADMINISTRATION	See 22 | LIGHTING FOR COMMON APPLICATIONS										
BUILDING ENTRIES	See 22 | LIGHTING FOR COMMON APPLICATIONS										
CLASSROOMS	See 24 | LIGHTING FOR EDUCATION										
CONTEMPORARY FORM	Contemporary ambience or exuberant worship										
• AV											
• Congregation											
◦ Feature presentation	E_h @2' AFF; E_v @4' AFF	F	5	10	20	Avg	D	3	6	12	Avg
◦ Participatory	E_h @2' AFF; E_v @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Screen (front projection)	Cited values are for screen plane when screen is in use										
◦ Feature presentation								10	10	10	Max
◦ Participatory								50	50	50	Max
• Choir	See CONTEMPORARY FORM/Reverent Focal Areas/High Reflectance Focal Surface Finishes/Secondary Focal Area										
• Congregation	Nave, Prayer Hall										
• Circulation	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• Dark-house ceremony	E_h @floor; E_v @5' AFF		2	2	2	Min	F	5	10	20	Avg
• Typical	E_h @floor; E_v @5' AFF		Avg = 0.3 times E_h of liturgical activity, but with min ≥10 lx					Avg = 0.3 times E_v of liturgical activity			
• Collective Meditation	E_h @2' AFF; E_v @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Participatory Action	E_h @3' AFF; E_v @5' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Personal Meditation	E_h @floor; E_v @4' AFF	H	10	20	40	Avg	F	5	10	20	Avg
• Pre/Post Worship	E_h @3' AFF; E_v @5' AFF	P	150	300	600	Avg	N	75	150	300	Avg
• Sermon	E_h @2' AFF; E_v @4' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Music	See CONTEMPORARY FORM/Reverent Focal Areas/High Reflectance Focal Surface Finishes; Secondary Focal Area										
• Narthex											
• Day											
• During worship		K	25	50	100	Avg	I	15	30	60	Avg
• Pre/Post worship		N	75	150	300	Avg	L	37.5	75	150	Avg
• Night		K	25	50	100	Avg	I	15	30	60	Avg
• Reverent Focal Areas	Illuminance on surface or surfaces of focal interest, including celebrants during respective liturgical activity										
• High-reflectance Focal Areas	For focal areas with surface finishes ≥50% during respective liturgical activity.										
• Primary focal areas	E_h and E_v @respective relevant planes on focal area										
◦ Collective meditation		R	250	500	1000	Avg	R	250	500	1000	Avg
◦ Dark-house ceremony		O	100	200	400	Avg	O	100	200	400	Avg
◦ Participatory action		T	500	1000	2000	Avg	T	500	1000	2000	Avg
◦ Personal meditation		O	100	200	400	Avg	O	100	200	400	Avg
◦ Pre/Post worship		T	500	1000	2000	Avg	T	500	1000	2000	Avg
◦ Sermon		T	500	1000	2000	Avg	T	500	1000	2000	Avg

Table 37.2 | Worship Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	3:1					
	3:1					
2:1						
2:1						
	5:1/3:1					
	5:1/3:1					
	3:1					
	3:1					
	3:1					
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	4:1					

Notes for Table 37.2

The table column headings are discussed in detail in 37.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 37.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 37.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 37.2 should be made at 1 fc to 10 lx. Regardless, codes and ordinances may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers or video display screens with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 37.2 | Worship Facilities Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
CONTEMPORARY FORM	(Reverent Focal Areas continued)										
• Secondary focal areas	E_h and E_v @respective relevant planes on focal areas. Also use for choir and music when these are part of the liturgical activity.										
◦ Collective meditation		P	150	300	600	Avg	P	150	300	600	Avg
◦ Dark-house ceremony		M	50	100	200	Avg	M	50	100	200	Avg
◦ Participatory action		R	250	500	1000	Avg	R	250	500	1000	Avg
◦ Personal meditation		M	50	100	200	Avg	M	50	100	200	Avg
◦ Pre/Post worship		R	250	500	1000	Avg	R	250	500	1000	Avg
◦ Sermon		P	150	300	600	Avg	P	150	300	600	Avg
• Low-reflectance Focal Areas	For focal areas with surface finishes <50% during respective liturgical activity.										
• Primary focal areas	E_h and E_v @respective relevant planes on focal area										
◦ Collective meditation		T	500	1000	2000	Avg	T	500	1000	2000	Avg
◦ Dark-house ceremony		Q	200	400	800	Avg	Q	200	400	800	Avg
◦ Participatory action		U	750	1500	3000	Avg	U	750	1500	3000	Avg
◦ Personal meditation		Q	200	400	800	Avg	Q	200	400	800	Avg
◦ Pre/Post worship		U	750	1500	3000	Avg	U	750	1500	3000	Avg
◦ Sermon		U	750	1500	3000	Avg	U	750	1500	3000	Avg
• Secondary focal areas	E_h and E_v @respective relevant planes on focal areas. Also use for choir and music when these are part of the liturgical activity.										
◦ Collective meditation		R	250	500	1000	Avg	R	250	500	1000	Avg
◦ Dark-house ceremony		O	100	200	400	Avg	O	100	200	400	Avg
◦ Participatory action		S	375	750	1500	Avg	S	375	750	1500	Avg
◦ Personal meditation		O	100	200	400	Avg	O	100	200	400	Avg
◦ Pre/Post worship		S	375	750	1500	Avg	S	375	750	1500	Avg
◦ Sermon		R	250	500	1000	Avg	R	250	500	1000	Avg
• Performance											
• House	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• During event			2	2	2	Min	F	5	10	20	Avg
• Pre/Post event		L	37.5	75	150	Avg	K	25	50	100	Avg
• Stage											
• Access ramps/stairs	See AUDITORIA/Circulation										
• Amateur productions											
◦ Dance (performance)	E_h @floor; E_v @5' AFF	P	150	300	600	Avg	R	250	500	1000	Avg
◦ Demonstration		T	500	1000	2000	Avg	R	250	500	1000	Avg
◦ Music		P	150	300	600	Avg	R	250	500	1000	Avg
◦ Theater	Simple, no stage lighting cues	P	150	300	600	Avg	P	150	300	600	Avg
• Professional productions	Stage lighting as determined by production crew; See IES DG-20 | Stage Lighting **A Guide to the Planning of Theatres and Auditoriums** for guidance on architectural and electrical infrastructure										
• Sacristy	E_h @2' 6" AFF; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
FOOD SERVICE	See 22 | LIGHTING FOR COMMON APPLICATIONS										
PARKING	See 26 | LIGHTING FOR EXTERIORS										
PEDESTRIAN WAYS	See 26 | LIGHTING FOR EXTERIORS										

Table 37.2 | Worship Facilities Illuminance Recommendations continued next page

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	4:1		☀		■	
	4:1		☀		■	
	4:1		☀	◪	■	
	4:1		☀		■	
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	4:1		☀		■	
	4:1		☀	◪	■	
	5:1/3:1					■
	3:1		☀			■
	1.5:1				■	
	3:1				■	
	2:1				■	
	2:1				■	
	4:1		☀			■

Notes for Table 37.2

The table column headings are discussed in detail in 37.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 37.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 37.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria.

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d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers or video display screens with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◪ signals high likelihood; gray and white ◪ signals moderate likelihood; pale gray and white ◪ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 37.2 | Worship Facilities Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b,c,d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
SUPPORT SPACES											
• Coat Check or Coat Rooms	E_h @3' 0"; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Copy/Print Rooms											
• General	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Machines	E_h and E_v @3' 6" AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Janitor's Closet	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Receiving/Shipping											
• Dock	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Receiving/Staging	E_h @floor; E_v @4' AFF	P	150	300	600	Avg	M	50	100	200	Avg
• Storage											
• Food	See 22 | LIGHTING FOR COMMON APPLICATIONS/Food Service										
• Frequent Use	E_h @floor; E_v @4' AFF	M	50	100	200	Avg	I	15	30	60	Avg
• Infrequent Use	E_h @floor; E_v @4' AFF	K	25	50	100	Avg	H	10	20	40	Avg
TOILETS/ LOCKER ROOMS	See 22 | LIGHTING FOR COMMON APPLICATIONS										
TRADITIONAL FORM	Traditional ambience or formal worship										
• Choir	See TRADITIONAL FORM/Reverent Focal Areas/High Reflectance Focal Surface Finishes/Secondary Focal Area										
• Congregation	Nave, Prayer Hall										
• Circulation	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• Dark-house ceremony	E_h @floor; E_v @5' AFF		2	2	2	Min	F	5	10	20	Avg
• Typical	E_h @floor; E_v @5' AFF		Avt = 0.3 times E_h of liturgical activity, but with min ≥10 lx					Avg = 0.3 times E_v of liturgical activity			
• Collective Meditation	E_h @2' AFF; E_v @4' AFF	J	20	40	80	Avg	H	10	20	40	Avg
• Participatory Action	E_h @3' AFF; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Personal Meditation	E_h @floor; E_v @4' AFF	H	10	20	40	Avg	F	5	10	20	Avg
• Pre/Post Worship	E_h @3' AFF; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg
• Sermon	E_h @2' AFF; E_v @4' AFF	J	20	40	80	Avg	H	10	20	40	Avg
• Music	See TRADITIONAL FORM/Reverent Focal Areas/High Reflectance Focal Surface Finishes; Secondary Focal Area										
• Narthex											
• Day											
• During worship		K	25	50	100	Avg	I	15	30	60	Avg
• Pre/Post worship		M	50	100	200	Avg	K	25	50	100	Avg
• Night		K	25	50	100	Avg	I	15	30	60	Avg
• Reverent Focal Areas	Illuminance on surface or surfaces of focal interest, including celebrants during respective liturgical activity										
• High-reflectance Focal Areas	For focal areas with surface finishes ≥50% during respective liturgical activity.										
• Primary focal areas	E_h and E_v @respective relevant planes on focal area										
◦ Collective meditation		O	100	200	400	Avg	O	100	200	400	Avg
◦ Dark-house ceremony		O	100	200	400	Avg	O	100	200	400	Avg
◦ Participatory action		R	250	500	1000	Avg	R	250	500	1000	Avg
◦ Personal meditation		O	100	200	400	Avg	O	100	200	400	Avg
◦ Pre/Post worship		R	250	500	1000	Avg	R	250	500	1000	Avg
◦ Sermon		R	250	500	1000	Avg	R	250	500	1000	Avg

Table 37.2 | Worship Facilities Illuminance Recommendations continued next page

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Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
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e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers or video display screens with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

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i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 37.2 | Worship Facilities Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
TRADITIONAL FORM	(Reverent Focal Areas continued)										
• Secondary focal areas	E_h and E_v @respective relevant planes on focal areas. Also use for choir and music when these are part of the liturgical activity.										
◦ Collective meditation		M	50	100	200	Avg	M	50	100	200	Avg
◦ Dark-house ceremony		M	50	100	200	Avg	M	50	100	200	Avg
◦ Participatory action		P	150	300	600	Avg	P	150	300	600	Avg
◦ Personal meditation		M	50	100	200	Avg	M	50	100	200	Avg
◦ Pre/Post worship		P	150	300	600	Avg	P	150	300	600	Avg
◦ Sermon		M	50	100	200	Avg	M	50	100	200	Avg
• Low-reflectance Focal Areas	For focal areas with surface finishes <50% during respective liturgical activity.										
• Primary focal areas	E_h and E_v @respective relevant planes on focal area										
◦ Collective meditation		Q	200	400	800	Avg	Q	200	400	800	Avg
◦ Dark-house ceremony		Q	200	400	800	Avg	Q	200	400	800	Avg
◦ Participatory action		T	500	1000	2000	Avg	T	500	1000	2000	Avg
◦ Personal meditation		Q	200	400	800	Avg	Q	200	400	800	Avg
◦ Pre/Post worship		T	500	1000	2000	Avg	T	500	1000	2000	Avg
◦ Sermon		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Secondary focal areas	E_h and E_v @respective relevant planes on focal areas. Also use for choir and music when these are part of the liturgical activity.										
◦ Collective meditation		O	100	200	400	Avg	O	100	200	400	Avg
◦ Dark-house ceremony		O	100	200	400	Avg	O	100	200	400	Avg
◦ Participatory action		R	250	500	1000	Avg	R	250	500	1000	Avg
◦ Personal meditation		O	100	200	400	Avg	O	100	200	400	Avg
◦ Pre/Post worship		R	250	500	1000	Avg	R	250	500	1000	Avg
◦ Sermon		O	100	200	400	Avg	O	100	200	400	Avg
• Sacristy	E_h @2' 6" AFF; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg
TRANSITION SPACES											
• Circulation Corridors	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.										
• Adjacency Passageways	E_h @floor; E_v @5' AFF	Avg ≥0.3 times task E_h of adjacent space or as cameras require, but with min ≥10 lx					Avg ≥0.3 times task E_v of adjacent space or as cameras require				
• Independent Passageways	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Elevators											
• Freight											
• Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Threshold											
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Passenger											
• Cab interior	E_h @floor; E_v @3' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Threshold											
◦ Cab exterior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg
◦ Cab interior	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg

Table 37.2 | Worship Facilities Illuminance Recommendations continued next page

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		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are					
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge	
TRANSITION SPACES	(continued)											
• Lobbies												
• Circulation, Elevator Lobbies	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.											
• At building entries	Close proximity to exterior. Lighting should assist with adaptation when passing to/from exterior..											
◦ Day	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg	
◦ Night	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	H	10	20	40	Avg	
• Distant from entries	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg	
• Information Desk		P	150	300	600	Avg	M	50	100	200	Avg	
• Lounges												
• Pleasure Reading		O	100	200	400	Avg	M	50	100	200	Avg	
• Social		M	50	100	200	Avg	K	25	50	100	Avg	
• Reception/Waiting Areas												
• Reception Desk		Q	200	400	800	Avg	N	75	150	300	Avg	
• Waiting Areas		O	100	200	400	Avg	M	50	100	200	Avg	
• Stairs	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.											
• High Activity[i]	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg	
• Live-surveillance	E_h @floor; E_v @5' AFF	M	50	100	200	Avg	K	25	50	100	Avg	
• Typical	E_h @floor; E_v @5' AFF	K	25	50	100	Avg	I	15	30	60	Avg	
TRANSITIONAL FORM	Transitional ambience or informal worship											
• Choir	See TRANSITIONAL FORM/Reverent Focal Areas/High Reflectance Focal Surface Finishes/Secondary Focal Area											
• Congregation	Nave, Prayer Hall											
• Circulation	As the architect coordinates contrast markings with steps, curbs, and ramps, localized lighting may be deemed appropriate.											
• Dark-house ceremony	E_h @floor; E_v @5' AFF		2	2	2	Min	F	5	10	20	Avg	
• Typical	E_h @floor; E_v @5' AFF		Avg = 0.3 times E_h of liturgical activity, but with min ≥10 lx					Avg = 0.3 times E_v of liturgical activity				
• Collective Meditation	E_h @2' AFF; E_v @4' AFF	L	37.5	75	150	Avg	I	15	30	60	Avg	
• Participatory Action	E_h @3' AFF; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg	
• Personal Meditation	E_h @floor; E_v @4' AFF	H	10	20	40	Avg	F	5	10	20	Avg	
• Pre/Post Worship	E_h @3' AFF; E_v @5' AFF	O	100	200	400	Avg	M	50	100	200	Avg	
• Sermon	E_h @2' AFF; E_v @4' AFF	L	37.5	75	150	Avg	I	15	30	60	Avg	
• Music	See TRANSITIONAL FORM/Reverent Focal Areas/High Reflectance Focal Surface Finishes; Secondary Focal Area											
• Narthex												
• Day												
• During worship		K	25	50	100	Avg	I	15	30	60	Avg	
• Pre/Post worship		M	50	100	200	Avg	K	25	50	100	Avg	
• Night		K	25	50	100	Avg	I	15	30	60	Avg	

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see Table 12.6			☀			
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e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers or video display screens with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 37.2 | Worship Facilities Illuminance Recommendations continued from previous page

Applications and Tasks[a]	Notes	Recommended Maintained Illuminance Targets (lux)[b,c,d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
		Visual Ages of Observers (years) where **at least half** are					Visual Ages of Observers (years) where **at least half** are				
		Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
TRANSITIONAL FORM	(continued)										
• Reverent Focal Areas	Illuminance on surface or surfaces of focal interest, including celebrants during respective liturgical activity										
• High-reflectance Focal Areas	For focal areas with surface finishes ≥50% during respective liturgical activity.										
• Primary focal areas	E_h and E_v @respective relevant planes on focal area										
◦ Collective meditation		P	150	300	600	Avg	P	150	300	600	Avg
◦ Dark-house ceremony		O	100	200	400	Avg	O	100	200	400	Avg
◦ Participatory action		S	375	750	1500	Avg	S	375	750	1500	Avg
◦ Personal meditation		O	100	200	400	Avg	O	100	200	400	Avg
◦ Pre/Post worship		S	375	750	1500	Avg	S	375	750	1500	Avg
◦ Sermon		S	375	750	1500	Avg	S	375	750	1500	Avg
• Secondary focal areas	E_h and E_v @respective relevant planes on focal areas. Also use for choir and music when these are part of the liturgical activity.										
◦ Collective meditation		O	100	200	400	Avg	O	100	200	400	Avg
◦ Dark-house ceremony		M	50	100	200	Avg	M	50	100	200	Avg
◦ Participatory action		Q	200	400	800	Avg	Q	200	400	800	Avg
◦ Personal meditation		M	50	100	200	Avg	M	50	100	200	Avg
◦ Pre/Post worship		Q	200	400	800	Avg	Q	200	400	800	Avg
◦ Sermon		O	100	200	400	Avg	O	100	200	400	Avg
• Low-reflectance Focal Areas	For focal areas with surface finishes <50% during respective liturgical activity.										
• Primary focal areas	E_h and E_v @respective relevant planes on focal area										
◦ Collective meditation		S	375	750	1500	Avg	S	375	750	1500	Avg
◦ Dark-house ceremony		Q	200	400	800	Avg	Q	200	400	800	Avg
◦ Participatory action		T	500	1000	2000	Avg	T	500	1000	2000	Avg
◦ Personal meditation		Q	200	400	800	Avg	Q	200	400	800	Avg
◦ Pre/Post worship		T	500	1000	2000	Avg	T	500	1000	2000	Avg
◦ Sermon		T	500	1000	2000	Avg	T	500	1000	2000	Avg
• Secondary focal areas	E_h and E_v @respective relevant planes on focal areas. Also use for choir and music when these are part of the liturgical activity.										
◦ Collective meditation		P	150	300	600	Avg	P	150	300	600	Avg
◦ Dark-house ceremony		O	100	200	400	Avg	O	100	200	400	Avg
◦ Participatory action		S	375	750	1500	Avg	S	375	750	1500	Avg
◦ Personal meditation		O	100	200	400	Avg	O	100	200	400	Avg
◦ Pre/Post worship		S	375	750	1500	Avg	S	375	750	1500	Avg
◦ Sermon		P	150	300	600	Avg	P	150	300	600	Avg
• Sacristy	E_h @2' 6" AFF; E_v @5' AFF	P	150	300	600	Avg	M	50	100	200	Avg

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Uniformity Targets[e] Over Area of Coverage: 1st ratio $E_h/2^{nd}$ ratio E_v if different uniformities apply			[f]	[g]	Typical Area of Coverage[h]	
Max:Avg	Avg:Min	Max:Min			Task Proper or Task Area	Room or Designated Area
	4:1		☀		■	
	4:1		☀		■	
	4:1		☀	◪	■	
	4:1		☀		■	
	4:1		☀		■	
	4:1		☀	◪	■	
	4:1		☀		■	
	4:1		☀		■	
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	4:1		☀	◪	■	
	4:1		☀		■	
	4:1		☀		■	
	4:1		☀	◪	■	
	4:1		☀			■

Notes for Table 37.2

The table column headings are discussed in detail in 37.3 Illuminance Criteria. See 12.5.5 Illuminance for discussion on procedures for establishing illuminance targets for a project. See Table 37.3 | SI Dimensional Conversions.

a. Applications, tasks, or viewing specifics encountered on any given project may be different from these and may warrant different criteria. See 37.3.1 Applications and Tasks. The designer is responsible for making final determinations of applications, tasks, and illuminance criteria.

b. Values cited are to be maintained over time on the area of coverage.

c. Values cited are consensus and deemed appropriate for respective functional activity. In a few situations, code requirements are within 10% of IES recommendations. This is apparently an artifact of metrication. Footcandle conversions of any values cited in Table 37.2 should be made at 1 fc to 10 lx. Regardless, codes and ordinances may supersede any of the IES criteria for any of the applications and tasks and the designer must design accordingly.

d. Targets are intended to apply to the respective plane or planes of the task.

e. Illuminance uniformity targets offer best results when planned in conjunction with luminance ratios and surface reflectances. Any parenthetical uniformity values reference respective parenthetical applications or tasks, such as a curfew situation associated with nighttime outdoor lighting.

f. Applications and tasks cited with sunburst icon ☀ are candidates for strategies employing any combination of daylighting and electric lighting to achieve target values during daylight hours. Daylighting may require unconventional approaches.

g. Tasks with specular components, like computers or video display screens with CSA/ISO Type III screens or printed tasks with glossy ink or glossy paper, are prone to veiling reflections. The likelihood of an application's or task's predisposition to veiling reflections is indicated by the reflected-light icon: black and white ◪ signals high likelihood; gray and white ◪ signals moderate likelihood; pale gray and white ◪ signals some likelihood; and all-white signals little-to-no likelihood.

h. The designer must establish areas of coverage to which targets apply. Green ■ highlight identifies task proper or task area as the typical area of coverage for respective cited targets. Amber ■ highlight identifies room or designated area as the typical area of coverage for respective cited targets.

i. See Table 22.4 | Indoor and Nighttime Outdoor Activity Level Definitions.

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Table 37.3 | SI Dimensional Conversions

US Customary	SI
General	**Hard Conversion**
inches	mm [inches × 25.40]
feet	m [feet × 0.30]
Specific	**Convenient Conversions[a]**
2'	610 mm or 0.6 m
2' 6"	760 mm or 0.75 m
3'	915 mm or 0.9 m
3' 6"	1065 mm or 1.1 m
4'	1220 mm or 1.2 m
5'	1525 mm or 1.5 m

a. Hard conversions rounded for reporting convenience. Not to be confused with metric-sized luminaires or other building materials. Not for precision construction.

37.2.5 Worship Needs

The need to fully program worship facilities such as cathedrals, churches, mosques, shrines, synagogues, temples or other houses of worship cannot be overstated. The religious sect, its kind of worship, and the congregants of a facility steer lighting among other design and planning decisions. Organized religion is categorized here as that taking a contemporary form, or traditional form, or a transitional form. These are cited in Table 37.2 in alphabetical order amongst the other applications and tasks. The designer must consult with the client to establish the appropriate form of worship, which may relate to the intended tone and dynamics of the ceremonies or liturgy, to the architecture, or to both. For personal meditation by one individual or an intimate group, see Table 34.2 | Residential Illuminance Recommendations/Residential Interiors/Meditation Rooms. Horizontal illuminance criteria for a task should not be the sole driver behind lighting solutions. Vertical illuminances, peripheral lighting, and accenting play a significant role in lighting for worship. See Figure 37.2. In addition to some discussion on the various forms of worship, controls, maintenance, and broadcast requirements are discussed below.

37.2.5.1 Contemporary, Traditional, and Transitional Forms of Worship

For contemporary forms of worship, illuminance criteria are cited in Table 37.2 for tasks and applications that are related to contemporary ambience or of exuberant worship. The illuminance criteria for traditional forms of worship are related to traditional ambience or formal worship. Illuminance criteria for transitional forms of worship are related to transitional ambience or an informal worship style. Generally, illuminances are highest for exuberant worship, lowest for formal worship, and moderate for informal worship. See Figures 37.3 and 37.4.

Criteria for each form of worship is available to address the following common applications and tasks: choir; congregation; music; narthex; reverent focal areas; and sacristy. The congregation may also be referenced as nave, prayer hall, or assembly depending on the religion. For the body of congregants, criteria are cited for circulation, collective meditation, participatory action, personal meditation, and sermon. The designer must determine which of these applications and tasks are relevant to the worship project at hand. A basic lighting situation for the congregation area should include lighting for participatory action and sermon.

Conventional church architecture may be laid out with traditional worship spaces and areas such as a chancel, nave, sanctuary, side aisles, and transept. Rather than light these areas to predetermined illuminances, they should be lighted according to applications and tasks and to the visual hierarchies the designer and client deem appropriate for the liturgy.

Contemporary form is most likely to have a need for lighting to address a broad array of AV and performance functions as part of the liturgy.

37.2.5.2 Reverent Focal Areas

Reverent focal areas might include those furnishings that support liturgy or are a significant artifact or feature, such as the altar, ambo, chair, ark, lectern, minbar, pulpit, raredos, reliquary, and tabernacle. These might be accented in a hierarchy relating to the worship activity or might be statically lighted for the duration of a service. The designer must coordinate such lighting schemes with the needs of the particular client. Reverent focal areas that are determined appropriate to the liturgy are lighted based on their reflectance, their relative importance, and the worship activity setting. Where icons or art are of some visual importance, but not of primary or secondary stature, Table 15.2 | Accent Illuminance Ratios is a useful reference. See Figures 37.4, 37.5, and 37.6.

37.2.5.3 Choirs and Music

Areas of music performance and choirs are considered secondary focal elements for purposes of illuminance criteria. These are dimensional focals, much like altars and lecterns, where horizontal and vertical illuminance are equal in value. This assures celebrants can

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perform the reading tasks and simultaneously be sufficiently lighted vertically to appear as a focal element to the congregants.

37.2.5.4 Narthex

A traditional term, narthex defines a foyer or lobby area that is a transition from outdoor to indoor assembly space. Many times the narthex serves as a greeting space. To assist with adaptation, daytime illuminances are higher than nighttime values. With respect to adaptation and circulation to the congregation area, the transition is best if floor surface reflectance values between the narthex and congregation circulation area are nearly identical. Otherwise illuminance at the congregation circulation floor should be adjusted by the ratio of the narthex floor reflectance to the congregation circulation floor reflectance.

37.2.5.5 Sacristy

Sacristy is a traditional term associated with the room where sacred objects may be stored or items associated with the liturgy, including robes, communion cups, and linens.

37.2.5.6 Controls

In even a modest place of worship where a number of ceremonies or functions are to be accommodated and where light will play a role in sequencing through the various ceremonies and functions, controls are necessary. Usually standard wallbox dimmers and switches are insufficient unless dedicated staff is consistently available and capable of punctual operation of the various lighting zones in a predetermined sequence. Typically preset control systems are employed for consistent settings and timely operation of all luminaires. Close coordination with the client is necessary to determine the number and location of control stations and which preset scenes are available at each location. In liturgies where performance is a significant component, a sound and light director may need access to a lighting control board for dynamic lighting effects tailored to a service or performance. The type of lighting control depends on the degree to which clergy requires or desires lighting operation and by whom. Where daylighting has an integral role, automated controls are necessary. Figure 37.7 illustrates just a few of many preprogrammed liturgical scenes which can be made available on a preset system.

37.2.5.7 Maintenance

Some architecture for worship poses two significant challenges: spatial volume; and accessibility to lighting equipment. A further challenge is one of budget which typically precludes extensive catwalks, motorized man lifts, or lowering lifts for luminaires. Spaces with tall ceilings and where recessed luminaires are a preference demand luminaires with precision optics. Any shift in the optical mechanisms during maintenance will result in ineffective and possibly glary lighting and essentially a waste of energy. Accessibility to lighting equipment complicates the process of cleaning and servicing luminaires. Lamping, type of luminaire, and luminaire layout are all influenced by accessibility. A review of maintenance options versus quality and quantity of light and dimming must be made with the client and might include discussion of man lifts, lowering lifts, top access and attic or catwalk requirements, or periodic use of riggers. Automated controls can greatly assist maintenance. Occupancy sensors or time clock controls for some or all of the lighting can lengthen in-service life of lamp and ballast, drivers, and transformers. Some facilities only require much or all of the lighting to be energized for perhaps ten hours a week. Automated controls can help achieve such a low use rate by scheduling when certain lights are available.

37.2.5.8 Broadcast Lighting

Some congregations broadcast services usually over local cable channels. Depending on camera technology and positions, architectural lighting may meet the needs of broadcast. However, some situations will require additional lighting for those services that are broadcast. The illuminance and contrast requirements of the cameras must be accommodated. Separate architectural lighting or theatrical lighting instruments can address these requirements and require separate control.



Figure 37.2 | Personal Meditation
This small hospital chapel is available 24/7. A personal meditation lighting scene offers lighting to an intimate group in the foreground. For intensely private situations, refuge exists beyond the lattice where only a tabernacle is accented. Lighting of the lattice offers spatial definition to both areas and serves as a meditative backdrop or focal element.
» Image ©INAI Studio



Figure 37.3 | Transitional Worship
The designer and client may determine that transitional worship lighting is appropriate to the liturgy, regardless of the architecture. Here, wood furnishings and a historic interpretation of the original ceiling introduce an informal quality. Therefore, the worship lighting criteria could arguably be based on transitional worship for both liturgy and architecture.

With a Sunday outreach of live broadcast to the home-bound and those in nursing homes, hospitals, and prisons, lighting was coordinated with camera requirements for both illuminance and contrast ratios.
» Image ©carr cialdella

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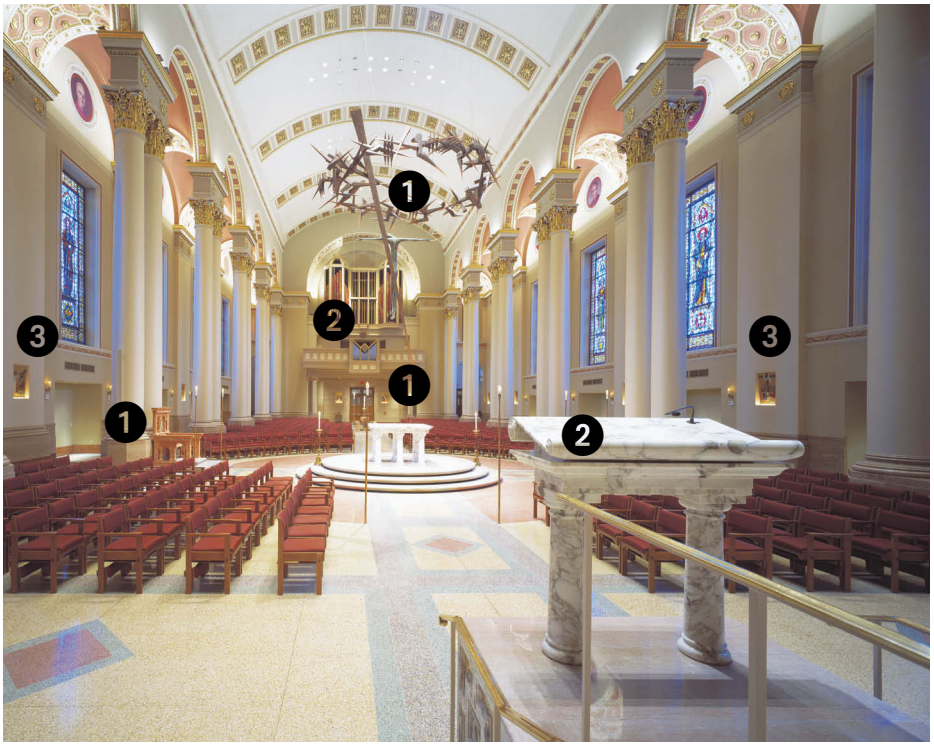


Figure 37.4 | Pre/Post Worship
The lighting in this restored cathedral consists of a variety of zones and presets coordinated with the liturgy. For pre/post worship and for participatory action, an "all-on" and "full-bright" arrangement can be used. The chair, altar, and sculpture above it are primary focal elements ❶ in this scene. Secondary focal elements ❷ are the lectern (also known as ambo or pulpit) and the organ pipes. Stations of the cross ❸ are lighted as art to "Subtle" in accordance with Table 15.2 (see detail in Figure 37.5, below). Indirect lighting accentuates roundel portraits in side-aisle arches and softly washes the barrel vault of the nave which improves overall brightness and accentuates architectural detailing and softly lights congregants faces.

Preset controls choreograph emphasis of various focal elements as outlined in Table 37.2 to accommodate the liturgy. The "sermon" scene prominently features the lectern while dimming the altar. Other scenes can be developed by dimming or extinguishing the indirect lighting or by dimming downlights and selected accents.

» Image ©John J. Korom Photography

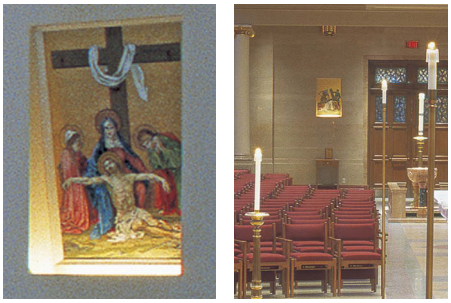


Figure 37.5 | Improved Coverage
To improve the coverage of light over the stations of the cross visible at ❸ in Figure 37.4, and in blow-up to the left, without using picture lights or other obvious luminaires with accent optics, a wall-niche was created at each station. The depth of the niche was sufficient to allow for a lighting detail at the bottom. The artwork was then tipped out to the face of the wall at the top of the niche. The gilt work is more uniformly bright when viewed head-on as seen in the detail on the right.

» Images ©John J. Korom Photography

37.2.6 Food Service

Food service lighting is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS.

37.2.7 Parking

Lighting for parking facilities is discussed in 26 | LIGHTING FOR EXTERIORS.

37.2.8 Pedestrian Ways

Lighting for pedestrian ways is discussed in 26 | LIGHTING FOR EXTERIORS.

37.2.9 Support Spaces

These relatively back-of-house citations are self-explanatory. For purposes of maintenance convenience, lamp types and color qualities should match those used elsewhere.

37.2.10 Toilets/Locker Rooms

Lighting for toilets and locker rooms is discussed in 22 | LIGHTING FOR COMMON APPLICATIONS. Addressing the fixture functional areas, such as toilets, urinals, vanities, will provide sufficient light where needed without overlighting the entire toilet room. Vanities are problematic when little or no vertical illuminance is designed to illuminate an imaginary facial plane (roughly a zone of sufficient size to encompass faces) in front of the mirrors. For purposes of maintenance convenience, lamp types and color qualities should match those used elsewhere.

37.2.11 Transition Spaces

Most of these spaces are self-explanatory. Many apply to very large facilities or a complex or compound. For purposes of maintenance convenience, lamp types and color qualities should match those used elsewhere.

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37.3 Illuminance Criteria

Illuminance criteria, when fully deployed, are a robust set of quantitative values that influence visibility, visual performance, and visual comfort and attention. Short-circuiting the criteria selection or designing to a single criterion value, such as horizontal illuminance, to address worst-case tasks will surely result in dissatisfaction. Even if clients accept the visual results, not getting the most from the energy expended or, worse, energy waste is a likely result. Following are notes related to various aspects outlined in Table 37.2.

37.3.1 Applications and Tasks

Applications and tasks encountered on any given project may be different from those identified in Table 37.2 and may warrant different illuminance criteria. Cross-referencing closely-associated applications or tasks is appropriate. Sometimes naming trends or conventions for space types or liturgical areas and functions change to conform to current practice, client programming, or architectural or liturgical conventions, but the actual activities and tasks remain the same and this cross-referencing works. Failing this technique, reviewing the list in Table 37.2 may be in order to determine if any applications or tasks exhibit a similar visual-component to the unique applications or tasks. Additionally, reviewing the tasks of other applications sometimes yields insight. For example, a lounge or game room for teens is addressed by criteria cited in Table 28.2 | Hospitality and Entertainment Facilities Illuminance Recommendations/TRANSITION SPACES/Lounges/Clubs and Game Rooms. Where no similar-in-nature tasks can be found, then reviewing 4.12 An Illuminance Determination System and Table 4.1 is necessary to establish a task category based on the task characteristics or visual performance descriptions most closely associated with the unique tasks.

37.3.2 Notes

Notes may refer to other application and task headings in the table or to other handbook chapters as appropriate. Where some degree of clarification is warranted, notes are made.

37.3.3 Recommended Maintained Illuminance Targets

Values cited are maintained on the area of coverage for the task under consideration. Illuminance is additive. Where practical and without negatively affecting the intended application of light, target values are achieved with any combination of daylighting and/or electric lighting in whatever mix of ambient, task, and accent lighting is deemed appropriate to meet these and the other lighting goals established during design. See 12 | COMPONENTS OF LIGHTING DESIGN and see 10.7.1 Light Loss Factors.

With respect to light loss factors, account for anticipated losses through the point in time at which group relamping and cleaning should occur. Group relamping and cleaning should be standard practice, though these need not occur at the same frequency. Periodic cleaning and group relamping essentially maintain the illuminance at criteria and make the most efficient use of the installed equipment. For purposes of sustainability, cleaning and group relamping can no longer be presumed to be infrequent or unlikely. Maintenance procedures must be part of the design discussions with the client. See the IES document IESNA/NALMCO RP-36 Recommended Practice for Planned Indoor Lighting Maintenance for additional information. Where maintenance is deferred or practiced poorly or not at all, the actual illuminance values will fall below criteria targets. This is inefficient, unsustainable, and may be unsafe while adversely affecting users' quality of life or work. Maintenance may be especially problematic with LEDs where promises of extraordinarily long life may be offered, but usually with the caveat that lamp lumen depreciation (LLD) at that rated life is 70% or perhaps even as low as 50% of initial rating. If replacement cycles are presumed to be rated life, then LLD alone must be 0.7 or 0.5 or whatever lumen rating is certified by the LED vendor. See 13.3 Life and Lumen Maintenance.



Figure 37.6 | Focal Areas and AV
House lighting and focal lighting control zones are carefully discretized to achieve best effect. Well-designed optically-controlled downlights and theatrical instruments are used. All of these attributes contribute to distinctly rendered focal areas and provide good contrast at AV screens while providing sufficient house lighting.
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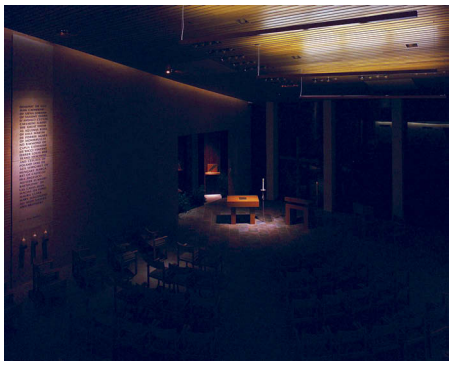


Figure 37.7 | Liturgical Presets
For sustainability, all accent lighting here is achieved with 39W/T6/CMH lamps exhibiting 3000 K CCT and 80CRI. Careful sequencing of presets throughout worship is necessary to avoid the unacceptable delays involved when CMH lamps are extinguished and immediately recalled for operation. By switching off various zones of CMH accents and dimming various zones of fluorescent luminaires, available scenes include (from top):

1. CELEBRATION OF MASS;
2. MUSICAL EVENT (focusing on a music area on the left although altar and tabernacle remain accented);
3. NIGHT MEDITATION.

» Images ©2005 Gene Meadows

A detail involving LEDs and maintenance that is especially relevant to places of worship involves difficulty of access in large-volume high-ceiling spaces. At this writing, LEDs remain untested over long periods of time. It has not been unheard of that LEDs designed into nearly inaccessible areas have failed prematurely. The mechanics and labor involved to service these luminaires and their auxiliary components, including, but not limited to drivers, transformers, and control interfaces has proved difficult and costly. Regardless of the promise of longevity, the designer should confirm warranty coverage for the cost of equipment and labor, preferably for a period of at least 5 years. Detailing and access with design team members and clients prior to layout and specification.

Targets cited are consensus and deemed appropriate for respective functional activity. For some applications, IES recommendations are within 10% of code requirements. This apparently is an artifact of metrication. Footcandle conversions of any values cited in Table 37.2 should be made at 1 fc to 10 lx. This soft conversion avoids a redundant diminishing of illuminance values after multiple citations and conversions over time. This also eliminates a false sense of accuracy advanced by an ever-increasing number of decimal places and a false sense of urgency advanced by eccentric fractional values introduced by hard conversions. Nevertheless, a lighting design must meet code and the mechanics of which must be coordinated amongst the design team. The IES recommendations should not, do not, and cannot reflect all of the various code requirements in force in all jurisdictions at any given time.

Targets are intended to apply to the dominant plane of the task, typically, but not always, horizontal or vertical. In some situations, illuminance criteria are cited for one plane, such as the vertical plane for a front projection screen, while the other plane is blank. The blank signifies that illuminance on that plane is unimportant and may be a consequence of the illuminance of other tasks within the vicinity or by whatever illuminance results from meeting the target illuminance for the prescribed plane of interest.

37.3.3.1 Target Planes

Many, though certainly not all, tasks are performed with the task in roughly a horizontal orientation or vertical orientation. A dominant orientation must be assigned and the illuminance target determined accordingly. There may be situations where the IES recommended target relating to the typical planar mode of a task must be applied to a different plane.

Nearly all tasks are expected to have both a horizontal illuminance component (E_h) and a vertical illuminance component (E_v). This allows some degree of task flexibility for off-plane viewing and accommodates various aspects of the task. In some applications, like participatory action where hymn singing might occur, horizontal- and vertical-plane illuminances address the common situation where reading takes place on near-horizontal to half-way between horizontal and vertical planes.

Where illuminance targets are intended at differing planar elevations, this is indicated under “Notes.” For example, for some congregation areas, horizontal illuminances apply to the lap plane or standing-hymnal plane. Depending on the form of worship and the religion, the designer may elect to set the lap-plane elevation to the floor plane if congregants are seated on floors or floor cushions. Tracking task plane locations and their orientations and addressing both horizontal and vertical illuminance is necessary. If a single focal element is scheduled to be oriented on some plane off axis from horizontal or vertical by more than 10°, say, then the illuminance criteria must be applied to that off-axis orientation. This is an important distinction for luminaire optical selection and aiming capabilities and for layout, calculations, and field measurements.

For planes related to vertical illuminance targets, some guidance is indicated under “Notes” where the directional orientation of the plane is straightforward and easily identified. However, the designer must establish orientations based on project conditions. For example, in a sermon-in-the-round situation, and especially where reconfigurable loose seating is used, the designer must determine if vertical illuminances apply to one plane or multiple

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planes. Additionally, the resolution of a "one-plane" approach must be assessed with respect to the other congregants located at 90° and, most critically, at 180° to the design area in question as luminaire orientation and optics to achieve the desired illuminance outcome may inadvertently create discomfort glare for these other congregants.

37.3.3.2 Visual Ages of Observers

Illuminance criteria are based on the visual ages of more than half the intended observers. In some worship settings, this must be applied to each application or task item. For example, the sermon may be made by clergy over 65 years old, yet the illuminance of the pulpit task plane is likely driven by the focal area illuminance criteria necessary for congregants to appreciate of the significance of the focal element. The focal area illuminance is most often well in excess of the illuminance required for reading by the clergy at an ambo or lectern, for example. The designer can confirm this by reviewing samples of typically sermon texts for font size, paper, and ink quality, and then comparing this to tasks identified in Table 22.2 | Common Applications Illuminance Recommendations/READING AND WRITING and their respective illuminance criteria. The greater issue for clergy over 65 years of age is sensitivity to the glare created by the focal area lighting. The designer should take action to limit glare, which may involve lamp and luminaire optics, off-axis luminaire positions to either side of the focal element (to avoid "straight-in-the-face" aiming), and somewhat more grazing aiming angles of 25° to 30° from nadir rather than the more flattering 35° to 40° from nadir. All deserve modeling in computer or mockups, but certainly require review with client. In any event, the observers' ages, task sets for age groups, and illuminance targets should be resolved during programming with the client. See 12.5.5 Illuminance and 4.12 An Illuminance Determination System for additional information and guidance.

37.3.3.3 Illuminance Categories

Illuminance categories are designated by letters A through Y. These are listed in Table 37.2 for more convenient reference to Table 4.1 | Recommended Illuminance Targets should the designer wish to explore other criteria targets or if applications or tasks on a specific project are not readily correlated to the table citations.

37.3.3.4 Gauge

The common gauge for determining illuminance target compliance is cited for each application. All gauges presume that point-by-point techniques are used for predictive calculations and presume that uniformity criteria are closely monitored. Where an average illuminance value over the area of coverage can satisfy target compliance, "Avg" is cited. In applications or tasks where a minimum or maximum target is necessary, the gauge for compliance is "Min" or "Max" respectively.

The designer may elect to use other methods to evaluate target compliance, such as criterion rating (CR) or coefficient of variation (C_v). See 4.12.4.5 Tasks at Uncertain Locations Over a Large Area.

In any event, once illuminance targets and uniformities are established, then any calculated deviation from them should be limited. Standard engineering allowance of ±10% might be acceptable for targets gauged as average unless contractual or code obligations demand otherwise. Minima and maxima must be achieved as intended.

Designs should be adjusted until predictions are within allowance for averages and meet minima and maxima. For additional information, see 4.12.4.1 Recommended Illuminances at Design Time, 4.12.5 Illuminance Ratios, 9.15.1.1 Average Illuminance, and 10.8 Assessing Computed Results.

37.3.4 Uniformity Targets

Illuminance uniformity targets work in conjunction with luminance uniformities and surface reflectances all of which must be addressed as part of the design to avoid visual

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Figure 37.8 | Progressive Daylighting
Siting, orientation, and appropriately configured architecture and daylight-aperture geometry can yield settings where electric light is only necessary during dark hours, depending on liturgical needs. Here, north daylight is distributed onto and then softly and efficiently reflects from the white architectural form of Alvar Aalto's Riola Parish Church, Riola, Italy. See 11.2.1 Progressive Planning for more information on lighting planning techniques.
» Image ©Richard Einzig/Arcaid/Corbis

discomfort, glare, and strain. Uniformity ratios are targets that define the widest recommended ranges. In many situations, uniformity ratio criteria are those between average values of an array of points and the minimum value in the same array of points. Uniformity targets apply to both horizontal and vertical illuminances over the area of coverage. Where horizontal uniformity criterion is different from vertical uniformity criterion, two ratios are reported with the first value for horizontal illuminance (E_h).

Generally the more important speed and accuracy and the more demanding the visual task, the tighter the ratio.

37.3.4.1 Maximum-to-average
This is the recommended ratio of maximum illuminance to the average illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations sensitive to even a relatively small degree of overlighting.

37.3.4.2 Average-to-minimum
This is the recommended ratio of average illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where illuminance too far below average conditions is noticeable and detrimental to task performance or inconsistent with normal expectations.

37.3.4.3 Maximum-to-minimum
This is the recommended ratio of maximum illuminance to the minimum illuminance found on the area of coverage of interest. This ratio is typically ascribed to situations where too much variation in illuminance is considered undesirable and untenable from a performance or safety perspective.

37.3.5 Daylighting Advancement

Generally, design strategies should embrace any combination of daylighting and electric lighting to achieve target values during daylight hours. The preference is for daylighting to provide all or most of the recommended illuminance presuming that all aspects of daylighting are properly addressed. A sunburst icon depicts those applications and tasks where daylighting is considered a strategic candidate. Use photocells and stepped-dimming or continuous dimming to reduce or eliminate electric lighting during daylight hours. See 14 | DESIGNING DAYLIGHTING and 15 | DESIGNING ELECTRIC LIGHTING. Even for those applications where daylighting is not traditionally a strategic candidate, it may be determined that very careful and coordinated design will offer great sustainability opportunities along with positive influences associated with daylight and views. Figure 37.8 illustrates progressive daylighting for worship and Figure 37.9 illustrates conventional daylighting for worship.

Daylight must be controlled to provide illuminances appropriate to the task. Overlighting with daylight can accelerate fading and bleaching and the ultimate demise of sacred or historic artifacts.

37.3.6 Veiling Reflections

Tasks with specular components, like printed tasks with glossy ink or glossy paper or, worse, both, are prone to veiling reflections. The likelihood of particular applications and tasks predisposed to veiling reflections is indicated by a "reflected light" icon: black and white signals high likelihood; gray and white signals moderate likelihood; pale gray and white signals some likelihood; and all-white signals little-to-no likelihood. Veiling reflections are minimized by controlling the overall amount and direction of light with respect to the task locations and orientations. Alternatively, tasks sensitive to veiling reflections can be screened or isolated. Effective strategies include employing some amount of indirect soft, diffuse electric lighting or direct electric lighting with multiple low-output luminaires, or positioning tasks and luminaires and luminance patterns to avoid harsh reflections from tasks. Where clergy or celebrants are likely to be reading text, such as part of participatory

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action or a sermon from an altar, ambo, lectern, pulpit, or minbar, the accent lighting on these focal areas is sufficient to cause veiling reflections. Using multiple lights positioned off axis from the main direction of the reader's view will help minimize veiling reflections.

In situations where sacred or historic documents and objects are behind glass, veiling reflections are minimized by carefully analyzing geometry of luminaire-to-glass-plane-to-viewer. Placing lighting equipment outside the typical viewing orientations can help as can the use of anti-reflective glass for the case. Using lighting within the display case is generally superior, though LEDs or fiber optics are best to avoid excessive heating of the display case and limit UV and IR.

37.3.7 Defining Areas of Coverage

In addition to establishing planes of task orientation, the areas of coverage to which targets apply must be determined. Typical areas of task illuminance coverage are identified here, but these may not be appropriate to specific project situations. One area of coverage is "task proper or task area." Here, the illuminance criteria are applied to the task itself or to a relatively small area to which the task is confined. See 12.5.5.1 Applications and Tasks and Figure 12.22 | Task Coverage Example. It is important to remember that illuminance is additive, that is, task illuminance can be achieved with some combination of ambient lighting, task lighting, and/or accent lighting, providing that the total illuminance on the task proper or task area meets the illuminance criteria outlined in Table 37.2.

Another area of coverage is "room or designated area." In this situation, illuminance criteria are applied to the room or an area of fairly substantive size representing the zone in which the applications and tasks are expected to occur. The designated area is typically established by the layout of furnishings.

In worship settings, areas of coverage for some focal elements such as ambo, altar and chair might be collectively configured on a platform or a broadly defined area such as a chancel. To light celebrants' actions in this area, illuminance may apply to the entire defined area. This is especially important for video recording where cameras focused on and panning with celebrants' movements cannot tolerate contrast ranges that would be achieved with the more dramatic look of distinctly lighted individual focal elements.

An assessment and determination must be made on which area of coverage best satisfies the lighting goals on a particular project.

37.4 Designing

Information provided here is specific to worship facilities and should be used as part of the design and documentation processes outlined in Chapters 12, 15, and 20. See 25 | LIGHTING FOR EMERGENCY, SAFETY, AND SECURITY for additional information on respective aspects.

As noted in 37.2 Application Types, worship facilities are unlike most other application types. Design must accommodate very specific needs and desires of a client or client team. Programming should include worship rituals and procedures if lighting is to be successful. An appreciation of client preferences on color, light levels, brightnesses, manual and automated technologies, and style and design is a must. An understanding of client priorities such as initial and operating costs, leadtime, comfort, sustainability, and project life cycle is also necessary. Details on worship range from entertainment needs to how much time and what times are spent at worship. Some congregations express beliefs through music and performance. For lighting of relatively straightforward entertainment events, see AUDITORIA/Performance citations in Table 24.2 | Educational Facilities Illuminance Recommendations. For professional stage situations, stage lighting should be designed by



Figure 37.9 | Conventional Daylighting
Where siting, orientation, and architectural configuration offer conventional daylighting approaches, T_{vis} of glazing and shading must combine to provide appropriate conditions. Here, west sky at late-afternoon mass would be problematic without glazing T_{vis} of 18% and additional shading available with T_{vis} of 5% for an aggregate T_{vis} of about 1%. Top image is without shades deployed. Surfaces adjacent and opposite the daylight apertures are lighted to balance luminances and limit harsh contrasts. Focal areas are electrically lighted to overcome silhouetting of celebrants and focal elements. Liturgical presets could be used to automate and combine electric light and shading control for various liturgical functions. However, in this situation it was determined that automated shade control would disrupt services at various times of the year and sky conditions.
» Images ©2005 Gene Meadows

IESH/10e Economics Resources

> 15.3.3 Budgets
- for more on budgets and value engineering

> 18 | ECONOMICS
- for more on estimating costs
- for more on life cycle costs
- for more on paybacks and rates of return

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IESH/10e Energy Efficiency Resources

> 17.2 New Construction
- for more on designing for daylighting
- for more on electric lighting equipment
- for more on lighting controls

> 17.4 Lighting Codes, Regulations and Standards
- for more on application standards
- for more on equipment regulations

IESH/10e Lighting Exteriors Resources

> 12.5.5.6 Nighttime Outdoor Illuminances
- for more on lamp efficacies under mesopic adaptation

> 26 | LIGHTING FOR EXTERIORS
- for more on criteria

IESH/10e Sustainability Resources

> 13.11 Sustainability
- for more on lamps

> 19 | SUSTAINABILITY
- for more on controls
- for more on earth resources
- for more on energy
- for more on life cycle analyses
- for more on lighting design
- for more on recycling

theater lighting designers. See IES DG-20 | Stage Lighting A Guide to the Planning of Theatres and Auditoriums for guidance on architectural and electrical infrastructure

Lighting can only be appropriately tailored to a congregation's needs if a high degree of familiarity with the ceremony is known. Similar to the programming steps on other application types, visits and reviews of existing situations, including observing at least one worship service is recommended if the designer is not familiar with the liturgy.

Addressing all code requirements is a must. Energy efficient and sustainable practices are an integral part of all IES recommendations. Key design tenets include, but are not limited to:

- designing for the satisfaction of the observers intended to use the project
- using baseline reflectances of 90-60-20 (percentage light reflectance values [LRVs] of ceilings, walls, and floors respectively) in interior production and work-oriented spaces
- using daylighting that meets luminance and illuminance criteria
- using highest-efficacy lamps that meet color, optical and electrical control, and output criteria
- using highest-efficiency luminaires that meet aesthetic and luminance criteria
- using accenting to provide luminance balancing or improve brightness perceptions where necessary
- using controls liberally, preferably automated varieties such as presets, occupancy and vacancy sensors, astronomical time clocks, and photocells
- establishing IES-recommended illuminance criteria to meet programmed tasks
- establishing layouts that just meet IES-recommended illuminance criteria
- addressing outdoor environmental needs
- using calculations, photometrically-realistic renderings, and operational samples and mockups to prove concepts
- identifying and designing to code-specific requirements, if any, for ambient, task, and accent lighting
- documenting all code-, energy-, sustainability-, and IES-criteria compliance
- documenting criteria and design deviations and rationale and subsequent disposition by team, client, or AHJ
- documenting clearly the layouts, controls, and luminaire and lamp selections

Designing for the satisfaction of the observers is the paramount design tenet and must be kept in perspective during all aspects of design. If the observers' expectations are not fulfilled, then how much energy could be saved is moot, as is how many fewer earth resources were spared, as is how much the whole affair cost or how much value engineering saved or the photogenic qualities of the project. See sidebar references for additional guidance on the key tenets. The design effort must be undertaken with coordinated and realistic expectations by all involved on initial and life cycle costs. Budgeting should include designer input and dialogue with the team and client at project commencement and design milestones. In other words, and paraphrasing Thomas Edison, genius is, indeed, just 1% inspiration and 99% perspiration.

37.5 References

[1] [DOE] US Department of Energy, Energy Information Administration. 2003. Table E5A. In: Electricity Consumption (kWh) by End Use for All Buildings [Internet]. DOE. [cited December 2008]. Available from: http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html#enduse03.

[2] Mark S. Rea, ed. 2000. The IESNA lighting handbook: Reference and application. 9th edition. New York: IESNA. Ch 14.

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