

Theatre, Television, and Photographic Lighting

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For theatre, television, and film, the lighting system design and luminaire choices are based on production plans. The size and complexity of the system are based on production needs, from elementary training facilities to professional facilities. In all facilities, however, the budget usually determines the degree of complexity.

Theatre design requires information concerning the types of programs (opera, orchestra, choral, dance, drama, variety) that are produced by resident groups or touring companies. Television design requires information concerning types of productions (variety shows, dramas, news, soap operas, panel shows) that will be produced for network or local broadcasting or for closed-circuit or syndication release. The actual illuminance levels for television vary from under 1000 lx (100 fc) to several thousand lx (several hundred fc), depending on the type of camera used.

In lighting for film, both still and motion picture, the function of the lighting is to produce the photochemical changes on the film required to produce the image. Thus, the illuminance required is determined largely by the sensitivity of the film. Additional material on motion picture lighting and projection lighting can be obtained from the Society of Motion Picture and Television Engineers (SMPTE) at <<http://www.smpte.org>>.

LUMINAIRES, LAMPS, AND CONTROL SYSTEMS

Luminaires for Theatre, Television, and Photographic Lighting

In theatre, television, and photographic (film) lighting, different types of luminaires are used to produce qualities of light that fall within three basic categories:

1. Key light is illumination with defined margins. Its output produces defined but soft-edged shadows and highlights. (A typical luminaire is the Fresnel spotlight.)
2. Soft-edged light, sometimes referred to as "fill light," is diffuse illumination with indefinite margins. Its output produces poorly defined shadows,

and it softens and fills the shadows produced by key light. (A typical luminaire is the soft light.)

3. Hard-edged light is illumination that produces sharply defined, geometrically precise shadows. (A typical luminaire is the ellipsoidal spotlight.)

The basic types of luminaires used in theatre, television, and film production have a variety of optical characteristics (Figure 15-1).¹ Most luminaires contain provisions for color filters or diffusion materials. Some special luminaires, or accessory devices, have the ability to remotely control aiming, focus, or color.

Nonlens Luminaires. The nonlens luminaire (primarily used in film location applications) embodies a lamp, a reflector, and frequently a focus mechanism to change the field and beam angles, corresponding to 10% and 50% of maximum intensity, respectively. The spectral quality of the illumination produced by a nonlens luminaire can vary depending on lamp type, reflector finish, heat filters, daylight correction filters, and color frames.

There are many different types of nonlens luminaires that can be considered as spotlights or floodlights. They utilize tungsten-halogen lamps from 100 to 2000 W, and discharge sources from 200 to 4000 W. Nonlens luminaires include a variety of light distributions.

Barn doors are swinging flaps attached to the front of a luminaire to control the shape and spread of light; however, the degree of control afforded with barn doors is limited.

Scoops are floodlights consisting of a lampholder, lamp, and reflector with a matte or brushed finish. The lamp and reflector can have a fixed or variable relationship. Scoops are equipped with front clips to hold a color frame containing either color media or diffusion material. The scoop produces illumination having a field angle of 90 to 180°. The quality of the illumination is considered soft, and the shadow sharpness depends primarily on the texture of the reflector. Scoops are available from 250 to 450 mm (10 to 18 in.) in diameter and are usually equipped with incandescent pear-shaped (PS) or tungsten-halogen lamps from 400 to 2000 W. The lamps are usually frosted for further softening of illumination. In general, the larger the diameter of the scoop, the softer the light output. There are variable-focus scoops.

Parabolic (reflector) spotlights consist of a lamp and a

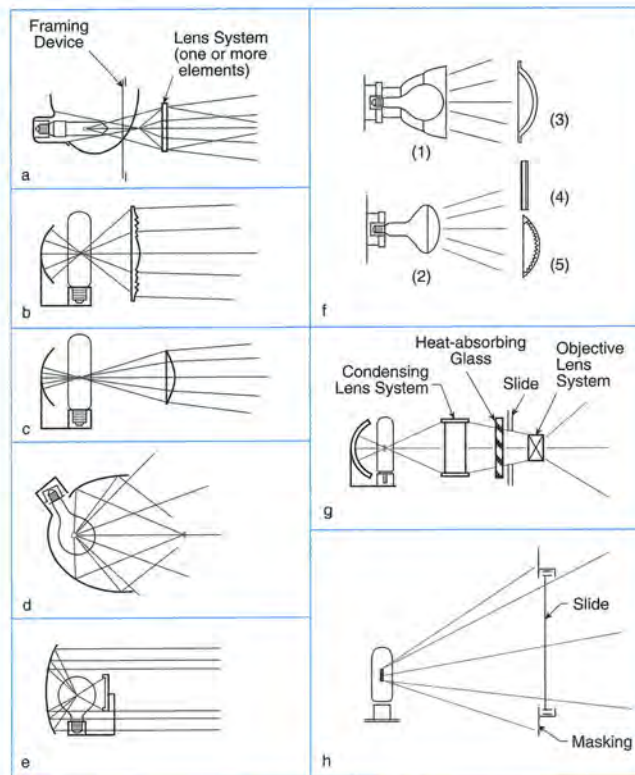


Figure 15-1. Optical characteristics of stage lighting equipment. (a) Ellipsoidal reflector spotlight. (b) Fresnel-lens spotlight. (c) Plano-convex lens spotlight. (d) Scoop-type floodlight. (e) Parabolic-reflector floodlight. (f) Striplight: (1) reflector with general service lamp; (2) reflector lamp; (3) glass roundel; (4) sheet color medium; (5) spread lens roundel, plain or colored. (g) Lens-type scenic slide projector. (h) Nonlens-type scenic slide project (Linnebach type). The luminaires shown in c and e are used primarily in Europe.

parabolic specular reflector. Some luminaires have a reflector in front of the lamp to redirect light into the main reflector. Other luminaires are equipped with spill rings to minimize spill light and glare. In most types of parabolic spotlights, the lamp and reflector are adjustable to produce a wide or a narrow beam of light; the closer the lamp is to the reflector, the wider the beam. This luminaire produces a hard-edged beam that cannot be easily controlled, except, in part, by spill rings. A parabolic spotlight is also known as a sun spot or beam projector. Parabolic spotlights have not enjoyed great interest in North America, but they are becoming more popular.

Soft light luminaires are well-diffused, almost shadow-free, light sources used in special applications. All of the light in these units is reflected off a matte-finish reflector before reaching the subject, and due to this design, they are not efficient sources of illumination.

The soft light is the most common fill light chosen for television studio applications. Soft lights are available from 500 to 8000 W and are used where either shadows or reflections must be minimized.

Broads are small, rectangular floodlights used primarily in television for a very wide, soft lighting effect and fill light. Broads are available in ratings up to 1500 W and are generally designed to use double-ended tungsten-halogen lamps. They commonly have different distributions in the horizontal and vertical directions. Horizontal spreads of over 100° and vertical distributions of near 90° are common.

Cyclorama, or cyc, lights provide an overall wash of illumination over the cyclorama curtain for background. There are two types of cyc lights: strip cyc lights, which are compartmentalized luminaires with lamps on 200 to 300 mm (8 to 12 in.) centers, and cluster lights, mounted on 1.8 to 2.4 m (6 to 8 ft) centers.

Strip cyc lights, when mounted either from above or on the floor, can generally light a cyclorama which is 3.6 to 6.0 m (12 to 20 ft) high. If lights are used on both top and bottom, or if they have an asymmetrical reflector to improve the beam distribution, even higher surfaces can be suitably illuminated. Normally a single group, either suspended from above or floor mounted, has an illuminance falloff greater than 50% from the top of the space to the bottom. Lamps for

these luminaires are available from 300 to 2000 W. Strip-lights have the advantage of much closer mounting to the cyclorama than the cluster lights. This can be critical in those theatres where stage space is limited.

Cluster lights can light a cyclorama up to 9 m (30 ft) high by lighting from the top only, and the illuminance falloff is less than 5%. Since these lights are mounted on 1.8 to 2.4 m (6 to 8 ft) centers, rather than the 300 mm (12 in.) centers for striplights, the power savings is substantial. This type of cyc light usually requires greater stage depth than striplights. Striplights for two-color luminaires use 3300 W/m (1000 W/ft), whereas cluster lights use 820 W/m (250 W/ft) for the same two-color coverage.

Lens Luminaires. The lens luminaire used in theatre, film, and television embodies a lamp, a reflector, a system of one or more lenses, and, frequently, a focus mechanism to change the light output by varying the field and beam angles. The quality of the illumination produced by a lens luminaire can vary from soft to hard, depending on lamp type and reflector finish. External beam control is possible with barn doors, gobos (devices that allow patterns to be projected onto the stage or curtain, usually cut into a flat metal sheet), irises, shutters, color frames, and in some cases adjustable-focal-length arrangements to permit zoom control.

There are many different types of lens luminaires that can be considered as spotlights or floodlights. They utilize tungsten-halogen lamps in the range of 100 to 6000 W. Among those luminaires considered "lens" are Fresnel and ellipsoidal spotlights, parabolic aluminized reflector (PAR) luminaires, striplights, and follow spots. Plano-convex spotlights also fall into this category; however, while they are popular in other parts of the world, they get little use in North America, and for that reason they are not discussed here.

Fresnel Spotlight. The Fresnel spotlight is a luminaire that embodies a lamp, a Fresnel lens, and generally a spherical reflector behind the lamp. The field and beam angles can be varied by changing the distance between the lamp and the lens. The distance between the lamp and the reflector is defined by the optical design and cannot be changed.

The quality of illumination produced by a Fresnel spotlight tends to be intermediate or hard, and the beam angle is soft-edged. The illumination varies considerably depending on the optics of the luminaire. Typical luminaires of this type have a beam angle of 10 to 50°, depending on the relative position of the lamp and lens.

Fresnel spotlights are generally equipped with tungsten-halogen lamps with C-13 or C-13D planar filaments. Many Fresnel spotlights are now available using a compact-source metal halide lamp as well. In order to shape the light beam, barn doors are used, as well as snoots. Snoots are metal tubes mounted on the front of spotlights to control stray light. They are also called funnels, top hats, or high hats. The light beam may also be colored or diffused by means of materials placed in its color frame.

Fresnel spotlights are manufactured in lens diameters from 75 to 610 mm (3 to 24 in.) and in wattages from 75 to 12,000 W. Remote operation (pan, tilt, focusing, on/off) is available on some luminaires. Remote operation of these units can be achieved manually by using a pole, or electrically by use of servomotor-equipped units.

These units are generally designed to be operated within approximately 45° of horizontal, particularly in the higher wattages in the range of 1 to 2 kW. Operating Fresnel luminaires in this wattage range for long periods of time in a vertical position can cause damage to the luminaire and reduce lamp life (which is fairly short anyway), because the fixture cannot dissipate heat well in that position.

Ellipsoidal Spotlight. The ellipsoidal spotlight, or pattern light, consists of a lamp and ellipsoidal reflector mounted in a fixed relationship. The light is focused through the gate of the unit, where the beam can be shaped with the use of shutters, a gobo, or an iris. The shaped beam is then focused by the lens system.

The output of the ellipsoidal spotlight is a hard-edged light with precise beam control. By defocusing the lens system, the hard edge can be softened somewhat. Units are also available with variable beam angles. The lens diameter and focal length determine the throw and coverage of the unit.

Ellipsoidal spotlights are available in sizes from 90 mm (3.5 in.) and 400 W to 300 mm (12 in.) and 2000 W. Units employing metal halide lamps as the light source are also available. The effective throw of the larger units is about 30 m (100 ft).

PAR Luminaires. PAR luminaires embody a PAR lamp, lampholder, and housing. The performance of the luminaire depends on the type of lamp selected. The beam pattern of most PAR lamps is oval, so the luminaire is designed to rotate to cover the desired area. Glare can be reduced by barn doors, and the intensity can be modestly increased by applying a top hat.

PAR luminaires using 650-, 1000- or 1200-W lamps are designed to accommodate either single lamps or groups of lamps in clusters of 3, 6, 9, 12, or more. For special effects, low-voltage, narrow-beam aircraft landing lights are commonly used.

The PAR-64 luminaire is used in many theatres because it can do many jobs and is fairly inexpensive. It is popular with traveling road shows because it can withstand physical abuse.

Striplights or Borderlights. Striplights are compartmentalized luminaires. Every compartment contains a reflector lamp, or a lamp and reflector, and a color frame. The compartments are arranged in line and wired on two, three, or four alternate circuits, with each circuit producing a different color.

Striplights provide an overall wash of illumination on a stage. They can also be located at the front of a stage as footlights to provide an overall low illuminance.

Although striplights have been replaced in many applications by more versatile individual units such as Fresnel and ellipsoidal spotlights, they are still used in applications where cost is a major consideration. Striplights and borderlights are less expensive than Fresnel and ellipsoidal lights. They are also used in applications where labor costs are high and the use of more flexible units would increase the labor required to set up a show.

Luminaires using PAR-38, PAR-46, and PAR-56 lamps can be arranged in linear strips functioning as borderlights or striplights. There are striplights available that use 12-V multifaceted reflector (MR)-16 lamps wired in series. These units are useful in applications where space is at a premium, but they are generally not considered a suitable substitute for full-size striplights. In addition, cost and required maintenance are relatively high for these units.

Follow Spot. A follow spot is a special type of spotlight, stand mounted, with a shutter (commonly a douser), an iris, and a color frame or "boomerang" to hold color media. Most follow spots utilize a tungsten-halogen lamp, a metal halide lamp, or an arc source and a lens system. For high-intensity follow spots, the carbon arc has been almost totally replaced by compact metal halide or xenon lamps.² All of these arc units produce more output, watt for watt, than the tungsten-halogen units. Follow spots are selected to provide the throws required for the application.

Arc Light Luminaire. There are still some arc units in use today, although they are not popular in new installations. An arc light luminaire uses a carbon electrode arc as the source of illumination. These produce carbon monoxide as a by-product. In some concentrations this is a deadly gas. In addition, the operators required for these luminaires can be expensive, particularly for the small theatre or school auditorium.

Lamps for Theatre, Television, and Photographic Lighting

The most prevalent light source for the theatre stage is the tungsten-halogen lamp that has been designed especially for this type of service. For television and film lighting, tungsten-halogen and hot-restrike mercury arc discharge lamps are the two most common sources. Conventional incandescent spotlight lamps have been supplanted by tungsten-halogen lamps designed to retrofit into existing luminaires. Ballasts for hot-restrike mercury arc discharge lamps that produce no noticeable flicker have been developed for use in television and film lighting.

Carbon arc lamps are still used occasionally, principally for motion picture production, but they have been supplanted to a great extent by multiple lamp arrays of 650- or 1000-W tungsten-halogen or PAR lamps, often with integral daylight filters, and more commonly by compact metal halide lamps.

Virtually all types of light sources find occasional use in theatre, television, and film production. For example, metal halide high-intensity discharge (HID) lamps are used to light such areas as stadiums and arenas, providing illuminances and color quality suitable for televising performances. They also have the capability of providing "day-light fill" for movie and television productions. Fluorescent lamps with a variety of spectral power distributions, often on special dimming systems, may light cycloramas in television studios or theatre stages, or backings of motion picture sets. Fluorescent lamps are also used as television and motion picture base lights. Both fluorescent and HID lamps for use in television and film work require high-frequency ballasts to overcome the flicker effect inherent in these lamps when operated on 60-Hz power.

Xenon flash tubes, similar to those for photo studios, may be used in a repetitive-flash mode for theatrical effects. Lasers and light-emitting diodes may also be used for spectacular effects. Standard PAR and reflector (R) lamps, as well as sign, decorative, and indicator lamps, have a variety of common theatrical applications. Fiber optics are employed in many stage settings for special effects such as star curtains or irregular linear shapes. In still photography, tungsten-halogen and variable-output xenon strobe lights are the most common lamps.

Tungsten-Halogen and Incandescent Lamps.³⁻⁶ General information about the lamps most frequently used in lighting for theatre stages, television and motion picture production, and professional still photography are found in Chapter 6, Light Sources. In many cases lamps may appear to be mechanically interchangeable with each other, that is, they have the same base and light source location. However, caution should be exercised. For example, in luminaires designed specifically for tungsten-halogen lamps, the bulbs of some incandescent lamps may be too large to fit within the luminaire. Furthermore, there may be differences in filament configuration that could affect the luminaire's optical performance. The designer should consult manufacturer information before making a lamp type substitution.

In addition, some luminaires may not provide adequate heat dissipation for higher-wattage lamps. Lighting equipment manufacturers should be consulted for the maximum allowable wattage.

The drive to conserve energy and reduce heat from theatrical lighting equipment has led to the introduction and acceptance of lower-wattage tungsten-halogen lamps with efficient reflector systems. For example, ellipsoidal spotlights are now available with dichroic reflectors that use 575-W tungsten-halogen lamps. Previously a 1000-W tungsten-halogen ellipsoidal spotlight would have been required to accomplish the same effect.

High-Intensity Discharge Lamps. A wide variety of metal halide lamps are used for general interior and exterior lighting systems. These compact arc lamps are also used to pro-

vide supplementary light to approximate daylight for television and film production and have been adapted into such specialized equipment as scenic projectors and follow spots. Xenon short arc lamps of the types commonly used for motion picture projection are also used in some scenic projectors and follow spots.

Special types of metal halide lamps have been developed with characteristics that are often better suited to the requirements of lighting for film and television production outside of the studios and for scenic projectors and follow spots.⁷⁻⁹ These lamps are ac-operated discharge lamps in which the luminous arc burns in a dense vapor atmosphere comprising mercury and the halides of rare earths. They are of single- and double-ended construction, and they have short arc gaps, which means that their arc brightness is several times that of typical incandescent spotlight lamps. This feature makes them useful in follow spots and effects projectors. These lamps are available in a range of sizes, from 200 to 18,000 W. They are also available in PAR configurations and have a broad spectrum with a very high color rendering index (CRI), making them well suited as sources for "daylight fill" in movie and television shooting. Effective service lives range from 300 to 2000 h. After ignition, they require a minute or so to warm up. Most ballast and ignitor equipment can restrike the lamp immediately after it has been turned off. The flicker produced by these ac-operated lamps is not generally a problem for television, but for motion pictures careful coordination of frame and flicker is needed to prevent stroboscopic effects. Ballasts are available that provide waveform and frequency modifications that minimize or eliminate stroboscopic motion in movies. Refer to Chapter 6, Light Sources, for information on lamp correlated color temperature, color rendering, and life.

Low-Noise Construction. Most tungsten-halogen and incandescent lamps for theatre have special low-noise construction to minimize audible noise generation when operated on ac circuits. The lamp manufacturer should be consulted for information on which lamps have low-noise construction. Lamps, sockets, and wiring often generate noise when used with solid-state dimmers because they distort the normal sine-wave and such noise is minimal with autotransformer and resistance dimmers. Recent developments in dimmer choke design and firing techniques reduced the noise generated by lamps operating on dimmers that distort the waveform. Generally noise is not generated on dc circuits.

Caution Notices. Caution notices are generally provided with most lamps for stage and studio service. Virtually all tungsten-halogen lamps operate with internal pressure higher than 1.0 atmospheres; therefore, protection from lamp abrasion and avoidance of overvoltage operation is advised. The use of screening is advised where appropriate to protect people and surroundings in case a lamp shatters.

Control Systems for Theatre and Television Lighting

The design of a lighting control system is based on the artistic and technical needs of projected productions.¹⁰⁻¹⁴ It is related to the building architecture, luminaire rigging system, and density of electrical outlet distribution. Design parameters are expressed in terms of power capability, number of lighting outlets, dimmer bank capacity, interconnection system, and lighting control facilities.

A lighting control system must provide the designers with total flexibility of control over all of the luminaires lighting the set. There must, therefore, be adequate dimmers, circuits, and control equipment to establish the number of lighting channels required, to assemble those channels into cues, and to switch and fade from one cue to another, thus achieving the desired lighting changes.

Lighting control systems for the theatre and for television differ slightly. Theatre lighting control systems make extensive use of memory, require accurately timed faders, and must be capable of complex simultaneous operations, whereas television lighting control systems generally require less memory and fewer operational features and benefit from automated dimmer channels.

Dimmers. Almost all of the lighting control devices used in theatre and television lighting use silicon-controlled-rectifier (SCR) dimmers, which are manufactured in a range of 1 to 12 kW. Triac dimmers, manufactured in a nominal capacity of 2 kW, are used occasionally in inexpensive portable dimming equipment. Dimmers are rated by Underwriters Laboratory (UL) for continuous operation at 100% of their rating. Dimmers are assembled into portable packs of 6 to 24 or into racks that can contain several hundred dimmers custom built to suit the installation.

European countries have much more stringent harmonic requirements than North America, and companies wishing to do business on both continents have to comply with European requirements. This likely requires a change from the current SCR-based dimmer circuits, which produce significant harmonics during dimming operation, to sinusoidal dimming circuits, which create no harmonics and also have the advantage of not producing high neutral currents.

It is highly desirable for electronic dimmers to have stable output, cause no interference to audio and video circuits or to other dimmers, be insensitive to load, and have high efficiency. The relation of the dimmer line voltage output on the control input voltage is usually fixed,^{15,16} but some systems allow other dimming curves to be selected from software options in the dimmer rack or at the control console.

All electronic dimmers require ventilation to maintain components within specified operating temperature ranges. The amount of ventilation required depends on the dimmer's

efficiency and the individual manufacturer's recommendations. A 97% efficient dimmer produces approximately 100 to 120 Btu/h for each kilowatt of connected load.

Distributed dimming systems, those in which individual dimming modules are located at the lighting instrument rather than in a centralized dimmer enclosure, are becoming more common. They are particularly cost effective in older theatres where existing wiring is to be reused and capacity is limited. The controls can follow a common protocol that can be easily "daisy-chained" to reduce the cost of installation and maintenance.

Properly sized dimmers can be connected directly to the various lighting outlets. This is termed the dimmer-per-circuit control method and is contrasted with power programming systems that employ a cord-and-jack or slider-and-bus system to switch individual outlets to larger-capacity dimmers. While the dimmer-per-circuit method leads to a large number of small dimmers, the improvement in wiring efficiency and the elimination of enclosures and power interconnect panels, when considered in conjunction with the added flexibility of these systems, usually amount to a cost savings and significant operating advantages. The control console, whether computerized or manual, generally contains an electronic soft patch that connects the control channels to the dimmers, performing much the same function as the power interconnect panels formerly did.

Manual Preset Lighting Control System. The basic form of lighting control is the manual preset system, which employs groups of manual controllers for each dimmer or control channel. These controllers are arranged in horizontal rows termed presets. Presets are connected to submaster faders that are, in turn, switched to paired master faders for proportional, dipless (smooth dimming curve) cross fades between presets. Illuminances are set as required on individual controllers in each preset, and lighting cues are achieved through submaster and master controllers.

Memory Lighting Control Systems. Memory lighting control systems are generally programmed software-based systems. In such a system, the operational program is permanently stored in a read-only-memory (ROM) section, which may be updated by the manufacturer to provide additional operational facilities as they are developed. These systems may incorporate video monitors for displaying cue information and have a floppy disk or cassette for storage of program information. Peripheral equipment used with memory lighting control consoles may include hand-held remote controllers used with remote receptacles at lighting positions to assist in focusing lights, designer's remote consoles (used in conjunction with the console in the operator's booth), printers, and remote monitors.

Communications between control positions and the dimmers can be accomplished by discrete analog signals, by multiplexed control signals, by digital and analog multiplexed protocols, and by discrete analog methods. These

standard protocols provide for interchangeable hardware, and may reduce the complexity and cost of wiring.

There has been an industry shift toward standardizing on the Digital Multiplexing (DMX512) protocol. This control signal can now drive a whole range of peripheral equipment such as fog machines, moving lights, color scrollers, and more. The signal can be distributed to a number of control and equipment locations throughout the facility including back stage, orchestra pit, and equipment and lighting positions for total flexibility. This is relatively economical and allows the lighting console to drive all of these devices.

Electrical Installation. A major expenditure in any lighting system, whether theatrical or architectural, is the cost of the electrical distribution. To minimize this cost, care should be taken to locate the dimmer racks so as to achieve the most economical balance between the cost of the electrical feeders to the dimmer racks and the cost of the distribution wiring from there to the individual lighting positions or outlet boxes. For SCR-type solid-state dimming systems it is required to install a "hot" wire and a neutral from each dimmer module to its outlet. Therefore, the distribution wiring required for an electronically dimmed lighting system requires more wires than for a typical room lighting system. The cost of installing these additional wires must be included when determining the best location for major system components.

The designer should consult the applicable codes when determining the size of power distribution feeders for electronic dimming systems (i.e., the wiring from the building electrical system to the dimming rack). Recent code changes have given more flexibility to the designer in determining the actual dimmer lighting load and required feeder size. Caution should be exercised in sizing the neutral conductor because SCR dimmer circuits can cause harmonic distortion that may result in neutral currents that are substantially higher than the line currents. Neutral wire sizing for current capacities in the range of 1.5 to 2.0 times the line conductors is common. In portable installations, many municipalities have mandated two parallel neutral conductors, each sized the same as the individual feeder conductors, to provide adequate capacity for the neutral current.

In addition to the cost and number of wires required, there are noise considerations in locating and installing the dimming equipment and the wiring. It is important that noise generated by the dimming equipment is considered when locating the equipment. Although there may be no perceptible noise from modern dimming units, there may be a cumulative effect if a large number of dimming units are installed in the equipment racks. In addition, there is a significant amount of heat generated by the dimming equipment that must be removed from the equipment cabinets to keep operation within the temperature limits of the solid state in

the dimmers. Fans are traditionally installed in the dimmer racks to force air through the rack. As the number of dimmers in a rack is increased by more effective miniaturization of the dimmers, the heat as well as the noise generated by the cooling fans increases. It is important that the dimmer racks be located far enough away from the audience, or in a sound-conditioned location, to control the level of noise that can be heard in the theatre.

Another potential source of noise is the alternating magnetic field generated between the "hot" and "neutral" wires of the individual dimmer circuits when the wiring is installed in the raceway system. If several individual circuits are installed in a common raceway, the additive effects of the wiring noise could be audible. Therefore, it is wise to consider banding the individual hot and neutral wires of each circuit together to minimize some of this noise. It may also be appropriate to consider "tie-wrapping" all of the circuit wires in an individual raceway to reduce the generated noise. Caution must be exercised in doing this to ensure that there is not a significant heat buildup as a result of reducing the air flow around the individual conductors. The services of a qualified electrical engineer should be sought to help with these questions.

Emergency Power. A system of emergency lighting is required for spaces suitable for occupancy by 100 or more people. The lighting required to be supplied by the emergency system includes, as a minimum, house lights necessary to meet the minimum egress lighting illuminance requirements, exit signs, aisle lights if provided, step lights, and back stage lighting to allow safe egress. It is very difficult to provide the required emergency lighting throughout large spaces with self-contained units with adjustable heads.

Lighting other than that legally required may be added within the capacity of the emergency power system if it is judged to enhance the safety of the facility. Regulations now require dimmer-controlled lighting circuits used as part of the emergency lighting to be transferred by an automatic transfer switch that meets the requirements of UL 1008.¹⁷ Optional lighting deemed desirable for emergency lighting must be installed in accordance with the requirements of NFPA 70, Article 702.¹⁸ Requirements for the emergency lighting system can be found in the applicable regulatory documents.¹⁷⁻²¹

LIGHTING FOR THEATRES

There are two basic types of theatres, for live productions and for film (motion picture). The former can be further classified as legitimate, community, and school theatre. The term "live production" refers to the presence of live actors on stage. In the case of motion picture theatres, there is only one classification to consider, and that is the indoor auditorium. Drive-in theatres, which were popular several years ago, have all but disappeared.

Lighting requirements for the marquee, lobby, and foyer are similar for live and for film auditorium theatres. An important goal common to both types of theatre is to provide transitional illuminances to accommodate readaption as patrons proceed from the brightly lighted marquee and street area to the lobby, the foyer, and eventually the auditorium. The lighting requirements for the various types of spaces within the two types of theatres are quite different, however.

Marquee. Attracting attention is one of the motives in the design of theatre exteriors. Much of the selling for current and coming attractions can be done here. Flashing signs, running borders, color-changing effects, floodlighting, and architectural elements are but a few of the many techniques employed (see the section "Lighting for Advertising" in Chapter 17, Retail Lighting). As styles and tastes change, it is necessary to design the exterior elements of a theatre to convey the feeling of the neighborhood. Many marquee "current attraction" panels are lighted with incandescent filament lamps, fluorescent sign tubing, or fluorescent lamps behind diffusing glass or plastic. Opaque or colored letters on a lighted field are generally more effective than luminous letters on a dark field. The principal requirement is uniformity of luminance, because variations in luminance across the face of the sign that exceed a ratio of 3:1 from the brightest to the darkest area are noticeable and detract from the message being presented (Figure 15-2). Luminaires designed to emit infrared radiation for heating and snow melting can be used in cold climates.

Lobby. An illuminance of 200 lx (20 fc) is desirable in theatre lobbies. The ceiling luminaires are often integrated with the marquee soffit. Many lighting treatments are applicable here; some considerations are easy maintenance, designs that retain architectural elements, and brightness patterns that attract attention as well as influence the flow of traffic. (People tend to move toward brighter areas over darker areas; this is known as phototropism.) Poster panels often contain their own lighting system, including fluorescent lamps, spotlighting, or transillumination. Poster luminances should range from 70 to 350 cd/m², depending on surroundings brightnesses. An important consideration is to allow suffi-

Figure 15-2. Recommended Illuminances and Theatre Advertising Sign Luminances in Various Locations

Type of Area in Which Theatre Is Located	Range of Ambient Horizontal Illuminances, lx (fc)		Recommended Sign Luminance, cd / m ²
City center	50–100	(5–10)	500–1200
Shopping mall	20–70	(2–7)	400–700
Residential	10–50	(2–5)	300–500
Under marquee	200–500	(20–50)	2000–5000

cient depth behind the illuminated panel so fairly uniform brightness may be obtained. (See the section "Lighting for Advertising" in Chapter 17, Retail Lighting, for further information on sign construction.)

Foyer. Usually a restful, subdued atmosphere is desirable in the foyer. Illumination from large, low-brightness elements, such as coves, is often employed. Wall lighting and accents on statuary, paintings, posters, and plants are important in developing atmosphere. Obviously, light must not spill into the auditorium. Before and after performances, general illuminance levels of 50 lx (5 fc) for motion picture theatres and 150 lx (15 fc) for live production theatres are recommended.

Lobbies and foyers can also be used as public gathering places and as places of assembly for civic and business events. The likelihood of these events occurring should be considered in planning the lighting system as well.

Live Production Theatres

Although there are many varieties of indoor and outdoor live production theatres, such as amphitheater, music tent, arena, and open stage, the most common are the traditional proscenium and the open stage or thrust type (Figure 15-3).

The proscenium-type theatre is composed, typically, of a seating area and a stage area. It may serve not only as a theatre, but as an assembly and lecture hall, a study room, and a concert area. Considerable attention is being given to the development of speech and theatre arts programs not only in

schools but also as a community activity among adult groups. The many uses of the theatre require well-planned lighting.

It is important to provide a large number of power outlets at various locations, as well as the proper luminaires and control equipment, so that the stage lighting designer can create lighting for all stage performances. The necessary structural provisions must be made to allow placement of the lighting equipment and access for their installation, operation, and maintenance.

Seating Area. The seating area should have diffuse, comfortable illumination. Because the seating area often accommodates a variety of activities, different illuminances are necessary. A minimum illuminance of 100 to 200 lx (10 to 20 fc) should be provided in the seating area when performances are not taking place. This general lighting should be under dimmer control, preferably from several stations, such as the stage lighting control board, the projection booth, and a staff entrance. There should be transfer capabilities, however, so that the lighting is not accidentally turned on during performances. Lighting equipment for the seating area may include general downlight luminaires, coves, sidewall urns, and curtain and mural lights. Higher illuminances of at least 300 lx (30 fc) are required to perform visual tasks, such as reading or the taking of examinations. Selected lighting system circuits can be used for cleaning and rehearsals. "Panic" switches independent of dimmers and switches should be provided to allow an operator to bring on selected lights in the house in case of emergency. In accordance with local and national codes, an alternate electrical supply for emer-



Figure 15-3. Two views of the Ford Centre for the Performing Arts in Vancouver, British Columbia. The theatre has a traditional proscenium stage, shown here set for a chamber music performance with a large spotlight on the piano. An orchestra pit is located in front of the stage and would be used for musicals, opera, and ballet performances. The interior lighting design features evenly spaced downlights, mounted on the building's structural supports. The lighting provides adequate general illumination and contributes to the pleasantness of the space.

gency lighting must be provided. This system may include emergency house lights, exit lights, shielded aisle and step lights, and other required lighting (see Chapter 29, Emergency, Safety and Security Lighting).

Stage Lighting.²²⁻²⁵

Basic Lighting Functions. An appreciation of the dramatic potential of lighting begins with an understanding of its four basic functions:

- **Visibility.** This is the most basic function of lighting in the theatre. For the audience to hear and understand in the theatre, they must be able to see.
- **Motivation.** Motivation or naturalism is the term given to the expression of time and place.
- **Composition.** Composition is revealed artistically through light and shadow. Warm and cool light give plasticity and composition to the visual effect. The concept of the production as indicated by the playwright and implemented by the director determines the approach of the designer.
- **Mood.** Mood, or atmosphere, as created by the total visual effect, brings the stage into focus with the meaning of the play. The final visual effect is provided by equipment that has been chosen by the designer because it supplies the desired output of light in terms of intensity, form, color, and movement.

Properties of Light The controllable properties of light as they apply to the theatre include intensity, form, color, and movement. The control exercised by the designer over these properties has a direct bearing on the success of the performers in achieving the intended response from the audience.

Intensity. Intensity control is achieved with various types of luminaires, lamps, mounting positions, and color media and, of course, with dimmers. Precise, consistent dimmer control is essential for establishing and maintaining various intensity levels. Vertical illuminances of 2000 lx or higher are required to highlight selected performances.

Form. Form, meaning the distribution of the light, calls for a wide variety of luminaire types and mounting positions. The angle of the light relative to the object and the viewer creates dimensionality, which in turn is a function of the fixture type, location, focus, and dimmer balance. Luminance ratios on the stage should not exceed 100:1.

Color. Color in lighting design is used to accent, enhance, distort, and motivate the scene. Color is controlled by means of lamp selection, dimmers, and filters that can be placed in front of each source. Incandescent lamps, in particular, become much yellower as they are dimmed. A tonal quality can be obtained by the additive mixture of two or more sources. The color rendering index (CRI) of light sources used in theatre should not be less than 80.

Movement. Movement consists of a change in one or all light properties. Movement is usually accomplished by dimming individual luminaires rather than by luminaire movement. However, manually operated follow spots are commonly used.

Lighting Locations.²⁶ There are two basic locations for lighting equipment (Figure 15-4): (1) in front of the proscenium opening, including the auditorium ceiling, side walls of auditorium and proscenium, balcony front, follow-spot booth, and edge of the stage apron; and (2) behind the proscenium opening, including pipes for attaching tormentor (side) lights, overhead cyclorama or top lights, and stage electrics (see below) above the stage. Also employed are cyclorama pit or base lights as well as special locations in free spaces at the side or rear of the stage, including ones that are floor mounted, hanging, or set beneath the stage area.

Though the positions may be fixed, virtually every luminaire is portable and gets shifted around for each production. The focus, direction, intensity, and color generally are different for each production. To determine the required lighting positions, the stage is divided into lighting areas. Although every project has its own unique requirements, the following example is typical.

A typical multipurpose stage can be divided into smaller lighting areas 3 to 4 m (10 to 12 ft) in diameter. Therefore, a stage 12 m (40 ft) wide by 9 m (30 ft) deep would each have three rows of four lighting areas, for a total of 12 lighting areas. Each lighting area should have four sets of luminaires (Figure 15-4):

1. Two luminaires, 35 to 45° above horizontal and 45° to both sides of the lighting area should be located on a "front-of-house" ceiling bridge, box boom, stage electric, or tormentor position. Ellipsoidal and possibly Fresnel spotlights can be used at these locations.
2. One luminaire, 35 to 45° above horizontal, should be mounted directly in front of the lighting area on the same supports as those in number 1 above. These luminaires are also of the same type as in number 1 above, with the possible addition of PAR-type luminaires for the upstage positions.
3. One luminaire should be mounted from the stage electrics directly above the lighting area. An ellipsoidal spotlight, a PAR, a striplight or borderlight, or, possibly, a scoop can be used.
4. One luminaire 45 to 75° above the horizontal should be mounted from the stage electrics directly behind the lighting area as a back light. An ellipsoidal spotlight or a PAR can be used for this purpose. If low cost is a consideration, striplights (borderlights) can be used in this position.

In addition to the positions listed above, a row of cyc lights located at the top and ideally about 2.5 m (8 ft) in front of

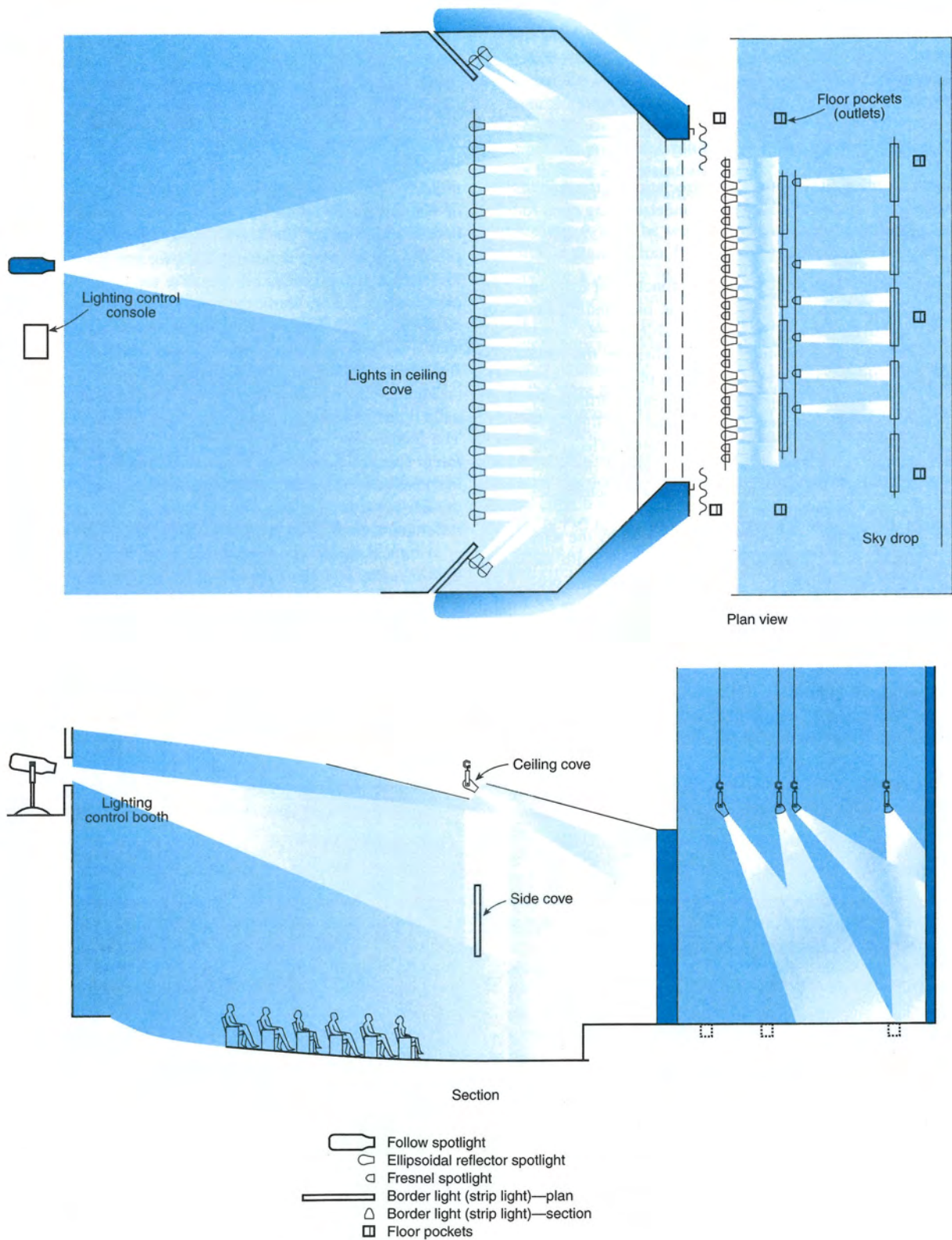


Figure 15-4. Typical plan and section of an average size theatre.

the cyclorama can be used to illuminate the background. Many times this space is not available for luminaires and compromises have to be made. In the case of high cycloramas, the cyc lights can be placed at the bottom of the cyclorama.

There are many other possible luminaire positions. For example, a luminaire mounted 25 to 35° above the horizontal at the front of a balcony can be effective in reducing shadows, particularly for television work. Further, the side-wall slots and tormentor positions are effective for modeling and for dance productions. In general, the lighting systems should permit the stage lighting designer enough flexibility to be as creative as necessary to provide the lighting required for the full range of activities envisioned for the stage.

Luminaires in Front of the Proscenium Opening

Luminaires in the Auditorium Ceiling. Stage-lighting luminaires in the auditorium ceiling are generally used for lighting downstage and apron acting areas. Each luminaire should produce a well-defined light beam that can provide an average illuminance of 500 to 1000 lx (50 to 100 fc) of white light on a vertical plane, with adjustable means for a controlled cutoff, so that the beam can be varied in shape to cover a desired area with little or no spill onto adjacent areas (Figure 15-1). These spotlights are best located behind slots, or coves, in the ceiling and are ideally mounted in a continuous slot stretching across the ceiling from side wall to side wall.

Luminaires in Auditorium and Proscenium Side Walls. Luminaires located on or in the side walls are recommended, although not absolutely required. They are used mainly as a supplement to the ceiling spotlights and are of a similar type. Preferably, these luminaires should be recessed into wall slots. They provide lower illumination angles than the ceiling luminaires as well as a variety of side lighting angles.

Luminaires on the Balcony Front. There are occasions when the balcony position affords desirable low lighting angles or a soft wash of directional front lighting. Attention must be paid to shadows, however. There is a danger that shadows from low-angle front spots may fall on the scenery and move as the actor moves. This causes an unacceptable distraction. Easy access must be provided to these spaces so that the luminaires can be readily put in place, focused, and lamped.

Follow Spot Booth. Follow spots are used to highlight selected performers. A follow spot should be capable of providing a level of at least 2000 lx (200 fc) in an area of 2.5 m (8 ft) in diameter and should have available beam size and shape so that it can be reduced to only cover the head of a person or widened to flood a considerable portion of the stage. In addition to the usual accessories, such as an iris, spread lens, or horizontal paired shutters, follow spot equipment often includes a color wheel or boomerang (a device for inserting individual filters of several different colors into

the follow spot) that can be operated from either the side or the rear of the spotlight. Follow spot positions should be near the center of the house at the rear. It should be possible for the beam of light to reach all areas of the stage and the orchestra pit in front of the stage, particularly because a portable stage can be used to fit over the orchestra pit.

Footlights. Footlights are a set of striplights, sometimes multicolored, at the front edge of the stage platform, used to soften face shadows cast by overhead luminaires and to add general tone-lighting from below. Footlights may be used to light large flat scenery, for special effects, for mood, or to duplicate period scenes.

Luminaires Behind the Proscenium Opening

Overhead Locations. The greatest number of luminaires in any one location upstage of the proscenium is mounted on the first pipe, or bridge, immediately upstage. The luminaires for this position may include spotlights, borderlights, and scenic projectors. The majority of the spotlights have variable focus to produce a soft-edged beam. A number of ellipsoidal reflector spotlights or PARs are usually mounted in this row. There should be provisions for mounting additional rows of lights on pipes parallel with the proscenium opening every 2 to 2.5 m (6 to 8 ft) of stage depth.

Stage Electric. The stage electric is a pipe, or bridge, with an electrical connector strip mounted to it and running the width of the stage proscenium opening. The basic purpose of the connector strip is to provide a simple and quick method of electrically connecting a number of luminaires above the stage. Outlets on the connector strip should not be spaced closer than 300 mm (12 in) apart, and every outlet should be on an individual circuit with a separate neutral.

A more flexible alternative to connector strips incorporates a number of multiconductor cables and electrical boxes. Every cable should be long enough to locate the outlet box at any position on the stage electric and at any height above the stage.

Border Lights and Scoops for Stage Light Pipes. Although Fresnel and ellipsoidal luminaires are most commonly used on stage light pipes, other luminaires can also be used. A borderlight or series of scoops provides general stage lighting and illumination on hanging curtains and scenery. They contribute tonal quality to the overall lighting effect. Separate control of the borderlight or scoops enables parts of the stage to be variously accented in brightness and color. These luminaires should illuminate the whole width of the curtain or flat scenic drop but should be wired on three or four separate circuits to enable changes in the color of illumination. They should be mounted at least 1.2 m (4 ft) upstage of the conventional borderlight equipment. The illuminance provided by borderlights or scoops in the center of the vertical surface should not be less than 250 lx (25 fc) of white light when measured at a point 1.8 m (6 ft) from the stage floor.

Cyclorama Top Lighting. Cyclorama borderlights must illuminate the visible width of the background, independent

of illumination from cyclorama bottom lighting. Cyclorama lighting requires at least twice the illuminance provided by other borderlights. When the cyclorama is an important feature and deep color filters are used, then the wattage of the associated borderlight equipment can be from two to four times that of a regular borderlight, depending on the density of the filter. The required illuminance may necessitate two parallel rows of borderlights, using, for example, 250-W PAR-38 lamps on 150 mm (6 in.) centers or 500-W PAR-56 lamps on 200 mm (8 in.) centers in each strip. An alternative is striplights using series-wired MR-16 lamps.

Backlighting From an Upstage Pipe. It is desirable to provide a row of high-intensity, narrow-beam luminaires, such as Fresnel spotlights, parabolic spotlights, or PAR luminaires, suspended on an upstage pipe and directed downstage to provide backlighting of artists in the main acting area. There may be one 500- to 750-W luminaire for every 1.2 to 1.8 m (4 to 6 ft) of effective stage width.

Mounting for Stage Side Lights. There are two methods of providing side stage lighting; suspended three- or four-rung ladders or floor-mounted boomerangs or tormentor pipes. Side and modeling light are essential to a stage production.

Special Theatrical Effects. Fluorescent paints, fabrics, or other materials responding to ultraviolet (UV) radiation are often used for special theatrical effects. Sources for exciting the fluorescent materials include mercury lamps with filters for absorbing visible radiation; fluorescent "black light" lamps, which also require a filter; and integral-filtered fluorescent "black light" lamps. Carbon arc follow spots are sometimes filtered for "black light" effects. Strobe lights and lasers are used in today's theatre. Great care must be exercised where using UV and lasers to comply with all government and municipal regulations and to avoid operations that could cause permanent eye damage to the audience, performers, or operators. See Chapter 5, Nonvisual Effects of Radiant Energy, and the section "Museum Lighting" in Chapter 14, Lighting for Public Places and Institutions.

Automated Luminaires and Accessories. Many theatrical and television productions use luminaires that can be remotely moved or steered, or whose color, pattern and beam edge, and focus can be changed to achieve the effect of moving light. These luminaires generally are mounted in the same way as fixed luminaires but require additional power and control wiring.

Lens accessories are available for remote color selection. These require additional power and control wiring.

Scenic Projectors. An increased understanding of the techniques of slide projection by theatre personnel has led to an improvement of the basic optical design for projection in the live theatre. Some of the principal improvements include: increased projector lamp wattages up to 10 kW; the introduction of new compact metal halide lamps to provide additional scene illumination and coverage; improved methods for slidemaking; remote, programmed slide changing; wide-angle projection to screen widths of 1.5 times the pro-

jection distance; standardization of units to permit easy interchangeability; and the availability of relatively simple and inexpensive remote-control 35-mm projectors.²⁷

Motion Picture Theatre Auditoriums

The objectives of auditorium lighting in the motion picture theatre may be outlined as follows:

- To create a pleasing, distinctive environment
- To retain brightness and color contrasts inherent in the motion picture
- To create adequate visibility for safe circulation at all times
- To provide comfortable viewing conditions

For general lighting during intermission, 50 lx (5 fc) is considered the minimum. During the picture, illumination is necessary for safe and convenient circulation of patrons. Illuminances between 1 and 2 lx (0.1 and 0.2 fc) represent good practice. The screen luminance with the picture running is between 3 and 20 cd/m². The need to eliminate stray light on the screen dictates controlled lighting for at least the front section of the auditorium. Downlighting is one of the most effective methods for this purpose. In general, diffusing elements, such as coves, allow too much light to fall on the screen if they provide adequate illumination in the seating area. Diffusing wall brackets, semidirect luminaires, and luminous elements are generally too bright to be used for supplying illumination during the picture presentation.

The luminous contrast between the screen and its black border is sometimes more than 1000:1, creating uncomfortable viewing conditions. The luminances of areas around the screen can be raised; however, they should not have decorations that are distracting. Light for this purpose may be reflected from the screen under special conditions, or it may be supplied by supplementary projectors or by elements behind the screen.

Curtains may be lighted in color with a projector border during intermissions. Adequate spotlighting on the stage is desirable for announcements and special occasions.

Aisle luminaires should have low brightness and be spaced to give a uniform illuminance of 10:1 in the aisle. House lights should be dimmer controlled.

Meetings, Conventions, and Industrial Show Facilities²⁸⁻³⁰

Meetings and conventions require comfortable ambient illumination as well as accent lighting. Where open discussion takes place between speakers and audience, the lighting should be free of glare to support dialog. Lighting for industrial shows and new-product presentations may require some form of theatre lighting.

Stage locations may vary considerably from meeting to meeting. A show that uses rear projection may move the

stage area 4.5 to 6 m (15 to 20 ft) forward. Another meeting may require a simple platform with maximum space for an audience seated in classroom or conference style. Many meetings use a center area or theatre-in-the-round arrangement. Other producers find a projected stage along a wall more satisfactory for their presentation.

Many meetings are conducted in multipurpose spaces that are used for food service, fashion shows, motion pictures, social events, and meetings. The ease and speed with which these areas can be changed from one arrangement to another are important economic factors.

Lighting must be coordinated with many other elements. These include wall surface brightness, projection screen location, and communications and sound systems. Projection from audiovisual equipment and follow spots requires unobstructed views of the screens, stages, and acting areas. Chandeliers must not be placed in locations that interfere with the projection or "stage" lighting. A sufficient number of dimmers, as well as a flexible distribution of wiring and luminaire mounting locations, should be provided. For the required flexibility, no fewer than twenty-four dimmers should be available for spaces intended for complex presentations.

Theatre-Restaurants, Lounges, and Discos

Stage lighting design criteria for theatres and auditoriums are generally applicable to theatre restaurants, night clubs, and lounges. However, theatrical lighting in a small area, such as a lounge, utilizes more compact luminaires. For low ceilings, a basic luminaire is an "inky" with a 76-mm (3-in.) Fresnel lens or an adapter accessory having individually adjustable framing shutters and lamps up to 375 W. In larger spaces with longer throws, a Fresnel spotlight or a floodlight for 250- to 400-W lamps and a beamshaper accessory can be used. An alternative is a small ellipsoidal framing spot of 650 W or less, available with wide-, medium- and narrow-beam lens systems.

Discos employ many stage lighting techniques and a variety of theatrical equipment. Typically, flicker, flash, and movement in light patterns are introduced through the use of mirror shower balls, spinners, rotators, and police emergency lights. Control systems include presets, chasers, and programmers.

Luminaire Locations. Luminaires can be positioned closer to vertical than would be acceptable for legitimate theatre, the limit being closer to 30° than to the 45° prevailing in theatrical work. Downlights are used to produce pools of light on dancers and set pieces. Uplights, recessed in the stage floor, can also be used. Side-mounted luminaires, located from 45° in front of to 45° behind the performer, are essential for three-dimensional effects, particularly in dance and production numbers. Floor-mounted linear strips can be used for horizon effects on cycloramas. These may be of the disappearing type or recessed with expanded metal covers to permit performers to walk over them.

Follow Spots. Locations for several follow spots should be provided to light the performers from all viewing directions. One or more follow spots should be able to cover audience areas. Some performers enter from the audience, and runways are frequently used to bring the chorus closer to the viewers. Side stages on each side of the main stage are frequently used for bands and stage action, and provision should be made for adequate lighting of these areas.

Transparencies. Scrims are frequently used to hide the band when playing for a show. On the other hand, the band and performers are frequently revealed by bringing up lighting behind the scrim and keeping light off the front of the scrim. These changes may occur on the side or on the principal (center) stage.

Special Effects. Mounting devices and switching circuits and receptacles are required for "black lights," projectors, electronic flash, motor-driven color wheels, and for dissolves, fog and smoke machines, mirror balls, and similar equipment. Color organs are used to pulsate lights with music. Plastic-covered floors for dancing and entertainment should provide selectable color and pattern effects. In small spaces, fluorescent lamps and dimming ballasts are used. If ventilation can be provided, incandescent lamps can be used for special effects.

Controls. Single lights are frequently used. Receptacles should be on individual dimmer circuits. Permanent grouping should be avoided. Nondimmed controls should be integrated with the dimmer controls, that is, they should be switched with voltage-sensitive relays controlled by potentiometers of the same type as those used for the dimmer controls.

LIGHTING FOR TELEVISION

Television broadcast lighting requires extensive planning and flexibility due to continuous dramatic action on the set. Several scenes are arranged for several cameras and continuous switching from one camera to the next. Consequently, the lighting for each scene is preset for cameras positioned at different angles, and the lighting in one set should not interfere with adjoining sets. The quantity and quality of the lighting needed for television production depend on the absolute spectral sensitivity of the camera and the properties of the objects in the scenes. A limiting factor for any camera is the contrast range that the camera will accommodate.

Studio Lighting for Color Television

The spectral response characteristics of cameras are critical to color reproduction. Experience has shown that the light sources used for television should have very broad spectral power distributions. The gains of the red, blue, and green channels of a camera can be adjusted to operate with almost

any broad spectrum light source, but the wide variation in the spectral characteristics of the light sources used to illuminate a scene can cause unpredictable changes in color reproduction.

Incandescent filament lamps have long been used for color studio lighting because of their continuous spectra, their low cost, and their availability in a wide range of sizes with approximately the same correlated color temperature. Incandescent filament lamps having correlated color temperatures between 2900 and 3200 K are currently used. These lamps are favored because their housing equipment is generally less bulky and lighter in weight, and the smaller filament allows for better optical control of the light beam. Furthermore, color filters are easy to use with these luminaires. Where filament lamps are used, current practice indicates the correlated color temperature of all lamps used in a scene should be within a 300-K range for consistent camera colors.

New developments in fluorescent and HID light sources are now providing greater flexibility for mixing sources. In particular, discharge lamps are now being manufactured with much better, and in some cases continuous, spectral power distributions. Some sports arenas have successfully mixed 75% HID and 25% incandescent sources.

For televising color pictures, illuminances between 350 and 3500 lx (35 and 350 fc) are satisfactory. Many studios, especially those producing color spectacles, have found it desirable to provide up to 5000 lx (500 fc). This is done to compensate for older-model color cameras or to provide greater depth of field. In scenes employing a very low light level, the problems of focus may be complicated by the very narrow depth of field afforded by wide-open lenses.

Television Film Production

The significant element in lighting for television film production is the control of the contrast range. Most television film reproduction systems require that a picture luminance range not exceed 25:1. This differs from the current theatre projection range of about 100:1, and video recording should have contrast ratios less than 20:1. Contrast control can be obtained by the introduction of fill light to raise the luminances in shadowed areas. This does not mean that flat lighting is desirable, but rather that the lighting ratios used for modeling should be lower than is normally used when making films for theatrical projection.

Unlike the human visual system, color contrast is not enough to ensure an acceptable signal for television film. Brightness contrasts are required for a monochrome receiver tuned to a color broadcast. A poor monochrome picture is particularly conspicuous when scenery is painted in several pastel shades, all having similar reflectances.

Projected Backgrounds

A scene may be projected onto a translucent screen from behind. This technique is used to simulate background scenery,

which may take the form of stationary objects as produced by a slide, moving effects such as clouds and water, or continuous motion simulating moving trains or motion from an automobile as produced by a motion picture film.

For realism, projected highlight levels should be within a 2:1 ratio of live highlight levels. As a rule, it is desirable to have a projected highlight luminance of 250 cd/m² when the acting area is illuminated to 1000 lx (100 fc).

Chroma Key

The production technique known as chroma key is a special effect that enables any background material to be matted into a scene. In the studio, a color camera views the subject against a backdrop of a primary color that has sufficient saturation to produce a full output level in the corresponding channel of the camera. This signal output is used to key a special effect generator so that all information except the wanted subject is matted out of the original studio scene. Information from any other source, such as a film chain or video tape recorder, can then be inserted in the matted portions of the signal.

The primary color used in the backdrop is chosen on the basis that it is not present in the color of the wanted subject. When human subjects are used, blue is usually the best background color because it is absent in flesh tones. Additional precaution must be taken to avoid the use of the background color in costumes or stage props.

The illuminance on the backdrop must be high enough to produce a full output signal from the camera without excessive noise. Light should not be reflected from the background onto the subject, because it will create spurious keying signals.

Types of Illumination

A graphic representation of the following types of lighting is shown in Figure 15-5.

Base Light or Fill Light. Base light or fill light is usually supplied by floodlights that supply broad, soft illumination. It is desirable to aim base lights at a 12 to 15° angle below horizontal.

Key or Modeling Light. Key or modeling light is usually supplied by Fresnel lens spotlights ranging in lamp size from 500 to 10,000 W. Fresnel luminaires are equipped to hold supplementary masking devices, such as barn doors, snoots, and color frames. The barn door fits in front of the lens and is used to limit the bottom, top, or sides of the light beam. These units can either be hung or used on floor stands and are generally aimed at a 20 to 40° angle below horizontal. Back light is used for separation. Back lights are hung behind a subject and are aimed at approximately a 45° angle to light the back of the head and shoulders, and to separate the subject from the background. Back light illuminances

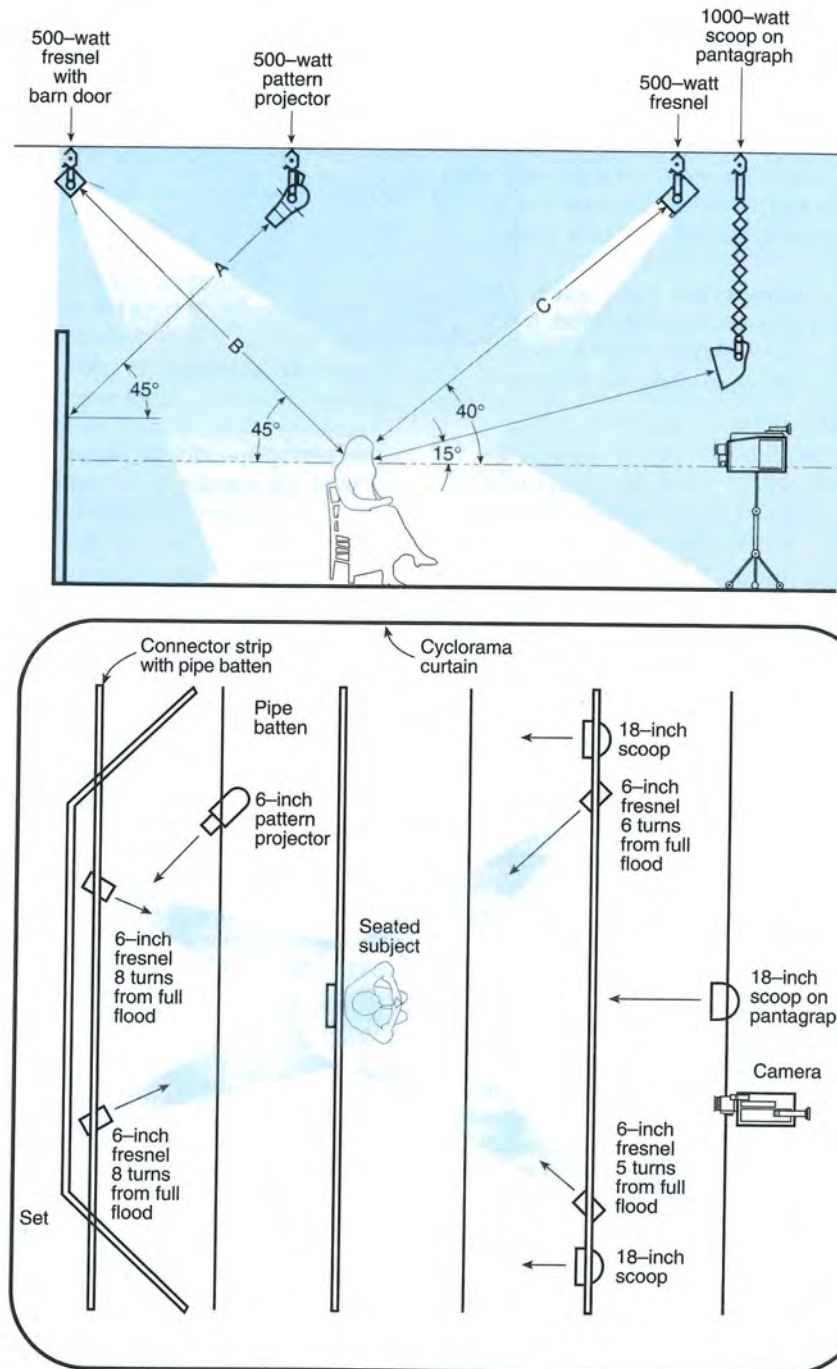


Figure 15-5. Diagrams showing good practice in luminaire location and aiming angles. In the top diagram $A = 3\text{ m}$ (10 ft), $B = 3.7\text{ m}$ (12 ft), and $C = 4\text{ m}$ (13 ft). The 1000-W scoop on the pantagraph provides base light; the 6-inch fresnels in front of the subject provide key light; the 6-inch fresnels behind the subject provide back light; and the pattern projector provides set light.

should be from one-half to the same as that of the front light, depending on the reflectance of the hair and the costume.

Set Light. Set light is used to decorate or help give dimension to scenery. The amount of light necessary is totally dependent on the reflectance of the scenery. Light skin reflects 40 to 45% of the illuminance. Therefore, the major part of the background must be kept below the luminance of the face. A gray-scale reflectance of 30% is a good average value for the background.

There are many other luminaires that can be used to help dramatize a show, such as sun spots, ellipsoidal spots, follow spots, pattern projectors, and striplights. These luminaires are described above in the section "Lighting for Theatres."

Balancing for Correct Contrast. It is important to have the proper balance among the different types of lighting discussed above. For instance, if the set is painted in a color value that reflects more light than the flesh of the actor, skin tones may appear darker than desired in the picture. This means that the set light should be reduced. A quick way to do this is to cover the set-lighting luminaires with diffusing material. Spun-glass diffuser material is available in 1 by 4 m (3 by 12 ft) rolls and can be cut to fit the luminaire. One 0.38 mm (0.015 in.) thickness cuts about 20% of the light. Additional thicknesses can be used until the correct contrast is obtained. The problem in using spun glass is that the character of the light has been altered from somewhat firm image-forming to soft, diffuse, flood, and less directional ambient light.

Another medium that is sometimes used to balance the lighting is one or more layers of ordinary house window screening. Black window screening material has the virtue of minimizing changes to the optical characteristics of the light.

If the installation includes dimmers and a cross-connecting system, the different luminaires can be grouped and then dimmed until the desired contrast is obtained. There is no apparent color effect due to dimming in black-and-white television. In the case of color television, the correlated color temperature decreases 10 K per volt for lamps operated at 120 V. As stated before, differences of 300 K contained in one scene are perceptible. A very low correlated color temperature contains little short-wave energy and may make blue hues dark and as a result introduce unwanted noise into the picture.

Lighting Equipment Installation

The method of supporting the luminaires depends to a great extent on the ceiling height and the intended use of the studio. Where the height is low, in the range of 3.5 to 5 m (12 to 16 ft), a permanent pipe or track grid is usually installed from which the luminaires are hung directly or through pantographs, which permit individual vertical positions (Figure 15-6). The luminaires are capable of complete rotation and tilting. In high-ceiling studios and in television theatres, the

luminaires are supported either from fixed pipe or track grids or on counterweighted pipe or track battens (Figure 15-6).

Television Control-Room Lighting

The lighting system for use during control-room operating periods should meet the following requirements:

1. General illumination. A diffuse, evenly distributed illuminance of 50 lx (5 fc) should be provided by low-intensity sources located so as to avoid any specular reflections in picture monitors, clock faces, windows, control panels, console desks, or similar surfaces, as seen from normal positions occupied by operation personnel.
2. Work illumination. Localized higher illuminances of approximately 250 lx (25 fc) should be provided on the production consoles, control consoles, switching consoles, and announcer's desk.
3. Correlated color temperature. The correlated color temperature of control-room operating lights should be nearly constant.
4. Emergency lighting. Emergency power from a separate source should be provided.

The lighting system used during maintenance of the area should have an illuminance of approximately 250 lx (25 fc). This system should be independent of the production lighting outlined above and used only for installing, repairing, and moving equipment or for cleaning.

Field Pickups of Sporting Events

Lighting recommendations for sports are largely based on the visual requirements of players and spectators (see Chapter 20, Sports and Recreational Area Lighting). When filming or telecasting is involved, the lighting requirements are often more stringent. Light sources should have a CRI of 80 or above. Horizontal and vertical illuminances should be no less than 750 lx at any point on the playing surface. Illuminance distribution is especially important for modeling players, and special calculation and measurement procedures are required to ensure satisfactory performance by the camera systems. See Figure 15-7.

Modeling. The vertical illuminances should be recorded along and perpendicular to the camera's viewing direction. Measurements of horizontal and vertical illuminances in four directions should be made at a height of 900 mm (36 in.) above the playing surface. The visibility for players and spectators depends on the values of horizontal- and vertical-plane illuminance, since modeling of an object is related to the proportion of horizontal to vertical illuminance reaching an object from different directions. As the number of vertical planes at any one point is infinite, it is convenient to con-

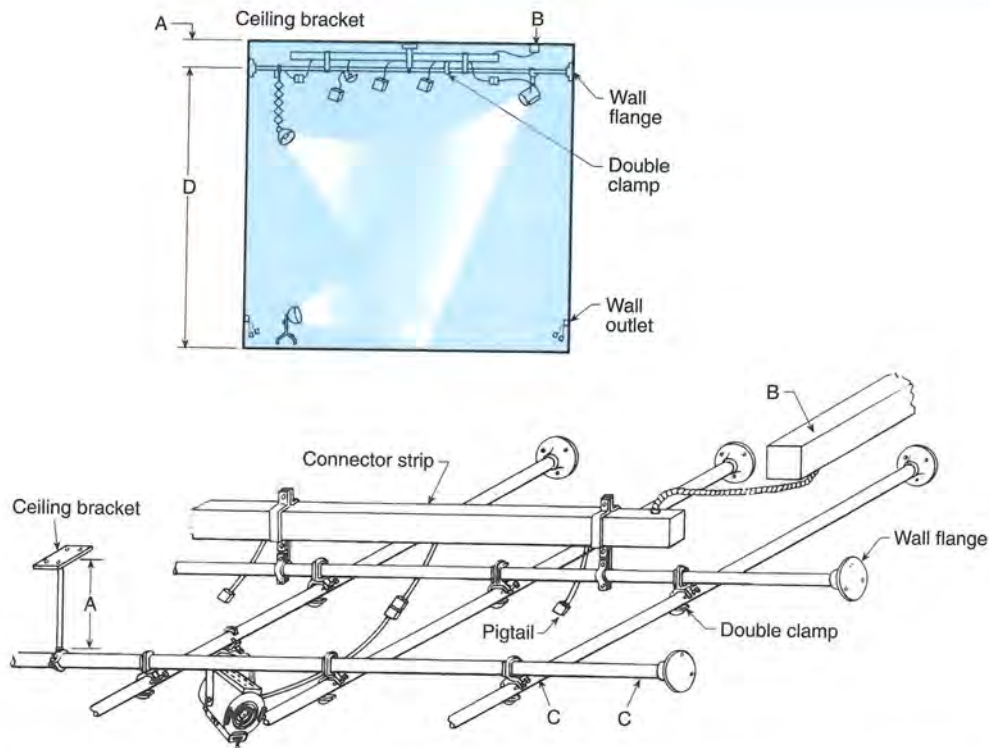


Figure 15-6. Diagram showing a typical overhead grid system for mounting lighting equipment in a small low-ceiling studio. Typical systems for larger studios with higher ceilings can be raised and lowered. In the drawings $A = 300$ mm (12 in.), $B = 100 \times 100$ mm (4×4 in.) duct, $C = 32$ mm (1.5 in.) ID pipe, and $D = 3$ to 3.7 m (10 to 12 ft).

sider only faces of two vertical planes at right angles (Figure 15-8).

If E_h (the horizontal illuminance at the point under study) and E_{v1} , E_{v2} , E_{v3} , and E_{v4} (the four vertical-plane illuminances at that point separated by 90°) are approximately the same, the modeling (or revealing power of the lighting) is poor, that is, it is difficult to see objects in three dimensions. On the other hand, extreme differences in these five values cause harsh modeling that can distort the appearance of the object. For the purpose of sports lighting, since viewing is from all directions, it is usual to take the average of the values at a number of points over the area. See Chapter 20, Sports and Recreational Area Lighting, for the distribution of calculation measurement points on the various playing surfaces. Acceptable modeling will generally be achieved if E_{hav} (the average horizontal illuminance over the area) is no greater than twice the average value in any one of the four vertical planes.

It is also important to provide illumination in the spectator area adjacent to the playing field for crowd shots and for wide-angle shots of the playing field. This is best accomplished from behind the spectators, to limit glare for both the spectators and camera positions in the spectator seating area.

PHOTOGRAPHIC LIGHTING

Photographic lighting is used by amateur photographers, portrait and commercial photographers, industrial photographers, and cinematographers. The needs of these photographers vary considerably, as do the film materials and lighting systems. A portrait photographer may use flashlights to minimize discomfort for the subject. Strobes and flashbulbs stop the motion of moving objects. Color photography requires compatibility between the film spectral sensitivity and the light source spectral output. In motion picture photography, the stroboscopic effect of fluorescent and HID light sources must be minimized with special ballasts or synchronized with the film speed and shutter angle. The lighting requirements are therefore many and varied.

Photosensitive Materials³¹

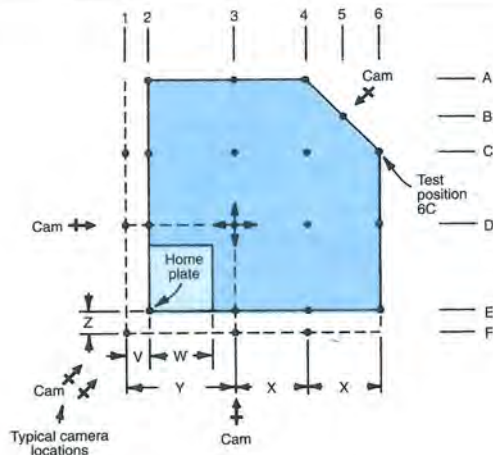
Commonly used photosensitive films and plates include the following (spectral sensitivity curves are given in Figure 15-9):

- Panchromatic (sensitive to all colors, produces a black-and-white image)

Figure 15-7. Recommended minimum illuminance levels and survey test position for television pickup of baseball.

Illuminance Readings in Lux (Footcandles) at Test Positions						
	1	2	3	4	5	6
A	—	1000 (100)	1000 (100)	1000 (100)	—	—
B	—	—	—	—	1000 (100)	—
C	1250 (125)	1250 (125)	1250 (125)	1250 (125)	—	1000 (100)
D	1250 (125)	1500 (150)	1500 (150)	1250 (125)	—	1000 (100)
E	—	1500 (150)	1500 (150)	1250 (125)	—	1000 (100)
F	1250 (125)	—	1250 (125)	1250 (125)	—	—

Distance	Meters	Feet
V	9.1	30
W	27.4	90
X	30.5	100
Y	45.7	150
Z	9.1	30



- Orthochromatic (sensitive to all colors except orange and red, produces a black-and-white image)
- Color (sensitive to all colors, produces a color image)
- Infrared (sensitive to red and infrared, produces a black-and-white image)

For photography, light sources must emit energy in the spectral region in which the photographic material is sensitive. Even with black-and-white photography, color delineation in the form of faithful gray values is required. In black-and-

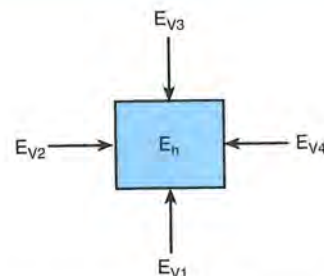


Figure 15-8. Five illuminance measurements used to determine acceptable modeling for sports lighting.

white photography, photographers endeavor to secure a scale of grays in their negatives corresponding to the various brightnesses of the subject; thus, it is necessary that the film and the light source complement each other. Where this is not possible, it is general practice to employ a filter at the camera lens.

For color photography, the spectral quality of the illumination is even more critical. Color emulsions are “balanced” for use with a particular quality of light. Because most color photography materials are based on three emulsion layers, each sensitive to a narrow spectral band, adjustment by filtering to a light source other than the one for which the material was originally intended calls for precise filter selection.

Photographic Lighting Equipment

Still camera lenses ordinarily cover an angle of about 45°; therefore, for lighting equipment placed at or near the camera, reflector beam patterns for complete light utilization should fill an angle of about 45°. However, difficulties caused by inaccurate aiming of the reflector and other variables are minimized by filling a 60° cone with reasonably uniform illuminance. A luminaire with a 60° beam angle usually provides lower illuminances toward the edges of the scene, but this is seldom objectionable, since the point of interest in a picture is generally in the middle.

The shadows and contrasts that help to light a person as normally seen are usually “soft,” such as those produced by a light source of appreciable angular size. Large reflectors 400 to 600 mm (16 to 24 in.) in diameter produce more natural modeling and are used in portrait studios or other applications where their size is not a handicap. Flashlamp equipment used with smaller-format cameras necessarily have smaller reflectors, which produce somewhat sharper and less natural shadows.

Photographic Lighting Techniques

The lighting required depends on the final effect desired from a photograph. If good rendering of shadow detail is desired, a rather narrow range of illuminances is required so

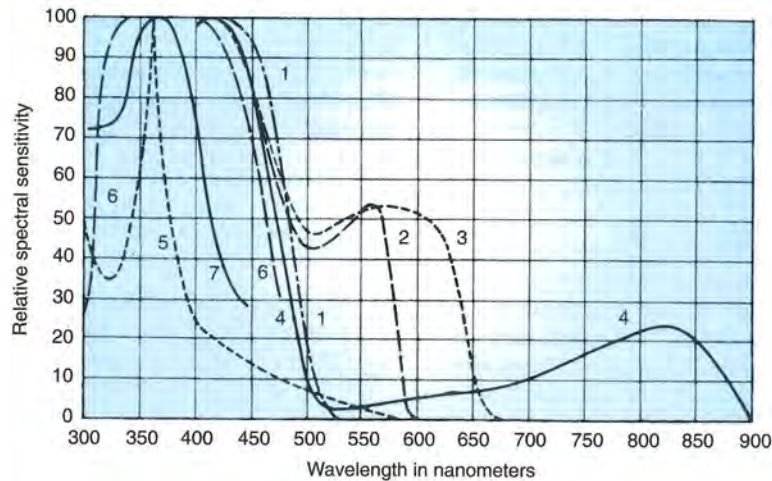


Figure 15-9. Spectral sensitivity curves for common types of photographic and photoprocess materials. (1) blue sensitives; (2) orthochromatic; (3) panchromatic; (4) infrared sensitive; (5) bichromate coating; (6) diazotype paper; (7) blueprint paper.

that both the brightest parts (highlights) and the darkest parts (shadows) of the scene are fully rendered in the final print or transparency. The brightness range reproduced on film is much narrower than brightnesses perceptible by the human eye, particularly in the case of color photography. With typical subject reflectance ranges, the recommended maximum illuminance range within the scene is 10:1 for black-and-white and 4:1 for color film.

In color photography the correlated color temperature of all of the light sources used must be the same. The eye readily accepts illumination of mixed correlated color temperature, but photographic film does not.

The monocular vision of the camera tends to render subjects flat; that is, they tend not to have a three-dimensional look. To compensate for the lack of stereo depth, the best lighting on photographic subjects emphasizes their roundness, form, and spatial relationship. This is largely a matter of lighting direction, such as lighting from the side or the back.

In photography, both general and modeling illumination are needed to produce a natural-appearing likeness of a subject. General illumination, if used alone, produces a negative that is flat and without modeling. Such illumination does not produce prominent shadows. Density differences in the negative are created by differences in the reflectance of various portions of the subject. This general illumination goes by several names, among which are front light, broad light, flat light, camera light, and basic light. Modeling light, if used alone, produces a negative in which the highlights can be well exposed, but the shadows show no detail at all. Modeling light is usually highly directional and is used for the express purpose of creating shadows and highlights.

For ordinary subjects, the background should not be very dark, very light, or too close behind the subject. Neither should it be of exactly the same luminance as important

parts of the subject, because such a condition would have the effect of merging the subject with the background. Better photographs result where less detail and fewer distracting spots are in the background.

Photography of Lighting Installations

The photography of installations by "existing light" does not require special photographic materials or equipment. Attention to focus, proper exposure, and composition is necessary, and the use of a tripod is recommended.

The finished picture should represent the actual installation as closely as possible.^{32,33} Because most installations have a luminance range that exceeds the range of the film, various techniques in photographing and photographic finishing are used to compensate and so produce a more natural-appearing photograph.

In taking the picture, exposures can be split (meaning a separate exposure is used on the same film frame for each different source of light), fill light may be introduced, lampshades may be lined, and bulbs may be substituted to reduce brightness. When fill light is used, great care must be taken to avoid unnatural shadows. This may mean bouncing light off of walls or the ceiling. In black-and-white photography, a 10:1 ratio of scene illuminance is desirable. In color photography, the ratio should not exceed 4:1.

The rule of exposing for shadows and developing for highlights is still valid for black-and-white photography. Through experience and testing, the photographer finds the best combination of lighting technique, film, and processing that yields an easily printed negative. The printer can also use various methods of compensation, such as dodging, flashing, and burning in, to overcome the deficiencies of a poorly executed negative.

When using color film, exposure should be for the high-

light areas where detail is desired. It is also imperative that all the light sources be similar in color. Fluorescent lamps generally should not be combined with incandescent fill light, since this usually produces a noticeable color mismatch in the final photograph.

Installations of discharge lamps photographed with color-positive material present color balancing problems. Because all films are designed to respond to a continuous spectrum, and HID lamps generally do not have continuous spectra, filtration in some form is required to produce an acceptable color balance. Lamps and film manufacturers can generally furnish recommendations for suitable filters to balance the various color-positive films to specific discharge lamps, both fluorescent and HID.

Another much simpler method of color photography is to photograph the installation on unfiltered color-negative material and to work with a professional color laboratory to produce prints or slides with the correct color, with the necessary filtration being done in the photofinishing laboratory.

Darkroom Lighting

In general, any type of darkroom safelight filter must transmit light that has the least effect on the photographic material and yet provides the most illumination for the eye. Any photographic material fogs if left long enough under even the best safelight illumination.

The placement, size, and type of safelight lamp depend on the purpose that the light serves. The two types of darkroom illumination are general, to supply subdued illumination over the whole room without concentration at any one point, and local, to supply higher illumination on some particular point or object. These are combined, depending on the size of the room and the type of work.

Because of the varying sensitivities of the different classes of photographic materials, several safelight filters are available, differing in both color and intensity. These have been produced by the manufacturers of the luminaires, and it is never safe to use substitutes. Other materials may appear to the eye to have the same color as a tested safelight filter, but they frequently have a much greater effect on the exposed,

unprocessed film. The use of makeshift safelight substitutes is not recommended.

Figure 15-10 indicates available types of safelight filters. Film manufacturers should be consulted for more complete information.

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Figure 15-10. Types of Safelight Filters

Color	Material Used with
Clear yellow	Contact printing papers
Bright orange	Bromide and other fast papers and lantern slide plates
Greenish yellow	(Better than orange for judging print quality)
Orange-red	Ordinary films and plates
Deep red	Orthochromatic films and plates
Green	Panchromatic films and plates
Yellowish green	X-ray film
Special green	Infrared films and plates

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Residential Lighting

18

This chapter serves as a guide for lighting residential spaces.¹ It is intended to aid in creating lighted spaces that are rich and varied and have adequate lighting for tasks and good color rendition. It covers design objectives, criteria for the quantity and quality of illumination, lighting methods, typical equipment, and electrical energy considerations. Methods for lighting specific visual tasks are detailed. Every task description discusses the task plane, the range of recommended illuminances, lighting design considerations, and typical equipment locations.

FACTORS AFFECTING THE INTERIOR LIGHTING PLAN

Human Factors

Light influences the emotional responses of the people who occupy the space. The appearance and character of a space is greatly dependent on the distribution and pattern of light and shadow. Lighting design does not start with the selection of luminaires, but with an evaluation of the occupants' needs, visual and physical capabilities, age, and lifestyle. (Older people require much more light than younger people; a 55-year-old requires twice as much light as a 20-year-old.) Because needs, lifestyles, and occupants can change, consideration should be given to the use of portable, modular, and easily controlled luminaires.

Design Factors

The designer must gather information to identify the client's needs and develop solutions. Those elements that contribute to the design solution are the design issues. Following the evaluation of the design issues, the designer should then select the light sources and luminaires and finally determine quantity, location, and appropriate controls.

Several important criteria must be considered in residential lighting design. They include safe movement from one space to another, lighting people as well as objects, flexibility in multipurpose spaces such as kitchens and great rooms, a sense of aesthetics, and the concern for energy efficiency.²⁻⁴

Finally, the designer should consider how alternative sources, equipment, placement, or controls would improve the end results and affect costs. The designer should provide a maintenance schedule and lamp replacement list for the

RESIDENTIAL LIGHTING DESIGN ISSUES

General

- Appearance of Space and Luminaires
- Color Appearance (and Color Contrast)
- Direct Glare
- Illuminance (Horizontal)
- Light Distribution on Surfaces
- Luminances of Room Surfaces
- Modeling of Faces or Objects
- System Control and Flexibility

Kitchen

- Color Appearance (and Color Contrast)
- Direct Glare
- Illuminance (Horizontal)
- Illuminance (Vertical)
- Reflected Glare
- Source/Task/Eye Geometry

Reading

- Direct Glare
- Illuminance (Horizontal)
- Illuminance (Vertical)
- Reflected Glare
- Source/Task/Eye Geometry

client to help keep the lighting system equipped to perform as planned. For more information on maintenance, see Chapter 28, Lighting Maintenance.

LIGHTING CRITERIA FOR INTERIOR SPACES

Quality of Light

Lighting may be diffuse or directional. Diffuse light minimizes shadows and provides a more relaxing and less visually compelling atmosphere. When diffuse light is used alone, no object in the visual scene is given prominence. Artful use of directional light can provide highlights and shadows that emphasize texture and form. Brilliance or sparkle can be achieved with small unshielded sources, such as a bare lamp or a candle flame. The glitter of crystal and

polished brass, the luster of table settings, and the sheen of surface materials can be heightened by directional lighting to create a sense of warmth and festivity. Low-voltage cable systems can be used for ambient and directional illumination.

In many residential spaces, it is desirable to create more than one mood or to be able to vary the atmosphere. Lighting control systems can provide this flexibility and should be an integral part of the design (see Chapter 27, Lighting Controls).

Brightness Relationships

Brightness is an impression of the appearance of a light source or an illuminated surface, described in terms of its perceived relative luminosity. This subjective impression can be correlated with light-measuring instruments (see Chapter 2, Measurement of Light and Other Radiant Energy) that determine the luminance of the surface or of the source. Luminance is expressed in candelas per square meter (cd/m^2). Luminance ratios play an important role in the comfort, eye fatigue, and difficulty of visual tasks.

Seeing Zones

A person's visual field consists of three zones (Figure 18-1):

- Zone 1: The task area itself
- Zone 2: The area immediately surrounding the task
- Zone 3: The general surroundings

Figure 18-1. Seeing Zones and Luminance Ratios for Visual Tasks



Zone	Luminance Ratios
2—Area adjacent to the visual task	
Minimum acceptable ratio	$\frac{1}{5}$ to 5 times task
3—General surrounding	
Minimum acceptable ratio	$\frac{1}{10}$ to 10 times task†

† Typical task luminance range is 40 to 120 candelas per square meter [4 to 12 candelas per square foot] (seldom exceeds 200 candelas per square meter [20 candelas per square foot]).

For visual comfort the luminance of the immediate surround (zone 2) should range between one-fifth of the task luminance and 5 times the task luminance. The luminances of areas in the general surround (zone 3) should range between one-tenth of the task luminance and 10 times the task luminance. These relationships should not be exceeded for visual comfort in visually demanding tasks such as studying, sewing, or reading.

Reflectance

Reflectance is the ratio of the amount of light leaving a surface to the amount of light incident on it. Reflectance can be expressed as a percentage or more roughly as a Munsell value (see Chapter 4, Color). Pale, high-reflectance colors for room surfaces and furnishings are important and often essential in achieving desirable luminance ratios. To assist the designer in obtaining the recommended luminance ratios, recommended surface reflectances with approximate Munsell values are listed in Figure 18-2.

Veiling Reflections

Light reflected from the task surface, which partially or totally obscures the details by reducing the contrast, is called a veiling reflection. When tasks involve specular glossy surfaces, such as high-gloss photographs and slick magazines, veiling reflections can be a problem (see Chapter 3, Vision and Perception).

Reflected Glare

When light sources are imaged on glossy glass-top tables or mirror-like surfaces in or near the visual task, the condition is known as reflected glare. If these reflections are excessively bright, they cause visual discomfort (see Chapter 3, Vision and Perception).

Light and Color⁵

Color recognition depends on the spectral characteristics of the light source and the spectral reflection characteristics of

Figure 18-2. Recommended Reflectances for Interior Surfaces of Residences

Surface	Reflectance (%)	Approximate Munsell Value
Ceiling	60–90	8 and above
Curtain and drapery treatment on large wall areas	35–60	6.5–8
Walls	35–60*	6.5–8
Floors	15–35*	4.0–6.5

* In areas where lighting for specific visual tasks takes precedence over lighting for the environment, the minimum reflectance should be 40% for walls, 25% for floors.

the object being lighted. These two factors provide object color to the observer.

Surface or object colors may match under one light source but not under another. For example, two colors may match under incandescent lighting but not under daylighting (see Chapter 4, Color). This fact should be noted when selecting materials, pigments, or dye lots for interior surfaces. One should examine and compare materials under the light sources that will ultimately illuminate them.

Surface Finish

Colors of objects sometimes appear to change with surface finish. Specular or mirror reflections from glossy surfaces may, in extreme cases, increase the chroma and saturation at one angle and obscure color at other angles. A matte finish reflects light diffusely and appears more or less the same from any viewing angle. Deeply textured finishes, such as velvet or deep-pile carpeting, cause shadows within the fibers that make the materials appear darker than smooth-surfaced materials such as satin, silk, or plastic laminates of the same color.

Fading

Light fades fabrics and finishes. Ultraviolet (UV) energy is one cause of fading (see Chapter 5, Nonvisual Effects of Optical Radiation). Since UV radiation cannot be completely eliminated, the amount, frequency, and length of exposure should be considered when materials or objects are of great value or irreplaceable (see the section on Museum Lighting in Chapter 14, Lighting for Public Places and Institutions). The use of appropriate UV and IR filters in luminaires to protect fabrics, furnishings, and art from light sources is recommended.

Quantity of Light

Visual activities in living spaces range from simple to extremely difficult tasks. For example, sewing is an activity with small visual details and low contrast that requires higher illuminance than determining orientation in an entry foyer. See Chapter 3, Vision and Perception, for a discussion of the factors involved in seeing, and Chapter 10, Quality of the Visual Environment, for the recommended quantities of illumination.

LIGHTING METHODS

General Lighting

Areas with Visual Activities. Residential lighting is planned on the basis of activities, occupants' ages, and physical capabilities and limitations, not on the basis of room type. The designer should provide enough general lighting for a range

of activities. General illumination prevents a spotty effect, maintains recommended luminance ratios in the field of view, and provides light throughout the interior for safety and housekeeping activities. General illumination also prevents excessive differences in illuminance between adjacent rooms.

In some spaces, particularly utility areas, general illumination can be designed to supply all of the lighting needed for visual activities. For most living areas, high-illuminance, uniform general lighting would be unacceptable. The equipment most commonly used to light room surfaces and create a satisfactory background for visual work includes general-diffuse ceiling luminaires, wall luminaires, indirect luminaires, built-in lighting systems, or portable floor or table luminaires (Figure 18-3). In small rooms, general illumination can even be supplied by the luminaires used for specific task lighting, as in the case of a vanity mirror light or an open-shade portable luminaire used primarily for reading or studying. In addition to a system that provides general illumination, portable task lighting may be needed for demanding visual tasks.⁶

Areas for Relaxation. A low level of illumination in combination with small areas of bright light creates a relaxing atmosphere (Figure 18-4). Uniformity of illumination need not be the objective. The primary considerations for these spaces are comfort and aesthetic satisfaction.

Connection Areas. Illuminance levels for hallways and stairs should allow for visual adaptation. If they adjoin an interior area with a higher illuminance, the level in the hall or



Figure 18-3. A home office is illuminated with several types of lighting: recessed downlights for general lighting, under-cabinet luminaires for task lighting on the desk top, and a wall sconce for style.



Figure 18-4. Lighting contributes to a room's aesthetics and atmosphere. This inviting living room, with its extraordinary view of the city, features downlighting in the seating area, accent lighting on the painting and sculpture over the fireplace, and shelf lighting to illuminate the stereo and highlight decorative items.

stair should be no less than one-fifth that of the adjacent area. Wall luminances are crucial in creating a sensation of brightness and reducing shadows on the stairs. Wall and floor finishes should have high reflectance values. Lighting in an entry hall should be flexible so that adjustments can be made for visual adaptation during the day and at night (Figure 18-5). On stairs, it is critical that treads be emphasized, and that the top and bottom steps be well lighted for safety. Under no circumstances should a built-in wall-mounted luminaire or portable luminaire be located where a person descending the stairway can see the light source directly.

Garages. Light is needed in a garage on both sides of the automobile and between automobiles, especially over the front and rear. Luminaires are usually located slightly to the rear of the trunk area and approximately in line with the front wheels. A portable trouble light can be provided for repair work.

Garages are often multipurpose spaces. In addition to ambient lighting, task lighting may be required for a work bench.

Closets. Light sources in closets should be located out of normal view, generally to the front of the closet and above the door. In walk-in closets, a ceiling luminaire should be mounted at the center of the traffic area so that shelves do



Figure 18-5. Left, a three-dimensional effect was created for the lighting of this hallway. Three recessed PAR-30 spotlights were used to wash the wall of the upper hallway and give depth to the view. The open passageway was lighted with wall-mounted up/down fluorescent lamp luminaires. A low voltage incandescent strip was used to light the railing. The bottom step of the staircase was illuminated with a downlight, while the dried reeds were illuminated with uplight. This lighting scheme plays with various brightnesses and emphasizes three-dimensional planes and depths. Right, a daytime view of the same hallway. While the skylight is pronounced, the three-dimensional features of the lighting scheme are not as noticeable.

not block the lighting of the garments. National and local electrical codes for closet lighting, which require enclosed luminaires, must be followed.⁷

High-color-rendering light sources should be selected, since color matching is a critical task in closets. Select lamps with a high color temperature and a color rendering index (CRI) of 80 or higher.

Lighting for Common Visual Tasks

In providing the recommended illuminance on the task, which corresponds to zone 1 in Figure 18-1, the essentials of good lighting quality, as previously discussed in this chapter and in Chapter 10, Quality of the Visual Environment, must not be overlooked. Rarely can the desired illuminance be provided by general lighting alone. At the same time, task lighting by itself is seldom totally satisfactory or comfortable; therefore, a combination of task and general lighting is needed (Figure 18-6).⁸ Daylighting also improves the quality of the lighting in a residence.

The common residential visual tasks are discussed in Figures 18-7 through 18-23. Included in this discussion is a description of the task and task plane, special design considerations, and typical equipment locations. For illuminance values see Chapter 10, Quality of the Visual Environment.



Figure 18-6. This bath features a simple soffit with overlapping up/down 4 ft T-12 fluorescent striplights that provide an even wash of light. The luminaires are outfitted with wooden egg-crate louvers.

OTHER INTERIOR LIGHTING DESIGN CONSIDERATIONS

Sparkle, Highlight, and Spatial Effects

In addition to lighting tasks and providing general illumination, lighting can be important in reinforcing spatial perception, activity, and mood. These effects depend on a person's previous experience, perception, attitude, and expectations. Specific impressions include perceptual clarity, spaciousness, relaxation, privacy, and pleasantness.⁹ Lighting can set a mood, render people flatteringly, and enhance colors and textures in a space (Figure 18-24). To create these effects, many factors have to be considered. One is the luminance between a highlighted space and its adjacent spaces. The contrast of a brightly lighted area adjacent to a dim area can create a dramatic effect. A minimum ratio of 10:1 is required for dramatic effects and to focus attention.

Wall washing provides smooth, even illumination that emphasizes the vertical plane and minimizes texture (Figure 18-25). When wall washing, the wall should be illuminated as close to ceiling planes as possible. Wall washers should be spaced 600 mm (24 in.) from the wall and 600 mm (24 in.) on center for a recessed adjustable accent or wall-wash downlight. Wall grazing provides drama and accentuates the textures of wall surfaces. Grazing luminaires should be spaced 300 mm (12 in.) from the wall and 300 mm (12 in.) on center. This technique is very effective for brick, marble, and stone.

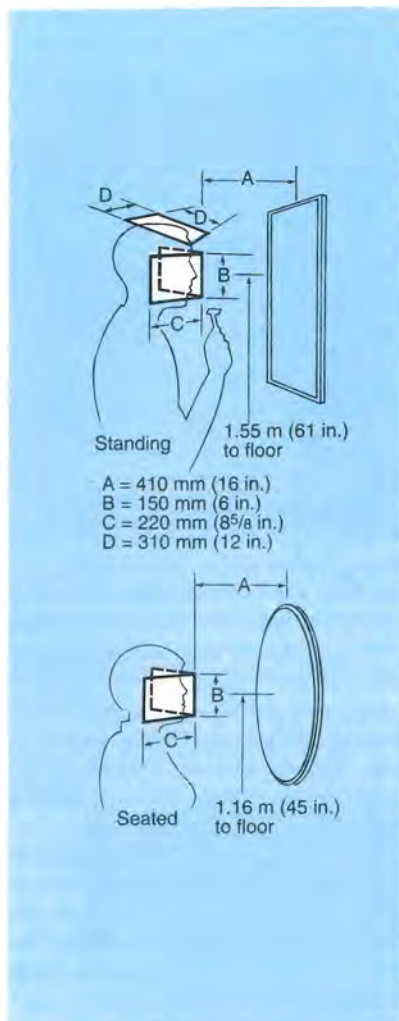
Sparkle is a small brilliance of light used to add visual interest to objects in a space and to attract attention. Glare results if the area of sparkle is too big, if the source is too bright, or if adjacent reflective surfaces are mirrorlike. The angle, intensity, and shielding of the source must be evaluated to assure visual comfort.

Playing light against darkness can create a striking visual effect within a space (Figure 18-26). The brightness ratios between luminaires and their background are very important. For example, the brightness of a translucent portable luminaire against a dark wall may result in a dramatic effect, but it can cause discomfort if the shade is excessively bright.

Lighting can reinforce spatial perceptions. It can make a space appear larger or smaller.⁹ Uniform lighting can make a space seem larger, but at the same time it can make the space seem flat or dull if there are no shadows. In contrast, nonuniform lighting can make a space seem smaller, particularly if walls, ceilings, and corners are dark, and can also create a sense of intimacy. Pretesting spatial effects is always recommended.

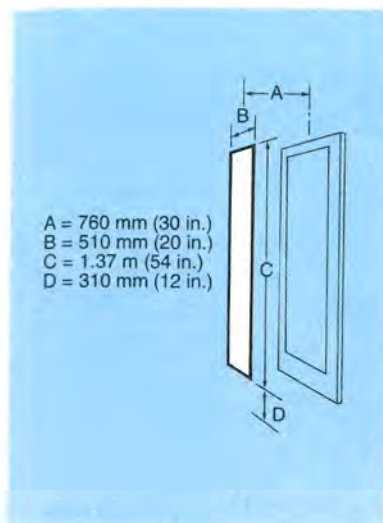
Art Created by Light

Light as an art medium is a way to enhance interior spaces. Art can be created by projections onto surfaces or transmission through surfaces of glass, acrylic, or neon and should be designed as part of the overall luminous environment

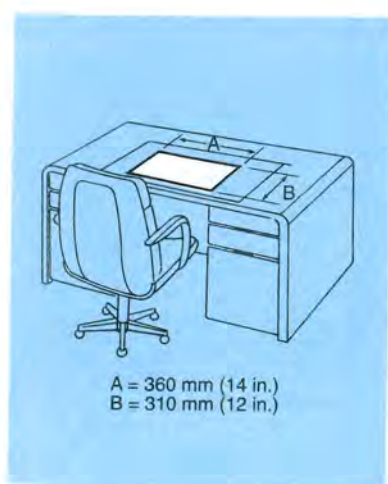
**Figure 18-7. Grooming**

Bathrooms require a combination of lighting, task, and mood. A high color rendering lamp, one that shows colors accurately, is best for grooming. Well-shielded incandescent or halogen lamps offer the greatest decorative options; fluorescent lamps with good color quality can provide high levels of light without the heat. The placement of the luminaires is especially important in using a mirror; elongated lighting alongside the mirror works best and should be at least 400 mm (16 in.) long. Lighting above the mirror should be at least 600 mm (24 in.) wide to properly illuminate both sides of the face. Recessed downlights are an excellent choice for mood and general lighting. These luminaires are most effective when placed on a dimmer.

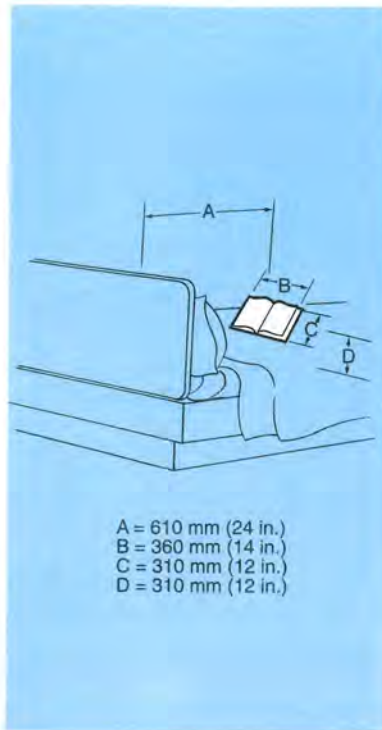
1. *The task:* The chief tasks are shaving and applying makeup. Because the apparent distance of the face or figure as viewed in the mirror is twice its actual distance from the mirror, and because the details to be seen in shaving or makeup are usually small and of low contrast with their background, the visual task may be critical. Skin and hair reflectance can be quite low, below 30%, and speed and accuracy while grooming can be critical for a fastidious person rushed for time.
 2. *Description of the task planes:*
 - (a) Standing position: The task area consists of two 150 by 220-mm (6 by 8⁵/₈ in.) planes at right angles with each other, converging at a point 410 mm (16 in.) out from the mirror and centered vertically 1550 mm (61 in.) above the floor. They represent the front and sides of the face. A third plane 310 mm (12 in.) square, its front edge also 410 mm (16 in.) out from the mirror, is tilted up 25° above the horizontal and represents the top of the head.
 - (b) Seated position: The two facial planes are identical in size and position to those mentioned above, except that the center of the planes is 1160 mm (45 in.) above the floor. The size of the third top-of-the-head plane is the same as above.
 3. *Special design considerations:* Lighting equipment at a mirror should direct light toward the person and not onto the mirror. The luminance of surfaces reflected in the mirror and seen adjacent to the face reflection should not be in distracting contrast with it.
 - (a) Adjacent walls should have a 50% or higher reflectance.
 - (b) Luminaires should be mounted outside the 60° visual cone with a centerline that coincides with the line of sight.
 - (c) No luminaire should exceed 2100 cd/m² in luminance, that is, an illuminance meter held against it should not read more than 6500 lx (600 fc).
 4. *Typical equipment locations:*
 - (a) Wall-mounted linear or nonlinear luminaires over the mirror
 - (b) Wall-mounted linear or nonlinear luminaires over and at the sides of the mirror
 - (c) Combination of wall- and ceiling-mounted luminaires flanking the mirror and over the head of the user
 - (d) Structural devices (such as soffits) extending the length of the mirror
 - (e) Portable luminaires with luminous shades flanking the mirror
 - (f) Pendant luminaires with luminous sides flanking the mirror
- Note:* If grooming is performed in a seated position, the relationship of the luminaires to the face should remain as specified above for standing.

**Figure 18-8.** Full-length mirror

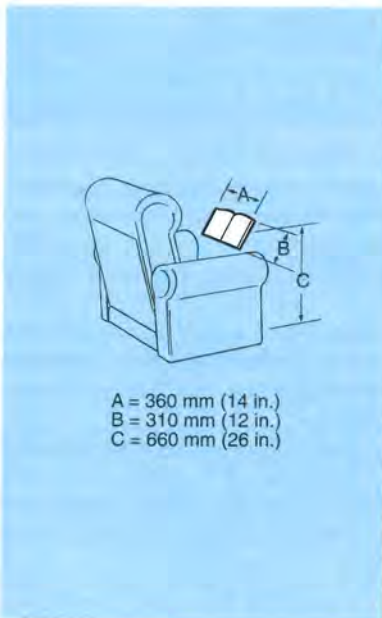
1. *The task:* The task is the alignment of clothing, commonly with reflectance between 30 and 70%, and casual overall appraisal. Speed and accuracy may or may not be important.
2. *Description of the task plane:* The task area is a plane 510 mm (20 in.) wide by 1370 mm (54 in.) high with the lower edge 310 mm (12 in.) above the floor. It is centered on and parallel with the mirror, 760 mm (30 in.) from the mirror surface.
3. *Special design considerations:* Lighting equipment at the mirror should direct light toward the person and not onto the mirror. The luminance of surfaces reflected in the mirror and seen adjacent to the face reflection should not be distracting.
 - (a) Luminaires should be mounted outside the 60° visual cone with a centerline that coincides with the line of sight.
 - (b) No luminaire should exceed 2100 cd/m² in luminance, that is, an illuminance meter in contact with the surface should not read more than 6500 lx (600 fc).
4. *Typical equipment locations:*
 - (a) Vertical linear luminaires wall mounted beside the mirror
 - (b) Vertical linear luminaires supplemented by wall-mounted or ceiling-mounted over-mirror luminaires

**Figure 18-9.** Home Electronic Office

1. *The task:* The task is reading the computer terminal screen, the keys and templates on the keyboard, and information written or printed on paper. In addition, printer and fax machine status settings must be read. Speed and accuracy may not be important for casual operation, but they may be important when doing work at home. Reflectances of equipment surfaces (other than the screen) are between 30 and 70%.
2. *Description of the task plane:* The terminal screen usually is in a vertical to near-vertical plane, while the keyboard is on a near-horizontal plane. The paper-based tasks can be on any plane from horizontal to vertical. Printer and fax status settings are usually in a near-horizontal plane.
3. *Special design considerations:* Luminance ratios between the terminal screen, the paper-based tasks, and the equipment and surface in the surround should be limited (see Chapter 11, Office Lighting). Luminaire, ceiling, and window brightness should be controlled to avoid reflections on the screen and specular surfaces of equipment.
4. *Typical equipment locations:*
 - (a) Desk-mounted or floor-mounted task lights for paper and keyboard tasks
 - (b) Wall-mounted direct/indirect luminaires at the front or side of the desk for ambient and task lighting
 - (c) Ceiling-mounted low-brightness luminaires

**Figure 18-10. Reading in bed**

1. *The task:* The majority of people who read in bed are only casual readers, perhaps reading for a few minutes before going to sleep. They are often interested in closely confining the light distribution so as not to disturb another occupant of the room. Such lighting arrangements are not satisfactory for comfortable reading over a long period. The following recommendations are for the person who reads for a more extended period, or for the person who performs critical seeing tasks while confined to bed. The normal materials vary from books and magazines to pocket editions and to newspaper print, with reflectances of 30 to 70%. Speed and accuracy vary from not important (for leisure reading) to important to critical (for critical tasks).
2. *Description of the task plane:* The task plane is 310 by 360 mm (12 by 14 in.), tilted at an angle of 45° from the vertical. The center of the task plane is 610 mm (24 in.) out from the headboard or wall and 310 mm (12 in.) above the mattress top. There are no customary reading positions or habits. These recommendations assume that the reader is in an upright or semireclined position.
3. *Special design considerations:* Equipment should be located so that no shadows are cast on the reading plane by the head or body, and so that the luminaire does not interfere with a comfortable position.
4. *Typical equipment locations:*
 - (a) Wall-mounted directly in back of or to one side of the user (both linear and nonlinear designs)
 - (b) Luminaire on bedside table or storage headboard
 - (c) Ceiling-mounted: (1) suspended, adjustable, or stationary; (2) surface-mounted, directional, or nondirectional; (3) recessed, directional, or nondirectional
 - (d) Luminaire incorporated into furniture design
 - (e) Track-mounted luminaires: Several types of lighting should be provided in the bedroom to accommodate different functions and moods—relaxing, romantic, and adequate for reading.

**Figure 18-11. Reading in a chair**

1. *The task:* Typical reading tasks encompass a wide range of seeing difficulty, from short-time casual reading of material with good visibility (large print on white paper) to prolonged reading of poor material (small type on low-contrast paper). The majority of tasks have reflectances between 30 and 70% or higher. Speed and accuracy may not be important for casual reading and may or may not be important for prolonged reading.
2. *Description of the task plane:* The task plane measures 360 mm (14 in.) wide by 310 mm (12 in.) high with the center of the plane approximately 660 mm (26 in.) above the floor. The plane is tilted at 45° from the vertical. The reader's eyes are approximately 1 m (40 in.) above the floor.
3. *Special design considerations:* The normal seated eye level is 0.97 to 1.07 m (38 to 42 in.) above the floor and is a critical consideration when the light source is to be positioned beside the user. The lower edge of the shielding device should not be materially above or below eye height. This prevents discomfort from bright sources in the periphery of the visual field, yet permits adequate distribution of light over the task area. Variations in chair and table heights necessitate selection and placement of equipment to achieve this relationship for each individual case.
4. *Typical equipment locations:*
 - (a) Table-mounted, floor-mounted, and wall-mounted beside or behind the user
 - (b) Ceiling-mounted, suspended beside or behind the user
 - (c) Directional small-area luminaires may be used (wall-, ceiling-, pole-mounted)
 - (d) Recessed downlight, placed over center of seat cushion (with a sofa, use an adequate number of luminaires to evenly distribute light over the cushions)
 - (e) Track-mounted luminaires for flexibility

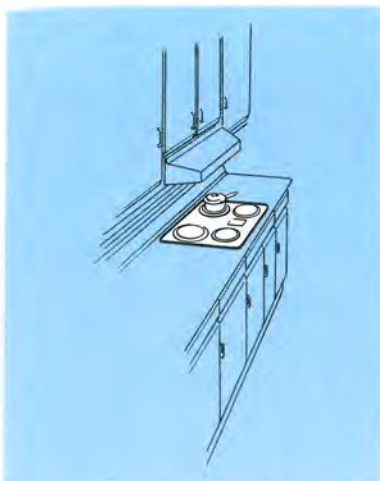


Figure 18-12. Kitchen range or cooktop

1. *The task:* Typical seeing tasks at the kitchen range or cooktop are the determination of the condition of foods in all stages of the cooking process (color and texture evaluation) and reading controls, instructions, and recipes. Food often has a reflectance of less than 30%. Speed and accuracy can be critical for some difficult preparation tasks.
2. *Description of the task plane:* The task area is a range top. Generally this is located 910 mm (36 in.) above the floor.
3. *Special design considerations:* Reflected glare is inherent in the shiny finish of utensils and range tops. Some reduction in the luminance of reflected images may be obtained by the use of diffuse luminaires or sources. Color rendering qualities of light sources are especially important in the kitchen. Controls, such as multiple-position switching and dimming equipment, can be utilized to lower the illuminance when there are no difficult seeing tasks.

Flexible general lighting should be provided for circulation and entertaining. Downlights properly spaced provide good overall illumination. Dimmers allow for adjustment to a range of light levels.

4. *Typical equipment locations:*
 - (a) Range hood
 - (b) Ceiling—recessed, surface-mounted, or suspended
 - (c) Structural—lighted soffits, wall brackets, or canopies
 - (d) Underside of wall cabinets

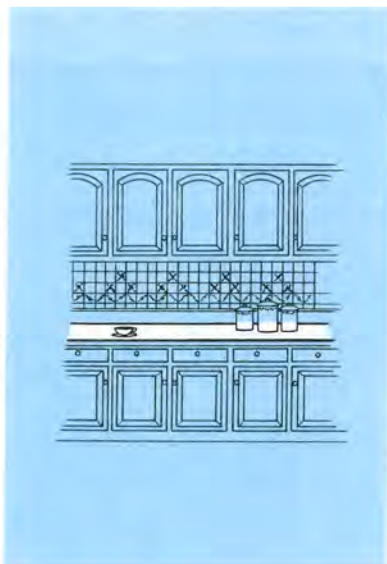
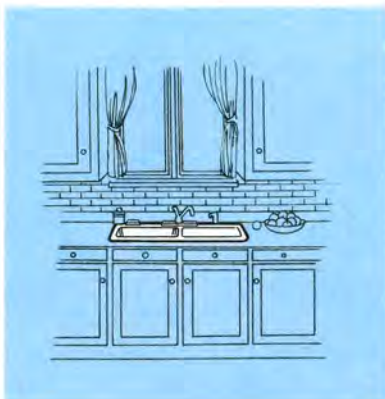


Figure 18-13. Kitchen counter

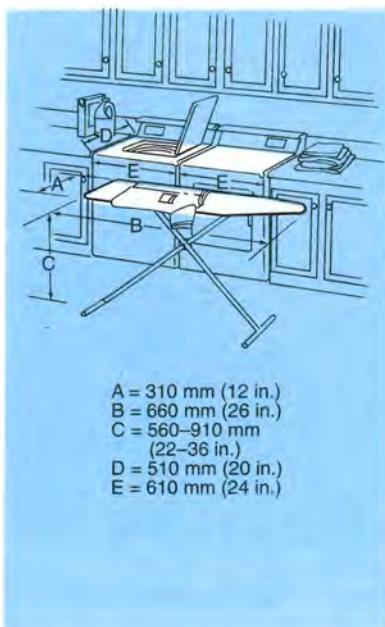
1. *The task:* Typical seeing tasks at the kitchen counter include reading fine print on packages and cookbooks, handwritten recipes in pencil and ink, and numbers for speeds and temperatures on small appliances. Other tasks include measuring and mixing, color and texture evaluation of foods, safe operation of small appliances, and cleanup. Task reflectances are usually less than 70% and often below 30%. Speed and accuracy may not be important for noncritical tasks, but they are critical for the difficult preparation and cleaning tasks.
2. *Description of the task plane:* The task area is a plane 510 mm (20 in.) deep (starting at the front edge of the counter) and as long as the counter.
3. *Special design considerations:* There are many ways to light counter surfaces, however, luminaires are commonly mounted under the wall cabinets, above the counter. These should be well shielded because of the cabinet structure itself, but if not, shielding should be added. Also, care should be exercised to see that the luminance of the luminaires is comfortable to other users of the room, particularly in seated positions. Controls, such as multiple-position switching and dimming equipment, can be utilized to lower the illuminance when there are no difficult seeing tasks.

Special attention should be paid to task lighting. Make sure surfaces are evenly and properly illuminated with glare-free light to avoid shadows. Luminaires should be placed 25 mm to 50 mm (1 to 2 in.) from the front of the upper edge of cabinets to properly illuminate counter surface.

4. *Typical equipment locations:*
 - (a) Underside of wall cabinets
 - (b) Ceiling—recessed, surface-mounted, or pendant
 - (c) Structural—lighted soffits or wall brackets
 - (d) Architectural lighting—above suspended cabinets to reflect off ceiling surface

**Figure 18-14. Kitchen sink**

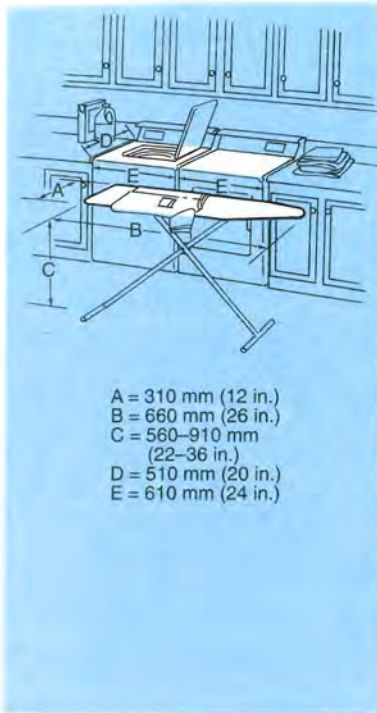
1. *The task:* Typical seeing tasks at the kitchen sink involve cleaning and inspection of dishes and utensils, evaluation of color and texture of foods in preparation, reading, and measuring. Task reflectances and speed and accuracy needs are similar to those at the counters.
2. *Description of the task plane:* The task area is determined by sink dimensions. It is usually at a height of 910 mm (36 in.) above the floor.
3. *Special design considerations:* Color rendering qualities of the light source are particularly important in kitchen illumination. The limited space available for luminaire mounting at the sink location increases the possibility of shadows being cast on the workplane by the head or body of the user. Controls, such as multiple-position switching and dimming equipment, can be utilized to lower the illuminance when there are no difficult seeing tasks.
4. *Typical equipment locations:*
 - (a) Ceiling—recessed, surface-mounted, or pendant
 - (b) Structural—lighted soffits or wall brackets
 - (c) Underside of wall cabinets

**Figure 18-15a. Ironing**

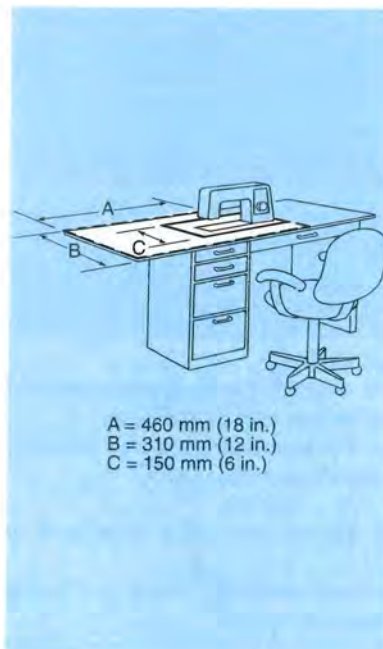
1. *The task:* The basic visual task in ironing is the detection and removal of wrinkles from garments and the detection of possible scorches. The majority of fabrics have a reflectance between 30 and 70%, but dark clothes have less than 30%. Speed and accuracy may be important.
2. *Description of the task plane:* The task plane is 310 by 660 mm (12 by 26 in.) and varies in its height, depending on the ironing board. In general, such boards are adjustable from 560 to 910 mm (22 to 36 in.) in height, for use either standing or sitting. The seat of the average stool is located 610 mm (24 in.) above the floor, which places the average seated person's eye level at 1350 mm (53 in.). In a standing position the eye level is 1550 mm (61 in.).
3. *Special design considerations:* A light source with a directional quality may frequently reveal shadows cast by small wrinkles or creases to the advantage of the user. Ironing and television viewing are often done at the same time. Under these circumstances it is important to ensure a good balance among the luminances of task, television screen, and other room surfaces in the line of sight.
4. *Typical equipment locations:*

Ceiling-mounted:

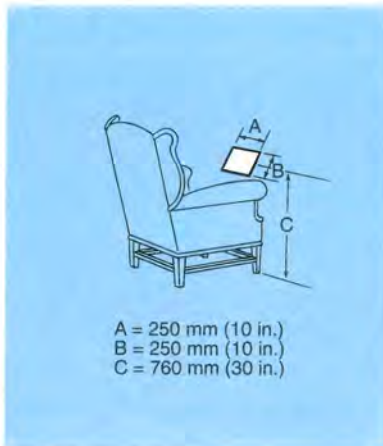
 - (a) Suspended, adjustable
 - (b) Fixed, directional
 - (c) Fixed, nondirectional
 - (d) Combination of luminaires (general diffusing plus directional component)

**Figure 18-15b. Laundry**

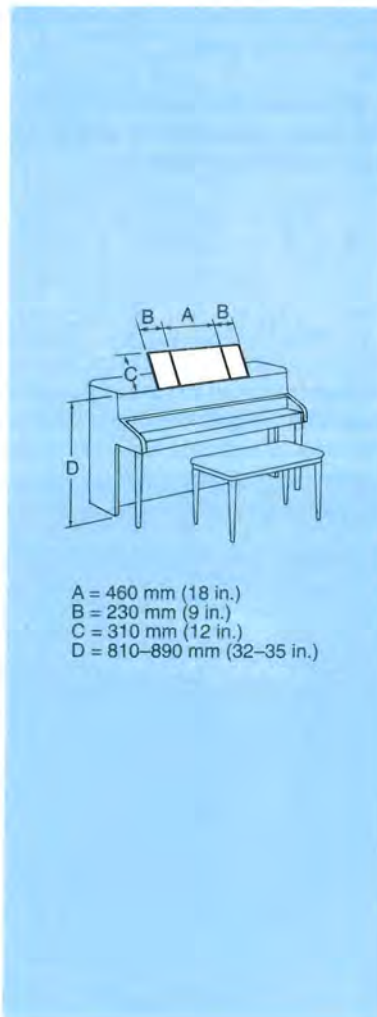
1. *The task:* In the preparation area, the tasks are sorting of fabrics by color and type, determination of location and type of soil, prewash treatment, tinting, bleaching, and starching. In the tub area, the tasks are soaking, hand washing, tinting, rinsing, bleaching, and starching. In the washer and dryer area, the tasks are loading, setting of dials and controls, and removal of clothes. Speed and accuracy may be important in the preparation and tub areas, but not important at the washer and dryer. Reflectances of fabrics and packaging vary widely but most are within 30 to 70%.
2. *Description of the task planes:* In the preparation area, the general task area is 510 by 610 mm (20 by 24 in.) with a critical seeing area 310 by 310 mm (12 by 12 in.). In the tub area, the task area is 510 by 610 mm (20 by 24 in.) on a single laundry tub, with a critical seeing area 310 by 310 mm (12 by 12 in.) in the middle. The washing machine and dryer area has no definable boundaries and can be illuminated by the general room lighting.
3. *Special design considerations:* Totally direct and not highly diffused light sources can contribute to the visibility of certain laundry tasks. In most laundry locations, task lighting equipment also must provide the general room illumination. Luminaires should in this case be selected and positioned to illuminate the ceiling and side walls for comfortable luminance relationships.
4. *Typical equipment locations:*
 - (a) Ceiling-mounted (suspended, surface, or recessed) linear or nonlinear luminaires centered over the front edge of the laundry equipment. As above, supplemented by wall-mounted or cabinet-mounted linear luminaires.
 - (b) Large-area luminous panels

**Figure 18-16. Machine sewing**

1. *The task:* The small detail and low contrast between thread and material usually involved in machine sewing make it a visually difficult task. The degree of difficulty varies with thread and stitch size, reflectance of materials, and contrast between thread and fabric. Speed and accuracy may be critical.
2. *Description of the task plane:* The primary task area is a plane 150 mm (6 in.) square located so that the needle point is 50 mm (2 in.) forward from the center of the back edge. The secondary task area of less critical seeing measures 310 by 460 mm (12 by 18 in.) with the needle point centered on the shorter dimension and 150 mm (6 in.) in from the right-hand edge.
 Maximum illuminance on the primary task plane should not exceed the minimum by more than 3:1. The minimum illuminance level on the secondary task plane should not be less than one-third of the minimum on the primary task plane, and not less than 200 lx (20 fc).
3. *Special design considerations:* Equipment should be located so that shadows are not cast on the task area by the user's hand. The use of light with a moderate directional component increases the visibility of threads by casting a slight shadow to increase contrast.
4. *Typical equipment locations (other than the light built into the machine):*
 - (a) Wall-mounted directly in front of the user (both linear and nonlinear sources)
 - (b) Ceiling-mounted (location of luminaire and machine should avoid the possibility of the user's head blocking out light or casting a shadow on the task): (1) suspended, adjustable; (2) fixed, directional (surface or recessed), or track-mounted; (3) fixed, nondirectional; (4) luminous area
 - (c) Floor-mounted or pole-mounted

**Figure 18-17. Hand sewing**

1. *The task:* The seeing task encompasses a wide range of difficulty using coarse to fine threads, light to very dark materials, and high contrast to virtually no contrast at all. Speed and accuracy may be important.
2. *Description of the task plane:* The task area is a plane 250 mm (10 in.) square tilted at 45° toward the eye. The plane is centered at 760 mm (30 in.) from the floor. The eye position is approximately 1000 mm (42 in.) from the floor. Maximum illuminance on the task plane should not exceed the minimum by more than 3:1.
3. *Special design considerations:* Equipment should be located opposite the hand being used, so that shadows are not cast on the task area.
4. *Typical equipment locations:*
 - (a) Floor-mounted or pole-mounted
 - (b) Ceiling-mounted: (1) suspended, adjustable; (2) fixed, directional (surface or recessed); (3) fixed, luminous area; (4) combination luminaire (general diffusing plus directional component)
 - (c) Wall-mounted (both linear and nonlinear) sources located beside or behind the user

**Figure 18-18. Music study at piano or organ**

1. *The task:* The task is the reading of musical scores, usually 30 to 70% reflectance or higher, ranging from very simple ones with large notes and staff lines to very difficult substandard-size scores with notations printed on the lines. Speed and accuracy may not be important for very simple scores, but they are important for advanced music students and critical for professional musicians.
2. *Description of the task plane:* The primary task plane is on the music rack in an area 310 by 460 mm (12 by 18 in.); it is tilted back from the viewer about 17°. The lower edge is 810 to 890 mm (32 to 35 in.) from the floor. The secondary plane includes an additional 230 by 310 mm (9 by 12 in.) on each side of the primary plane. The piano keyboard, typically 1220 mm (48 in.) long and 710 mm (28 in.) above the floor, is also a secondary plane. Note that these dimensions vary greatly with electric organs and miniature pianos.
3. *Special design considerations:* The maximum task illuminance should not exceed the minimum by more than 3:1. The minimum on the secondary task plane should not be less than one-third the minimum on the primary task plane. The musical instrument is in the best position for control of luminance values if the player faces a wall.
4. *Typical equipment locations:*
 - (a) Ceiling-mounted or recessed above ceiling:
 - (i) Directional source:
 - (i) Should be adjustable to strike the plane of the task at about 90°.
 - (ii) Should be located above the user's head to avoid a shadow of his or her body.
 - (iii) Should be located and shielded to prevent glare to other persons occupying or passing through the area.
 - (iv) Downlights are not desirable; their distribution is inadequate, and reflected glare and veiling reflections may be a problem.
 - (2) Large-area nondirectional source: The luminance should be within the comfort range and aesthetic considerations of the room.
 - (b) Mounted on the instrument:
 - (1) Uniformity of distribution over the task plane may be difficult to achieve.
 - (2) There should be no luminous part within the user's field of view having a luminance of more than 170 cd/m² (16 cd/ft²).
 - (c) Pole-type luminaires: Because of the directional quality of this type of light source, it is possible to get acceptable illuminance on the task as well as general surround light. Care should be exercised to avoid glare to other occupants in the room as well as veiling reflections on the task area.

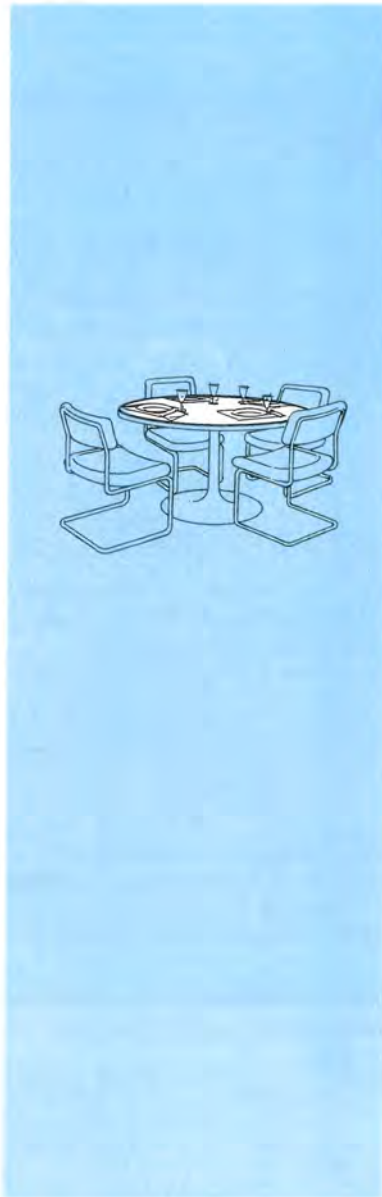


Figure 18-19. Dining area

1. *The task:* The main consideration is to enhance the color and texture of the food while creating a festive mood and providing adequate light levels.
2. *Description of the task plane:* The entire table top should be considered as the task plane. If carving and serving are done at a separate location, this becomes another task area and can generally be equated with the task plane for a kitchen counter.
3. *Controls:* Controls, such as multiposition switching and dimming equipment, can often add to the enjoyment of dining-area lighting by adapting the level of illuminance to the particular occasion. Room surface reflectances influence the selection of the level.
4. *Special design considerations:* Lighting with a strong downward component accents the table setting, creating attractive focal highlights; however, this type of distribution, if used alone, renders faces poorly, causing harsh shadows. Strong downward lights should be kept away from people's faces (that is, confined within the perimeter of the table itself) or should be well balanced by indirect light from table top, walls, or ceiling. The nature of the table top may also influence the choice of lighting distribution: downlighting may cause annoying specular reflections from glossy table tops such as glass or marble; if all the light is directed on the table, a colored tablecloth may appreciably tint the light by reflection. Exposed sources such as unshielded low-wattage bulbs can often be tolerated, especially if some general lighting is provided and the background is not too dark. The darker the walls, the more general lighting is required to keep luminance relationships in the room within a comfortable range. In situations where the dining table is moved from time to time, a flexible means of mounting a pendant luminaire is desirable.
5. *Typical equipment location:*
 - (a) Task area—center-of-table luminaires:
 - (1) Recessed (a group of recessed units is generally required)
 - (2) Surface-mounted
 - (3) Suspended, generally mounted so that the bottom of the luminaire is 690 to 910 mm (27 to 36 in.) above the table top
 - (b) Area surrounding the task:
 - (1) Luminous ceiling or large luminous area
 - (2) Luminous wall
 - (3) Cornice
 - (4) Valance
 - (5) Cove
 - (6) Brackets, for example, linear fluorescent or decorative incandescent
 - (7) Recessed luminaires, for example, incandescent downlights or wall washers
 - (8) Ceiling-mounted luminaires, for example, shallow large-area types
 - (9) Suspended luminaires, for example, small pendants
 - (10) Table lamp
 - (11) Floor lamp or torchiere

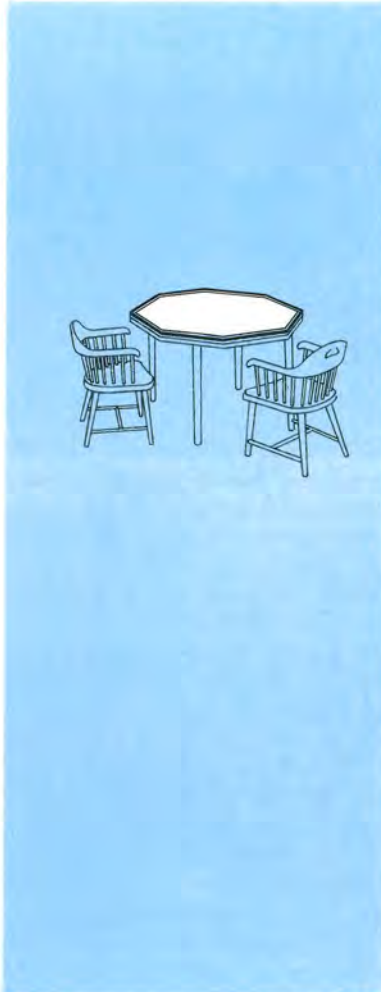


Figure 18-20. Multipurpose table

1. *The task:* The task includes both the creation of the desired mood or atmosphere for dining (Figure 18-19) and provision for other general visual tasks such as sewing, reading, hobbies, and table games. Task reflectances are generally 30 to 70%, and speed and accuracy can be important, particularly when sewing.
2. *Description of the task plane:* The entire table top must be considered as the task plane.
3. *Special design considerations:*
 - (a) A broad distribution pattern of light is required to illuminate the entire table top uniformly. To minimize veiling reflections, the light sources should have a high degree of diffusion or have substantial direct components.
 - (b) It is difficult for a single static light source to provide drama and atmosphere for dining while also providing widespread, diffused lighting (at a higher level) for other table activities; therefore, a multipurpose table usually requires more than one lighting system or a means of switching from one effect to another.
4. *Typical equipment locations:*
 - (a) Task area—center-of-table luminaires:
 - (1) Recessed (a group of recessed units is generally required)
 - (2) Surface-mounted
 - (3) Suspended—generally mounted so that the bottom of the luminaire is 690 to 910 mm (27 to 36 in.) above the table top
 - (4) Track-mounted luminaires
 - (b) Area surrounding the task:
 - (1) Large luminous area
 - (2) Luminous wall
 - (3) Cornice
 - (4) Valance
 - (5) Cove
 - (6) Brackets, for example, fluorescent or decorative incandescent
 - (7) Recessed luminaires, for example, incandescent downlights or wall washers
 - (8) Ceiling luminaires, for example, shallow large-area types
 - (9) Track-mounted luminaires
 - (10) Pendant luminaires, for example, small pendants
 - (11) Table lamp and floor lamp or torchiere
 - (12) Chandelier with or without downlight

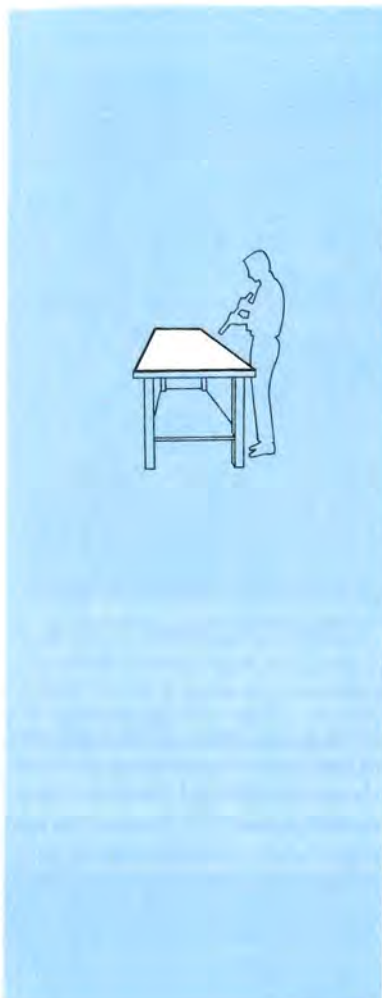
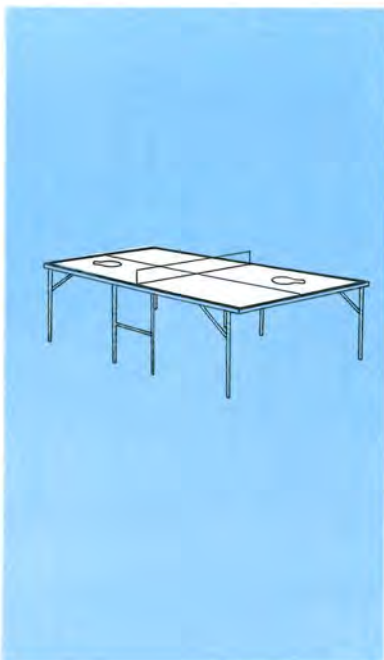
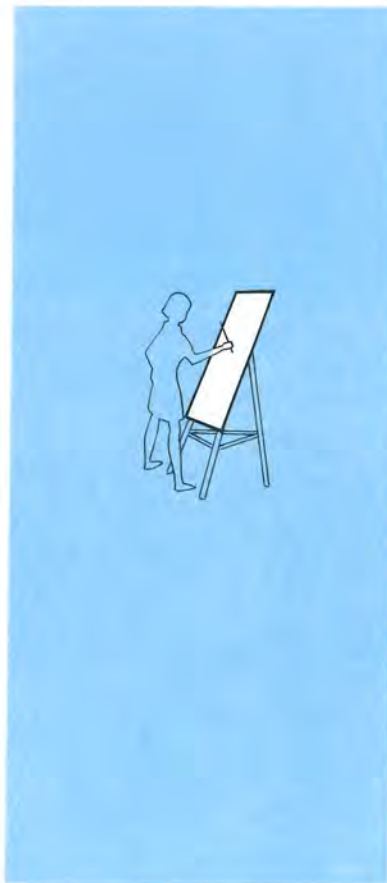


Figure 18-21. Workbench hobbies

1. *The task:* Activities carried on at the workbench include woodworking (sawing, hammering, vise operation, planing, assembling parts, and drilling) and craft hobbies. The majority of task reflectances may be below 30%, and speed and accuracy can be critical for power-tool operation. Hobbies vary greatly in visual difficulty and often require additional illumination and consideration of directional quality. Leather work, ceramic enameling, pottery, mosaics, wood carving, block cutting (linoleum-wood), model assembly, electrical and electronic assembly, and fly tying are considered to be difficult tasks. Metal engraving, embossing, lapidary work (gem polishing), and jewelry making are considered to be critical tasks. Among these, block cutting and jewelry making require large-area low-luminance reflections in order to see fine detail, which shows up as an interruption in a surface sheen. All of these tasks require a lot of light. In addition, good lighting is essential for safety. Care should be taken to avoid glare or shadows.
2. *Description of the task plane:* The task plane area is 510 mm (20 in.) wide, 1220 mm (48 in.) long, and 910 mm (36 in.) above the floor. (Home workbenches vary in length. The task plane extends the full length of the bench.)
3. *Special design considerations:*
Luminance balance within the visual field:
 - (a) The wall immediately behind the workbench should have a reflectance above 40%. The light reflected is necessary to provide illumination on the task plane as well as eye comfort from the standpoint of luminance differences.
 - (b) Additional room illumination should be provided to contribute to the luminance balance in the visual surroundings when the worker faces into the room.
 - (c) If the user is facing a window while working, then daylight should be controlled by blinds or shades, and light-colored window coverings should be used at night. The light source should be so positioned that its image reflected in glossy materials is not visible to the user in normal position, unless desired for some special application.
4. *Typical equipment locations:*
 - (a) Ceiling-mounted track or suspended linear luminaire running parallel with the task plane
 - (b) Ceiling-mounted or suspended nonlinear luminaires in a symmetrical arrangement over the work area to provide uniform distribution of light
 - (c) Wall- or shelf-mounted luminaire or luminaires with adequate shielding directly in front of the user
 - (d) Luminous ceiling area
 - (e) Portable equipment to provide added directional lighting for special conditions

**Figure 18-22. Table tennis**

1. *The task:* These lighting recommendations are for recreational play, where the speed of play is low to moderate and the player's skill is minimal.
2. *Description of the task plane:* In recreational play the task plane area is the 1.5 by 2.7 m (5 by 9 ft) table only.
3. *Special design considerations:* Although the general guides for luminance balance within the visual field still hold true in table tennis, the background surfaces seen by the player should not be too light, or they will not provide sufficient contrast with the white ball for good visibility. Wall and ceiling surfaces must not have strong, distracting patterns. Spottiness or uneven distribution of light can cause seeing difficulty. In table tennis, since the ceiling plane is the major part of the visual field, the luminance ratios at the ceiling become more important than usual.
4. *Typical equipment locations:*
 - (a) Ceiling-mounted linear sources with the centerlines of the luminaires crosswise over the table, located approximately 0.3 m (1 ft) in from each end, plus one or more in each runback area
 - (b) Ceiling-mounted linear sources positioned lengthwise above the table, centered over its outer edges and extending into the runback areas
 - (c) Ceiling-mounted nonlinear sources arranged in a symmetrical pattern over the entire task area
 - (d) Large-area luminaires of low luminance symmetrically located to cover the task area, and equipped with louvers or other material providing a minimum of 45° shielding

**Figure 18-23. Easel hobbies**

1. *The task:* Easel hobbies include painting, sketching, and collage. Unlike most tasks, which can be described in relatively exact terms, easel hobbies include widely diverse activities. In many cases the task reflectance can be less than 30%, and speed and accuracy can be important. It is impossible to define a "standard painting." If it is assumed the artist wishes to see small applications of nearly identical colors, a standard task may be described as the application of a spot of color 6.4 mm (0.25 in.) in diameter on a background of the next nearest color in a scale comprising 1800 different colors (Munsell).
2. *Description of the task plane:* The task area is a surface up to 0.9 m (3 ft) square. The plane of the task is inclined from the vertical to suit the user and the task. The average eye height is 1220 mm (48 in.) sitting and 1580 mm (62 in.) standing. There is also a palette and often an object being copied. The locations of these are not fixed.
3. *Special design considerations:*
Luminance balance within the visual field:
 - (a) The reflectance of wall surfaces should be above 35%.
 - (b) Additional room illumination should be provided to contribute to the luminance balance in the visual surroundings when the painter looks away from his or her work.
 - (c) If the artist faces a window while working, the glare should be controlled by blinds or shades, and light-colored window coverings should be used.
 - (d) The light source should be so positioned that its image reflected in glossy materials is not visible to the artist in normal working position, unless specifically desired. For instance, a large low-luminance reflection may be required in order to see fine detail in a glossy paint surface; the detail shows up as an interruption on a surface sheen. A general recommendation is to paint under the light source by which the painting will ultimately be seen.
4. *Typical equipment locations:*
 - (a) Ceiling-mounted track or suspended linear luminaires running parallel with the task plane
 - (b) Ceiling-mounted or suspended nonlinear luminaires in a line to provide uniform distribution of light
 - (c) Portable equipment to provide added lighting for fine detail



Figure 18-24. This living room features a 25-ft wooden ceiling to which 4-circuit track is mounted on both sides of the beam. All the track heads are positioned at less than a 25-degree aiming angle. The lighting contributes to the feeling of calm, spaciousness, and relaxation.



Figure 18-26. Playing light against darkness can create a striking visual effect.



Figure 18-25. Wall washing adds drama to this elegant foyer.

(Figure 18-27). The effect that a luminous piece of art has on the space must be evaluated by the same criteria as other lighting effects, including luminous contrast, glare, and day and nighttime impact.

Design Effects

The visual effects that can be created with lighting are almost limitless. Some of these possibilities are organized for easy reference in Chapter 10, *Quality of the Visual Environment*.

LIGHT SOURCES FOR INTERIOR SPACES

The most common electric light sources used in residential interiors are incandescent, tungsten-halogen, linear fluorescent, and compact fluorescent lamps. Tungsten-halogen sources provide whiter light, longer life, and higher efficacy than standard incandescent lamps. Incandescent and tungsten-halogen lamps are available for line voltage as well as low voltage, and are used extensively in portable luminaires, recessed downlights, track lights, wall sconces, and chandeliers.

Fluorescent sources are appropriate for most rooms in a residential space. Even the slender T-5 and T-2 lamps are being used in residential lighting.

T-8 lamps are more energy efficient than T-12 lamps and



Figure 18-27. An example of light as an art medium.

provide very good color rendering properties. They are available in a variety of lengths and color temperatures. T-12 lamps are still available but are gradually being replaced by the more readily available and efficient T-8 products.

Compact fluorescent lamps offer good color rendering and an energy-efficient alternative to standard incandescent lamps. For best results, luminaires designed specifically for compact fluorescent lamps should be used.

When choosing luminaires for a room, the designer should select more than one light source (layering the light) to create interest and to define a particular object, wall, or painting. A variety of light sources allows the designer to create a mood, enhance a focal point, and create a warmer, friendlier place for living and entertaining.¹⁰ See Chapter 6, Light Sources, for further information on incandescent, tungsten-halogen, linear fluorescent, and compact fluorescent sources.

Retrofitting

Compact, self-ballasted screwbase fluorescent lamps are commonly used to replace standard incandescent A-type lamps. These lamps can reduce energy consumption. They may not fit in existing luminaires, and the light may not be distributed properly when using a luminaire intended for an incandescent source. Typical applications are downlighting, wall sconces, and portable luminaires. Compact fluorescent lamps often require a special harp or extender for portable

table or floor lamps. In downlighting luminaires and wall sconces, the dimension of the luminaire must also be checked to assure proper fit. The operating temperature may cause the lumen output to be lower than expected. The color appearance of compact fluorescent lamps differs slightly from incandescent sources. Fluorescent retrofit kits for downlights, available from luminaire manufacturers, include ballast, cone, lamp, and trim. Some “energy saver” incandescent lamps reduce the wattage while producing nearly the same light output as their equivalent incandescent lamps.

LUMINAIRES FOR INTERIOR SPACES

Luminaires for interior living spaces range from portable luminaires to custom-made architectural lighting. Luminaires are categorized by their different light distributions by CIE designation as to the type of luminaire used (direct, indirect, or general diffuse). The choice depends on structural conditions, aesthetics, and economics. To select lighting equipment wisely, the designer should interpret manufacturers’ literature, photometric data, and charts for estimating illuminance.

Several types of luminaires are used in residences. A discussion of their types and applications can be found in Chapter 7, Luminaires.

In typical residential applications, the average luminance of the luminaire that provides general illuminance to the space should not exceed 1700 cd/m², except in utility areas. For equipment used in utility spaces, luminances as high as 2700 cd/m² are acceptable. Within the diffusing element, the luminance of the brightest 645 mm² (1 in.²) area should not exceed twice the average luminance of the overall element. Luminance ratios between the luminaire and the ceiling should not exceed 20:1. Even with the best diffusing glass or plastic, spottiness occurs if the lamps are widely spaced or too close to the diffuser.

When selecting interior luminaires, the designer needs to consider appearance, efficiency, and the luminaire’s ability to properly distribute light. Color rendering ability, color temperature, energy use, detailing, durability, finish, cost, and ease of maintenance are important considerations when choosing light sources.

EXTERIOR LIGHTING

Exterior residential lighting includes functional and aesthetic lighting that can add charm, appeal, and value to a home. Light at the door, in the landscape areas, and for plantings, providing focal points for sculptures, water features, and specimen trees, as well as for steps and walks, can heighten the appearance of the residence and contribute to its safety (see Chapter 21, Exterior Lighting). Lighting front yards and structures should be given as much attention as the backyard and family activity areas.

Purpose

Residential landscape lighting serves several purposes. It provides safety, security, and aesthetics for both the family and guests. Each of these three issues addresses specific needs, and all can be integrated into a cohesive, pleasing lighting composition. Safety lighting addresses the visibility of potential obstacles in the landscape such as the edges of pools, changes in elevation such as stairs and terraces, and other objects, whether permanent features of the landscape or household items left outside (Figure 18-28). Security lighting allows people to feel comfortable. The main purposes of night lighting are aesthetic, to accentuate the features of the landscape and to expand the hours of enjoyment of residential property. A lighting composition integrating safety, security, and aesthetics allows the option of having several lighting schemes within the overall composition through the inclusion of multiple control options.

Exterior lighting addresses specific needs and uses, including welcoming people to a residence with walkway and entry lighting, providing views from the interior to the exterior (and vice versa), and allowing nighttime activities. The overall effect may be subdued, stimulating, or dramatic, depending on the design and application of light.

Guiding Principles

Lighting ideas develop from an evaluation of the daytime landscape composition and the elements within the landscape. Nonuniform lighting provides the most interesting visual composition. The designer needs to assess the visual importance of all the elements and assign a nighttime role to



Figure 18-28. Swimming pool lighting must illuminate potential obstacles such as the edge of the pool, stairs, and landscape features such as fountains and brick terracing.

each element in the composition. This process establishes a hierarchy of luminance values to create order and cohesion in the nighttime scene.

Concept development must consider the following:

- The users' preferences and feelings about light
- The atmosphere they would like to create in the landscape
- The uses they intend for the space
- The condition of their eyes

While visual task needs such as food preparation, dining, and sports need to be considered, the view through windows, in many cases, has greater significance.

In many locations, landscape areas cannot be used during much of the year due to weather restrictions (snow, low temperatures, wind, and rain). However, a view of the landscape can be retained at night by balancing luminances on both sides of the windows to eliminate reflections that make them appear as black mirrors. Landscape lighting can serve as an extension of the interior lighting, expanding the apparent visual size of the interior space. To achieve this, luminances need to be balanced according to the direction of view. In most cases, the primary view is from interior to exterior, requiring the landscape lighting levels to match or exceed those of the interior. When the primary view is from the landscape into the interior, the interior lighting levels need to be higher. When the two directions of view are equally important, the lighting levels on the two sides of the window need to be nearly equal.

To create the desired composition, the designer must know the layout of pavement, plant materials, and features in the landscape. Knowing the reflectances of all elements in the landscape to be lighted is important. The lighting effects evolve from the reflection of light off the elements in the landscape. The importance of an object in the landscape depends on the contrast of brightness between it and the other elements in the composition. Contrast is the most important element in landscape lighting, because it directs where and how people see the features of the landscape.

Elements that serve as primary focal points can be as much as ten times brighter than the general grounds, and three to five times brighter than secondary focal points. To achieve these ratios, higher illuminance may be required on background elements that have lower reflectances than focal points. Providing fill lighting between focal points is critical to creating cohesion. The actual level of light required depends on the ambient level of the surroundings. Residential neighborhoods in downtown sections of cities tend to have higher street lighting levels than suburban and rural areas. In these areas, the exterior lighting levels can be higher without creating visual disturbance in the neighborhood.

Locating and aiming the lighting equipment should be done in such a way as to avoid creating glare in the landscape area or in surrounding properties. Generally, luminaires should not be aimed more than 35° off axis. This ap-

plies to both uplight luminaires and downlight luminaires. Further, shielding of the light source should be provided by recessing the lamp into the luminaire housing and using a glare shield.

Techniques

Consider the texture, form, line, reflectance, and relationship to the background of all objects to be lighted in the landscape. Head-on floodlighting tends to make objects appear flat; modeling is obtained by lighting from one or more sides with either equal or unequal illuminance levels. Light striking a surface at a near-grazing angle emphasizes texture. Lighting a surface behind the object accentuates form. The last technique works best when objects have strong shapes and the detail and color are not important.

Walkways. Providing a clear view of walkways constitutes an important aspect of all landscape lighting. Walkway lighting works best when the lighting is as even as possible. For example, luminaires should be placed on one side of the walk, rather than alternating sides along its length.

One option for path lighting is the use of decorative path lights. In selecting luminaires use caution to shield direct view of and brightness from the light source. Luminaires with optical systems that direct light to the path provide good task lighting and do not create distracting brightness or glare in the overall lighting composition. Adjustable accent luminaires either in trees or on a structure such as a roof overhang, a side of a wall, or a trellis to downlight a path can accentuate the landscape and light the path at the same time (Figure 18-29). This technique provides visual interest and increases psychological comfort by identifying the boundaries of the walk.

Entrances. Light is needed at doorways to help guests identify the entrance, for safety of passage, and for identifying callers. Lighting the doorway surface provides a visual destination for guests and lights their faces for identification. The designer should also be aware of the attraction of some insect species to certain light sources (see Chapter 5, *Nonvisual Effects of Optical Radiation*).

The foyer is where your first impression is created and where important transitions take place between public and private areas of the home and between the outdoors and indoors. The lighting in this area is important because one must be able to comfortably adapt from one environment to another. This area should maintain a fairly high light level for safety as well as for grooming purposes. Downlights are appropriate for overall ambient lighting and for lighting stairs. Wall sconces or portable table-top luminaires, placed on the sides of a mirror, add a decorative touch and are suitable for checking one's appearance.

Steps and Staircases. To provide for safe movement in a landscape, all changes in elevation must be lighted. The light on stairs must differentiate between risers and treads.



Figure 18-29. Low-voltage luminaires, mounted on stakes, uplight the structure (trellis) and the roses. MR-16 lamps are used as the light source.

As with pathway lighting, even illumination along the length of the staircase provides the most comfortable effect. Lighting the entire width of the staircase is typically less important; however, it becomes more important as traffic frequency and the occurrence of two-way traffic on the staircase increases.

Buildings and Structures. The residence and any auxiliary structures serve as part of the daytime view of the property and should remain as part of the nighttime composition. The importance of the structure needs to be considered along with the other elements in the composition. Often just a shadow pattern on the wall from an uplighted tree may be enough. In other cases, the architectural shape requires or deserves enhancement. The lighting on buildings should be planned to enhance their appearance. Typically nonuniform lighting enhances the appearance of the building.

Plant Materials. The lighting of plant materials requires more attention than other elements in the landscape. The designer should strive to understand the characteristics of all plants to be used in the landscape, even those that are not lighted. Evaluating the planting plan identifies plants that should be lighted and potential conflicts between plant locations and luminaire locations.¹¹ The characteristics important to consider include: overall shape and size; growth rate; mature height and width; trunk and branching structure; leaf characteristics, including shape, size, density, translucence, and color; flowering characteristics; and dormancy. These

issues affect which plants to light, where to locate luminaires, what type of light source to use, and how to light specific plants (Figure 18-30).¹¹

Plants are alive and continually change over time. Lighting plants requires careful planning and flexibility so that changes can be made in the luminaire aiming angle or location, the lamp beam spread or wattage, and the number of luminaires.

The physical characteristics of plants affect the types of lighting. For example, dense evergreen trees or those that produce branches close to the ground, such as junipers, must be lighted with luminaires located away from the tree and aimed towards it. Birches, maples, and other deciduous trees with an open trunk form or translucent leaves glow when lighted from inside the tree canopy. The trunk should have some light on it to tie the tree visually to the ground.

When the tree serves as a focal point, the designer must consider the overall appearance of the lighting on it. To make it appear natural, luminaires must be placed around the canopy to show the overall shape and provide depth. When the tree is seen from limited viewing angles, lighting only one side may be appropriate.

Sculptures. When lighting a sculpture, the designer should consider its size, its physical characteristics, and any special features that might be accentuated (Figure 18-31).¹¹ When the sculpture represents a life form, such as a human or animal, the sculpture should not be uplighted or downlighted

from a grazing angle. This creates unnatural shadows that detract from the appearance. Luminaires should be positioned far enough away from the sculpture to avoid creating exaggerated shadows. Life forms should be lighted from one or more sides, as with theatrical lighting. One-side lighting can enhance movement. Lighting from two sides provides the most natural appearance. See the remarks on three-dimensional objects and outdoor sculpture lighting in the section on Museums in Chapter 14, Lighting for Public Places and Institutions, and in Chapter 21, Exterior Lighting, respectively.

Water Features. Lighting of water features such as fountains, pools, waterfalls, and ponds differs from other landscape lighting in that the luminaires used must be rated for submersible use. Lighting water features also requires a greater maintenance commitment than other kinds of landscape lighting. A burned-out lamp can ruin the entire effect. As with any element, the importance of the water feature must be evaluated. Often, water features represent the primary focal point and need to have the highest luminance.

Some physical characteristics of light must be understood in order to provide effective lighting of water features. As light moves from water into air, the angle at which it is traveling changes. This change affects the placement of luminaires for illuminating objects outside the water such as sculptures or plant materials. Light also loses intensity by approximately 10% for every 5 cm (2 in.) of water it travels through.



Figure 18-30. Comparison of landscape lighting, same site, for summer and winter. The native willow tree was illuminated with just one eave-mounted luminaire housing a 50-W MR-16 lamp. The difference in depth is due to seasonal conditions and leaf life cycle.



Figure 18-31. The view at the end of a residential hallway, which features the fountain, the sculpture, and the plant material (papyrus). The lighting was accomplished with two surface-mounted underwater luminaires that employ 116-W long-life incandescent A lamps.

To make a fall of water visible, the characteristics of the water must be understood. Water falling over a rough surface has air bubbles in it. The bubbles catch light and make the water glow. Therefore, the luminaire needs to be located directly beneath where the falling water hits the surface of the lower water body. When water falls over a smooth edge, there are no air bubbles in it. This application requires luminaire placement in front of the falling water and aimed at it so that light is reflected back.¹¹

Water features do not always have to be lighted from beneath the water surface. Downlighting from a tree or nearby structure can be very effective, especially if air bubbles are present. Typically, downlighting does not create as dramatic an effect, but it is less costly and maintenance is easier. Another approach is to use a remote-mounted light source with a collecting lens and fiber-optic cabling to deliver light into the water feature. The benefit of this system is simplified maintenance.

Lighting Equipment

Light Sources. The appropriate lamps to be used in landscape lighting depend on the size of the project, the scale of the feature elements to be lighted, and the desired effects. A white light source normally provides the best effects and creates a natural appearance. Which white light source to select depends on the color and reflectance characteristics of the objects to be lighted. For residential landscapes, standard or low-voltage halogen incandescent sources offer flexibility through a wide selection of low wattages, beam spreads, and dimming capabilities. Sometimes metal halide or mercury vapor sources would be appropriate. On properties with large-scale trees (i.e., tree canopies 30 to 40 ft across, or 40 ft off grade or higher) or on large properties where the goal is to light a group of trees from a distance, higher-wattage lamps might be beneficial and would possibly decrease the number of luminaires required to create the desired effect (Figure 18-32).



Figure 18-32. The front yard of this California residence features illumination of selected redwood trees, pruned up to 100 feet above the ground, to emphasize the detail and texture of the trunks and the spread of the canopy. The impressive, almost spiritual effect is achieved with 90-W quartz PAR-38 spotlights.

Luminaires. The selection of luminaires constitutes perhaps the most important decision in landscape lighting. The daytime appearance of luminaires needs to complement the landscape or disappear from view. All the equipment must be able to stand up to the weather conditions. Rain, snow, fog, temperature variation, and other outdoor conditions encourage corrosion. Lamps should be protected from weather, since even lamps rated as weatherproof may fail sooner if exposed to water.¹¹

The construction of luminaires needs to be evaluated. The outdoor environment can damage the appearance and structure of luminaires and cause them to stop functioning. Since the landscape is continually changing due to plant growth, luminaire maintenance and refocusing need to be simple. Lamp access should be easy, requiring no tools and little disturbance of other components.

CONTROLS

Controls should be installed to make a lighting system easy to operate and flexible. A control should be conveniently located at the entry point of every space (both indoors and outdoors) and, ideally, luminaires should be controlled separately or collectively to achieve a desired lighting effect. Well-designed and conveniently located controls save energy by allowing the user to operate only those luminaires necessary to produce the desired effect.

Controls can range from wall-box switches and dimmers, to programmable dimmers that control several scenes, to home automation systems that control other systems (i.e., heat/air, audio/visual) along with the lighting. See Chapter 27, Lighting Controls, for more information.

ENERGY CONSIDERATIONS

Lighting decisions should include energy considerations. The criteria and information in Chapter 26, Energy Management, can be used to develop the most energy-efficient solutions. In new construction, early planning enables the use of energy-efficient techniques. In existing structures, luminaires and light sources previously installed influence how energy efficiency can be achieved. The choices are retrofitting with more efficient sources, modifying the existing lighting systems, or replacing luminaires and controls. In addition, daylight can be used in interior spaces to reduce dependence on electric light whenever it is suitable to the task and to the space.

CODES AND STANDARDS

Several types of codes and approvals affect residential lighting design both indoors and out. They can be federal, state, or locally based. Check with local code enforcement agencies to determine which regulations apply to the area.

Most electrical codes merely set minimum requirements for electrical wiring methods, but others may dictate specific requirements for lighting systems (e.g., lighting systems used in kitchens and storage closets). Additional require-

ments relate to energy consumption, minimum amount of light, and lamp or luminaire efficiencies.

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Exterior Lighting

21

Lighting the outdoor environment is different from lighting an interior space. Outdoors, the universal standard is the daytime sun and sky. The night outdoor environment presents the following design challenges:

- Electric lighting cannot light the sky as the sun does; therefore, the nighttime ceiling is always dark, often resulting in greater object contrasts.
- No single fabricated light source is as powerful as the sun; numerous, smaller sources in close proximity to the objects and area being illuminated must be used.
- At low light levels the eye works differently from the way it works at high daylight light levels.
- People experience different emotions at night. Lighting can affect these emotions, not only when viewing dramatic scenery, sporting events, and outdoor entertainment, but it also affects feelings of personal safety and security such as in a parking lot.
- Outdoor lighting can be seen at great distances, and nighttime visual clutter can be distracting and disturbing.
- Nighttime tasks, such as playing sports or driving automobiles, have very specific lighting requirements so people can perform these tasks safely and effectively.
- There is an expectation (or need) to control the light added to the outdoor environment. Some people want the dark for sleeping, star-gazing, or privacy. This need for darkness comes in close proximity to other people's need for light, making the optical control of light critical.

This chapter provides guidance in dealing with the preceding design considerations, allowing electric lighting systems to solve multiple design objectives. See Chapter 22, Roadway Lighting, and Chapter 20, Sports and Recreational Area Lighting, and the appropriate IESNA Recommended Practices¹⁻⁵ for additional information about specific outdoor lighting applications.

VISUAL ISSUES

The design issues surrounding outdoor lighting are complex. Some of the technical factors that need to be considered when designing and evaluating an exterior lighting system

EXTERIOR LIGHTING DESIGN ISSUES

- Appearance of Space and Luminaires
- Direct Glare
- Illuminance (Vertical)
- Light Distribution on Surfaces
- Light Pollution/Trespass
- Modeling of Faces or Objects
- Point(s) of Interest
- Reflected Glare
- Source/Task/Eye Geometry

include glare, visibility, color, illuminance, luminance, and brightness.

Glare

Glare can be disabling, discomforting, or simply a nuisance (Figure 21-1).

Disability glare is caused by stray light scattered within the eye, which reduces the contrast of the retinal image. Streetlights, pedestrian lights, floodlights, and landscape lights, as well as bright reflectors contribute to disability glare.

Discomfort glare from a light source produces a sensation of discomfort. It is caused by high contrast or a non-uniform distribution of luminance in the field of view. Discomfort glare can be reduced by decreasing the luminance of the light source, by increasing the background luminance around the source, or by adjusting the aiming angle.

Nuisance or annoyance glare has not been quantified, though research is ongoing. Essentially, nuisance glare occurs when light appears where it does not belong. It may be defined as glare that causes complaints, such as the "light shining in my window" phenomenon.

The Operating State of the Visual System

In exterior environments, the human eye's processes of visual adaptation and recognition operate in three categories of vision: photopic, scotopic, and mesopic. These categories are defined with reference to the adaptive state of the rod



Figure 21-1. Wet roadway surfaces, reflecting light from streetlights and oncoming traffic, will produce glare that can make night time driving difficult and possibly treacherous.

and cone photoreceptors (see Chapter 3, Vision and Perception). Under photopic conditions, above approximately 30 lx, only the cones are active for visual perception. Under scotopic conditions, below approximately 0.01 lx, only rods are active. Scotopic conditions are generally irrelevant for photopic conditions. Under mesopic conditions, between photopic and scotopic conditions, both rods and cones operate.

It should be noted that the fovea contains only cones and therefore is photopic under any light level.⁶⁷ The majority of exterior lighting conditions are mesopic (see Chapter 3, Vision and Perception).

Illuminance

Illuminance (in lux or footcandles) is a measure of flux density incident on a surface. Too often illuminance is the only metric used to design and evaluate exterior environments. It is strongly recommended that all the factors described in Chapter 10, Quality of the Visual Environment, and in this chapter, be included in every exterior lighting design.

Luminance and Brightness

Often, the terms “brightness” and “luminance” are used interchangeably, but they have different meanings. The luminance of a source or surface is the intensity of the source or surface in the direction of an observer. Brightness is what an individual sees or perceives largely as a result of the luminance of the source or surface.

Source size, temporal frequency (flash or flicker), and spectral power distribution (color) also affect perceived brightness. Subjective brightness is affected by the environment in which the luminaire resides. As the background luminance of a scene increases, the subjective brightness of a luminaire decreases. Viewing car headlights during the daytime is a good example of a situation involving high lumi-

nance but low subjective brightness. Also, due to the subjective nature of a lighting scene, one person may feel a particular luminaire is bright while another person may not.

Surface luminance and source luminance are two important factors in the outdoor environment. Examples of lighted horizontal surfaces outdoors are roadways, bike paths, sidewalks, and parking lots. Lighted vertical surfaces include people’s faces and bodies, building facades, signs, structures, statues, and landscape features such as trees. Surface luminance adds interest and depth to an outdoor scene and can be necessary for good outdoor visibility and security (Figure 21-2). It is important to see the *effect* of lighting, not the source.

Luminaire luminance results from not only the lamp but also the luminaire’s reflector, refractor, lens, or louver. In order to minimize glare, luminaire luminance in the typical direction of view should be minimized. Typical viewing angles lie between 45° and 85°. Luminance data indicate the brightness of some outdoor luminaires. Luminances from bollards, landscape lights, and floodlights should be low to attract minimal attention.

Luminaires that produce high-angle light (at a vertical angle 80° above nadir) can improve visibility and elicit feelings of safety by delivering high vertical illuminances on people, buildings, and scenery. Higher-angle light can also yield a more economical installation with wider spacings and fewer poles. However, this approach contributes to glare, especially with low mounting heights and high lumen packages. Even so-called full cutoff luminaires can produce excessive luminances if poorly designed. At the same time, noncutoff luminaires can be comfortable to view. As designers specify cutoff, semicutoff, or noncutoff luminaires, attention should be paid to the luminaire’s luminance and potential for excessive brightness.

Luminance Ratios. Excessive luminance differences between surfaces or areas within the field of view can reduce



Figure 21-2. The lighting for this church uses varied surface brightness to add interest and depth.

the ability to see a task, create a safety hazard, cause an annoyance, or disrupt the theme of a community.

Consideration of safety, visibility, annoyance, and community appropriateness in exterior lighting designs suggests the importance of establishing luminance ratio criteria for the site being lighted or for the community. These ratios should set the maximum permissible luminance levels between the site being illuminated and neighboring sites from which that site might be viewed. As a general rule, the luminance ratios should not exceed 20:1. However, flexibility with this value should be used. A community may opt for lower or higher luminance ratios in order to preserve lower overall lighting levels. An urban community may opt to permit higher luminance ratios in order to provide flexibility in facade and advertising lighting.

As the scene's background luminance changes from light surroundings (urban scenes) to darker surroundings (suburban scenes) to the darkest surroundings (rural scenes), luminaire luminance is more and more important. The relationships between adjacent luminances in the field of view (luminance ratios) indicate how the visual system perceives luminaire brightness.

The interaction of all the variables discussed above leads to the final perception of brightness. Because of its subjective nature, brightness is difficult (if not impossible) to measure. A mock-up of the scene or examination of an existing site can be helpful in predicting the final impressions of the scene.

COMMUNITY-RESPONSIVE DESIGN

Traditionally, street lighting has been the basic component of public outdoor lighting. In urban settings, it is the street lighting, along with traffic signals and signs, that organizes and defines the visual environment at night. The quality of this visual information is critical for both traffic safety and a pedestrian's sense of security.

Public lighting systems can help define urban character and image. These lighting systems may illuminate for streets, roadways, sidewalks, pedestrian malls, pathways, bikeways, parks, monuments, buildings, structures, statues, fountains, and landscapes. A hierarchy of public lighting connotes the relative importance and character of cityscapes and enhances their information-giving value. The height and location of poles and the size and shape of equipment all contribute to the lighting hierarchy (Figure 21-3).

Special features and amenities of urban environments should be lighted to reveal their importance. Buildings and monuments can serve as markers or reference points to provide visual orientation. Urban landscape elements can also act as visual anchors and serve as points of arrival for neighborhood residents. Consistency and coordination applied to lighting special features strengthens a public lighting design and can improve the sense of community. Also, the streetscape or pedestrian spaces should appear consistent



Figure 21-3. The height and location of poles contributes to the hierarchy of exterior lighting equipment along this street.

with the community theme, both day and night so the lighting equipment should be integrated into the daytime scenes (Figures 21-4 and 21-5).

There are seven steps (see IESNA RP-33*) that comprise an effective community-responsive design process for implementing a public lighting system.

1. Determine community lighting goals. List and prioritize community goals such as aesthetics, community identity, safety, security, crime prevention, light pollution, light trespass, equipment location, equipment appearance, energy effectiveness, and economics.
2. Determine a community theme. Establish the style of lighting desired, such as historical, modern, active, or subdued. The theme should relate to the architectural style of the area.
3. Develop a family of luminaires. Select luminaires that complement the community theme. Establish pole styles and mounting heights. Develop a hierarchy of luminaires matching the application.
4. Consider how luminance ratios impact visibility. Luminance ratios should not exceed 20:1 between



Figure 21-4. Uncluttered and well-integrated luminaires with a streetscape.

primary focal point and general surround, but lower ratios can be established for adjacent areas (e.g., advertising signs and pedestrian malls) through the design process.

5. Determine how luminaire luminances affect perceptions of the environment. High luminances projected directly from luminaires and excessive luminance differences between surfaces and areas within the field of view can be distracting, uncomfortable, and even disabling.
6. Provide design guidelines. Design guidelines that establish the steps for planning public and private lighting (residential and commercial) for communities, owners, and developers. These guidelines should explain community themes and goals, including the family of luminaires or related families for different districts selected to provide visual consistency and set the standard for construction and glare control.



Figure 21-5. The same uncluttered lighting scene as that shown in Figure 21-4.

7. Educate developers of lighting ordinances. Consideration might be given to developing a lighting ordinance in areas where light trespass or light pollution are important to the community.

SAFETY AND SECURITY LIGHTING

Safety can be defined as freedom from danger, whereas security is freedom from worry. Security is often considered the psychological version of safety. Features of the environment that compromise safety can be identified and illuminated, but because security involves psychology as well as vision, it is a more difficult design criterion for exterior lighting. In general, comfortable, well-defined exterior environments with clear zones of recognition are perceived as secure. This design approach provides a feeling that there is enough response time to avoid or escape potential threats. People often associate higher illuminance or greater luminance with safer surrounds, but poorly directed light can reduce visibility and thereby reduce both safety and security (Figure 21-6). For additional information, see Chapter 29, Emergency, Safety, and Security Lighting.

Successful exterior lighting employs layers of light. Layered lighting provides minimal ambient illumination with accents on hazards, destinations, and architectural features. Sidewalks, trees, and building facades can be used as reference points and backdrops for such important features as crosswalks and intersections on roadways, or stairs and changes in elevation on pathways (Figure 21-7). Highlights can also be provided on gathering places and on interesting features such as bridges, statues, or plantings. Layered lighting defines the spatial characteristics of the environment and helps minimize dark areas that would otherwise serve as areas of concealment (Figure 21-8).

Streets, of course, are important features to be illuminated at night. They should be illuminated according to



Figure 21-6. Extreme glare will cause a loss of visibility.



Figure 21-7. Effective hazard lighting on stairs. This lighting is unidirectional, emphasizing stair treads.

IESNA recommendations.² Special consideration should be given to illuminating vertical surfaces where pedestrians and automobiles intermingle. The reflected light from vertical surfaces helps illuminate the pedestrians sharing the roadway with the automobiles. This same technique is useful in pedestrian parks and on pathways. Face recognition and identification is extremely important to a pedestrian's sense of security, and vertical illumination is essential to achieving this design objective.



Figure 21-8. Layered lighting emphasizing the stair hazard with silhouette outlining.

UNWANTED LIGHT AT NIGHT

Light Pollution

Dust, water vapor, and other particles reflect and scatter light that is emitted into the atmosphere. The result is the sky glow found over all urban areas, sometimes called atmospheric or astronomical light pollution (Figure 21-9). Although this sky glow is not injurious, it does deprive urban residents of the opportunity to stargaze and can hamper astronomers' attempts to view the night sky through telescopes.

Light pollution is of special concern in areas near astronomical observatories. Professional astronomers prefer that low-pressure sodium be used outdoors because most unwanted light, which is essentially monochromatic, can be removed by filtering the light that enters their instruments. The methods that best control light pollution are:

- Limit flux above horizontal. Street and area-lighting systems, including lighting for sports activities, parking lots, and vehicle sales lots, should be designed to minimize or eliminate direct upward flux emission. A full cutoff luminaire does not emit light above the horizontal plane.
- Minimize non-target illumination. Lighting systems that project light upward, such as architectural and sign lighting, should be designed to minimize light that does not illuminate the target area.
- Turn off outdoor lighting during times of low use. Designers should discuss with owners turning off some or all of the outdoor lighting, including advertising sign lighting, building elevation lighting, and interior high-rise office building lighting, after normal hours of operation or before midnight unless needed for safety and security.

Light Trespass

The topic of light trespass is somewhat subjective, because it often relates to unmeasurable and undefinable factors. A



Figure 21-9. A satellite view of North America at night illustrates the magnitude of direct and reflected light from urban areas.

typical example is the “light shining in my window” complaint (Figure 21-10). A simple solution to this problem is to shield the offending luminaire so that its luminance is not directed toward the complainant.

Light trespass usually falls into one of two categories: unwanted light received in adjacent properties (high illuminance levels), and excessive brightness occurring in the normal field of vision (nuisance glare). Efforts have been made in numerous jurisdictions to write ordinances or laws controlling light trespass. Laws defining vertical and horizontal illuminance address only the former problem. See RP-33⁸ for a more complete discussion of lighting ordinances.

The following suggestions help control light trespass problems, including nuisance glare:

- Inspect areas adjacent to the lighting design location to identify and consider any potential problems involving residences, roadways, and airports.
- Select luminaires that have tightly controlled intensity distributions, using full cutoff reflectors and refractors.
- Contain light within the design area by carefully selecting, locating, mounting, and aiming (when appropriate) the luminaires.
- Use well-shielded luminaires (or select equipment that can be shielded) if a potential problem is found after installation.
- Keep floodlight aiming angles low so that the entire beam always falls within the intended lighted area during (and after) the design and installation process.

See RP-33⁸ for a more complete discussion of light trespass.

LIGHT SOURCES AND BALLASTS

Light sources for illuminating outdoor environments should be selected according to their application. If color rendering



Figure 21-10. The wall-pack lighting causes light trespass into the building's windows.

is important, then a light source with a high color rendering index (CRI) and appropriate correlated color temperature (CCT) is important. See Chapter 6, Light Sources, for more information on light sources.

Lamps should be selected that have lumen maintenance and rated life commensurate with the lighting installation's mission, the degree of difficulty involved in relamping, and the lamp maintenance schedule. A high crime area, for example, should emphasize color rendering, lamp life, and lumen maintenance.

Proper ballast selection is crucial. Select and specify ballasts that match the lamp and make sure that the starting temperature of the ballast is at or below the coldest winter temperature for the site. See reference 9 for a comprehensive discussion of ballasts.

LUMINAIRE CLASSIFICATION

Outdoor luminaires are classified by the manner in which they are mounted, by the intensity distribution they exhibit, by the degree to which they provide cutoff, and, if floodlights, by their beam patterns. See also Chapter 7, Luminaires, for additional information.

Pole-Mounted Luminaires

Pole-mounted luminaires are commonly used for roadway and parking lot lighting. The IESNA outdoor roadway luminaire classifications by intensity distributions are Type I, II, III, IV, and V. Degrees of cutoff are full cutoff, semicutoff, and noncutoff. A description of these classifications can be found in Chapter 22, Roadway Lighting.

One of the most common luminaires used in roadway applications employs a dropped-dish (ovate) refractor. These luminaires typically produce wide light intensity distributions, which permit extended pole spacing. In most cases, average horizontal illuminance and uniform horizontal illuminance are among the most important design criteria. Therefore, the luminaire intensity distributions used exhibit maximum values at high angles above nadir (typically 65° to 70°).

These luminaires are mounted on brackets off a vertical support pole. Based on appearance, they are generically referred to as cobra-head luminaires. Poles for roadway lighting applications are usually mounted back from the roadside to minimize collision with traffic. As stated previously in the section “Luminance and Brightness,” care should be taken to prevent excessive brightness. Cutoff cobra-head luminaires with flat lenses that provide better optical control are an alternative.

Parking lot lighting often uses cutoff luminaires with either flat-bottomed or clear dropped lenses. A dropped lens generally yields a slightly more efficient optical system, but higher glare. These luminaires are mounted on short arms and can be arranged in single, twin, or quad configurations.

Symmetric and asymmetric distributions and mounting schemes are used to provide the necessary flexibility in pole placement for parking lots.

Small luminaires mounted on short poles can be used to provide walkway and grounds lighting. Sometimes referred to as post-top luminaires, they can satisfy both functional and aesthetic needs.

Surface-Mounted Luminaires

Wall-mounted luminaires are often used for small parking lots or walkways adjacent to a building or inside parking structures. These luminaires usually have an asymmetric distribution necessary for lighting adjacent areas.

Surface-mounted luminaires are mounted on walls or ceilings of parking structures, and their lighting performance is enhanced by interreflection within the structure. Care should be taken to use wall-mounted and ceiling-mounted luminaires that distribute light onto surfaces without glare to motorists or pedestrians.

Bollard Luminaires

Walkway and grounds lighting is often accomplished with bollards. These luminaires have the appearance of a short, thick post, similar to those found on a ship or wharf, hence the name (Figure 21-11). The optical components, usually top mounted, produce an illuminated area in the immediate vicinity. Thus bollards are used for localized lighting, because their size is appropriate to the architectural scale of walkways and other pedestrian areas. They are not satisfactory as the only source of illumination because they do not provide illuminance to higher vertical surfaces, such as faces.



Figure 21-11. Bollard luminaires illuminate the immediate surroundings in a docking area.

Floodlight Luminaires

Floodlights are the most common type of luminaire used for sports lighting. Several types of floodlights are in common use for this application, including enclosed rectangular floodlights, enclosed round floodlights, shielded floodlights, and reflectorized lamps. The National Electrical Manufacturers' Association (NEMA) field angle is widely used by the lighting industry to classify the overall intensity distribution pattern of a floodlight. The NEMA classification is also useful to the designer for making preliminary design selections. See Chapter 20, Sports and Recreational Area Lighting, for a discussion of floodlight types and NEMA beam angles.

Building facade lighting, sports lighting, and other special applications often use floodlight luminaires. See Figure 21-12 for information on illuminances for lighting buildings and monuments. These applications can have wide-ranging intensity distributions (from narrow to very broad), depending on the angular size of the object being illuminated and the desired effect. Floodlight intensity distributions are usually not symmetric. Floodlights should have glare shielding (external or internal shields) to prevent light trespass and light pollution.

Building facade lighting uses luminaires with narrow and wide intensity distributions, depending on what portion of the building is being illuminated and the distance to the luminaire's mounting location. Column lighting, accent lighting, and distant mounting locations all require narrow distributions. Illuminating large areas from nearby locations requires very wide distributions. In these situations, the chosen luminaire often has an intensity distribution that produces a square or rectangular illuminance pattern.

Sports lighting often uses luminaires with very narrow intensity distributions, mounted to the side of the playing area, and luminaires with medium intensity distributions (and short cutoffs), mounted over the playing area. The use of the narrow-intensity-distribution luminaires almost always requires careful computations during design to correct horizontal and vertical illuminance levels and uniformities.

Figure 21-12. Illuminances for Floodlighting Building and Monuments

Area Description	Average Target Illuminance (vertical) (lux/footcandles)
Bright surroundings and light surfaces	50/5
Bright surroundings and medium light surfaces	70/7
Bright surroundings and medium dark surfaces	100/10
Bright surroundings and dark surfaces	150/15
Dark surroundings and light surfaces	20/2
Dark surroundings and medium light surfaces	30/3
Dark surroundings and medium dark surfaces	40/4
Dark surroundings and dark surfaces	50/5



Figure 21-13. Architectural lighting can emphasize an exterior's vertical structural elements.

Floodlight luminaire mounting usually includes a mechanical arrangement that permits aiming. Such luminaires are often grouped in banks, since their application usually involves limited mounting and access availability. However, each luminaire is aimed independently. Both sports and building facade floodlight luminaires require careful aiming during installation and locking of all movable fixture components to retain aiming. For more information, see Chapter 20, Sports and Recreational Area Lighting.

Application-Sensitive Choices

When specifying luminaires, select those that are suitably rugged for the application, adapted to the environment, and designed to give years of trouble-free service. As an example, when luminaire doors, lenses, or globes are involved, their latching or securing mechanisms should be capable of proper resealing after repeated relampings. Luminaires with air-filtering devices can maintain clear optic chambers despite dirty environments. Insect accumulation on interior optical surfaces may seem inevitable, but a well-designed door and continuous gasketing system can greatly reduce this problem. Whenever possible, luminaire components should be captive. Juggling glass, frames, nuts, and bolts creates an unnecessary burden for relampers on ladders or in bucket trucks. Luminaires selected for high vandalism areas should be mounted out of harm's way or rated to withstand heavy physical abuse. Luminaires installed in a seaside setting must be made of materials that withstand the ravages of salt air. The selection of high-quality luminaires may involve a higher initial cost, but the investment is returned in reduced maintenance costs and increased reliability.

Any lighting equipment installed underwater must be accompanied by a maintenance commitment, because servic-

ing is complicated. Fiber optics in swimming pools, building facades, signage systems, and an increasing number of other applications can deliver convenient light source locations, reduced maintenance costs, and increased reliability.

ENERGY CONSERVATION AND MAINTENANCE ISSUES

Even a perfectly designed and installed outdoor lighting installation does not provide design illumination levels continually. Lamps lose their efficacy and ultimately fail. Dirt and insects accumulate on light sources and optical surfaces. In addition, luminaire aiming may be disturbed due to vibration, pole-foundation settling, vehicle collisions, or routine maintenance. Sometimes plant growth can block a luminaire's intended distribution.

Properly maintained equipment results in a functional lighting system that suffers little from wasted power, misaligned luminaires, and lamp burn-outs (see Chapter 26, Energy Management). When outdoor lighting equipment is operating as designed, it suggests civic pride and a continuing concern about public safety and security.

Planned Accessibility

Good maintenance starts in the design phase and includes more than just keeping the luminaires clean and relamped. Important decisions affecting maintenance include selecting the proper luminaire, lamp, and other system components; accommodating luminaire accessibility; and considering the level of system maintenance that will actually be implemented.

Lighting system designs should be considered in realistic rather than optimistic terms when selecting maintenance factors that truly represent the lamp and luminaire lumen maintenance characteristics, ambient conditions (e.g., operating temperatures, the presence of air-entrained particulate matter), and the proposed relamping and luminaire cleaning schedule.

Pole Mounting. When laying out pole locations, especially aluminum standards, place poles on pedestals or mount them away from vehicular traffic. Always check the local department of transportation's setback requirements for poles adjacent to vehicular travelways. Break-away pole bases should not be used near pedestrian traffic since falling poles could inflict major injuries and property damage. Elsewhere, poles may include the use of 760 mm [30 in.] high pedestals to minimize pole damage from car bumpers.

The specification of suitably sized foundations and piers to accommodate soil conditions, pole and luminaire configuration, and ice and wind loadings is vital because replacement costs for downed poles are high, and a fallen pole obviously does not perform its lighting mission. Pole-mounted luminaires can become misaligned if the support pole is

nudged by a vehicle. Misaligned poles may not place light where it is needed and may contribute to unanticipated light trespass.

Other Mounting Systems. Bollards, if improperly placed, can be vulnerable to damage from snow removal equipment, lawn maintenance equipment, and vehicles such as bicycles and golf carts. Bollards should be installed on low bases, or surrounded by edging or mulch to reduce the chance that lawn maintenance equipment or snow plows come into contact with them. Because of their low mounting height, bollards can be particularly vulnerable to vandalism. Care should be exercised to select rugged, vandal-proof luminaire construction for public settings.

Step lights, if improperly specified and maintained, can be rendered useless over time and fail to properly perform their important safety function. Because step lights in public spaces are easily accessed, they should be specified with tamper-proof hardware. Their bodies should have a construction and finish suitable for the application (e.g., corrosion resistance, preferably using a tempered-glass face). Placing step lights off to the side of the riser (rather than on the face) helps minimize opportunities for physical damage.

Uplights, especially when recessed into the ground, present a particularly difficult maintenance challenge. Fallen leaves, foliage, mud spatter, and other debris can quickly reduce an installation's effectiveness. Spreading foliage must be kept trimmed, and suitable mulch may be required around the luminaires to prevent mud spatter. The lens of any uplight recessed into a sidewalk can quickly become scratched, reducing its light output. Light-attracted insects can quickly build into a thick layer, blocking light output and trapping heat. Adequate gasketing is essential for these luminaires. Anti-flotation methods may be required for installations in marshy areas. Uplight housings should be specified that are impervious to prevailing local conditions such as soil acidity (or alkalinity), corrosive elements, and moisture.

Installations that Complement Maintenance

Several steps can be taken during installation to facilitate the future maintenance process:

- Mount the ground-based equipment where it is accessible for easy inspection and maintenance.
- Clearly label all switching devices such as breakers, contractors, and switches regarding the circuits and equipment they control.
- Except under rare circumstances, run luminaire feeds underground in conduit. Avoid using overhead wiring.
- Securely fasten and tighten all luminaire components and aiming devices.
- Thoroughly test the equipment to make sure it is operating as specified.

Maintaining System Operation

Following the preceding steps during design and installation should result in a lighting installation that employs components and layouts that facilitate regular upkeep. This must be coupled with a maintenance program during normal operation that ensures that the installation continues functioning in accordance with the original design criteria. See Chapter 28, *Lighting Maintenance*, for a general discussion of lighting maintenance.

Maintenance Program Choices. The facility manager should establish a periodic relamping and cleaning program and decide whether to perform the maintenance in-house or hire outside contractors. Specialty contractors, who have the proper expertise and equipment to reach high-mounted luminaires and replace faulty components, are available.

Consideration should be given to both spot and group relamping programs. Spot relamping involves replacing each lamp when it burns out. With group relamping, all lamps are replaced after a predetermined operating period or when a predetermined percentage of the lamps are burned out. Spot relamping of critical lamps may still be required between regularly scheduled group relampings.

Lamp lumen depreciation also must be considered in determining the relamping schedule. In the long term, a combined relamping and luminaire cleaning program can be more cost effective than climbing a ladder, rolling out a bucket truck, or calling a contractor every time a lamp burns out. Planned periodic maintenance keeps the luminaires operating efficiently at design illuminances and prevents burnouts from forming dark patches in the lighting installation, which can cause significant safety and security hazards.

Certain lamp types, such as mercury vapor, continue to emit some light long after they need replacement. High pressure sodium ballasts continually restrike failed lamps. If ignored, this restriking can cause ballast failure. Relamping should not await burnout or failure but should be performed whenever illuminances fall below the design level.

Optimum Relamping. Regardless of the relamping scheme employed, several precautions must be taken during the relamping process. Lamp manufacturers give specific warnings about the operation and treatment of their lamps, and such warnings must be heeded. There are many discrete variations between lamps, such as the lamp's orientation in the luminaire, that can significantly influence its operation.

Always be sure that the replacement lamp has exactly the same catalog nomenclature, including CCT and coating characteristics, as the lamp being replaced. Failure to match the original lamp characteristics exactly may result in reduced light output, reduced lamp life, reduced lumen maintenance, and even violent failure of the lamp or ballast.

Be aware that the envelopes of standard tungsten-halogen lamps and certain high intensity discharge lamps are especially vulnerable to contamination from skin oils. This

means that direct finger contact with the new lamp during relamping must be avoided. Failure to avoid such contact could result in reduced lamp life.

After an old lamp has been replaced, take care that the luminaire's sealing and gasketing devices have been returned to their proper location, and that all fastening devices are properly seated and functioning as intended. This prevents foreign materials from entering the luminaire and keeps wind or vibration from subsequently dislodging components such as an optical assembly or globe. Also check that all mounting hardware is secure and that any aiming device alignments are verified. This ensures that no luminaire misalignment occurs during relamping.

Automatic Switching Devices. Photocontrols, time clocks, and motion detectors can operate luminaires only when they are needed, thereby contributing to lighting system longevity. Such devices, however, are not maintenance free. Malfunction can cause the lighting installation to be on during the day or off during hours of darkness, defeating the energy-saving mission and expectations that light trespass/pollution will be reduced. All automatic switching should be checked regularly for proper functionality, and then adjusted, repaired, or replaced as appropriate.

Trees and Shrubs. Tree and shrub growth around a lighting installation acts as a barrier that may prevent light from reaching the intended area. Even perfectly operating luminaires can leave streets or sidewalks unacceptably illuminated unless the blocking vegetation is pruned periodically.

Sometimes plants are purposely used to reduce or eliminate light trespass. Vegetation is constantly changing, however; trees and bushes die, the seasons determine leaf population, branches break off, and growth eventually places most tree leaves well above the luminaires they are supposed to be shielding. The best solution is to incorporate light-trespass controls into the lighting design through proper luminaire selection, placement, shielding, and aiming rather than relying on living screens.

Where it is not possible to incorporate certain glare control devices into the lighting design, any vegetation used against light trespass should be carefully maintained through the timely replacement of dead, dying, or rangy growths. Summer versus winter foliage variation must also be considered. Pine and other coniferous trees are usually effective as living screens.

STRUCTURE LIGHTING

During clear days, structures are lighted with strong, direct light from the sun. The sun casts deep shadows from every textured detail on an edifice. As the day progresses, the structure's image continuously evolves, even into the reddening, horizontal light of a sunset. On overcast days, shadows diminish from the flat light.

At night, structures look completely different from their daytime appearance. It is impossible to duplicate the intense sunlight and daylighting effects. Electric lighting brings its own unique element to the nighttime scene. The lighting designer's challenge is to define and enhance the building appearance, adding ambiance to the night scene (Figure 21-13).

Structure lighting serves many purposes and communicates prestige, safety, symbolism, and recognition (Figure 21-14). Whatever the application, distinctive, well-designed lighting is one of the best ways to attract attention and make a favorable impression on the viewer with a small investment. Modern light sources, when properly applied, can help enhance the intrinsic charm, beauty, and utility of any setting. The focus here is on essential principles of structure lighting.

Lighting and Architecture

Daylighting effects have always been given prime consideration by architects. The relationship of major masses, planes, and details are critically studied with regard to changing daylight conditions, which vary in direction and



Figure 21-14. Architectural lighting can accentuate a structure's massive presence.

quality depending on latitude, season, time of day, and local weather.

At night, the dynamic visual effects of natural daylight are lost. Structural identity is often destroyed. With optical control, the structure can be rendered in light to enhance its architectural characteristics (Figure 21-14). Major elements can be strengthened or subdued. There are many dynamic possibilities, including lighting structural members in a hierarchical manner. Subordinate details can be emphasized to create patterns and textures not dependent on sun location.

Architectural lighting may include floodlighting, outlining (Figure 21-15), spotlighting, or any applicable combination of these techniques. Projecting images on a structure is yet another dramatic effect. Whenever emphasis is placed on nighttime activities such as recreation, shopping, and traveling, lighting offers an opportunity to create architectural impressions.

Structure Lighting and Urban Design

Nighttime lighting can be applied to areas surrounding a building and to related groups of buildings and, perhaps



Figure 21-15. Structure outlining can convey the character of a building.

most important, can unify portions of a community. Focal points can be established through careful highlighting of major buildings, with more subdued lighting for secondary buildings. Circulation patterns can be reinforced and the entire area unified with street lighting and landscape lighting. Modern, well-planned nighttime lighting can make an important contribution to the success of any urban planning project.

Principles of Floodlighting

The techniques of floodlighting are few and simple. When used correctly, they let designers create anything from the most dramatic, exciting statement to the most subtle impressions.

When floodlights are aimed directly at a surface, shadows are essentially nonexistent. Details are flattened out and hard to see. The effect is somewhat like heavy, overcast daylighting. By contrast, when a floodlight beam grazes a surface, all the shadows from any surface irregularities are long and clearly defined. Planes more nearly perpendicular to the direction of the light become either highlighted or deeply shadowed. Other planes are less bright or are rendered in degrees of shadow.

Shadows shorten as the light source is moved away from the surface, and thus become less likely to interfere with the observation of other visual elements. These softer, attenuated shadows still give the viewer a strong impression as to the nature of surface detail. A source directed upward and sideward can produce modeling effects in several planes, strengthening the dimensional quality of the architectural element.

At short viewing distances, the lighting effects of major architectural planes and elements is secondary. Construction details, namely the finish, texture, and shape of surface materials, produce the desired impressions. Highly polished surfaces such as glass, marble, glazed tile, glazed brick, porcelain enamel, and various metals can reflect the image of the light source. Depending on source location and viewer position, this image may appear to be well inside the lighted area and quite unsightly, or close to the source and much less distracting. Avoid lighting these reflective surfaces directly, and provide proper baffling so that the light source itself stays completely hidden from normal viewing angles.

Luminaire size and number can dramatically affect the results of a floodlighting project. Too few units may leave holes and neglect detail. Too many may cause unwanted brightness and add unnecessary cost. In starting a project, the number of floodlights, locations, beam spreads, and lumen outputs can be estimated in the following manner. Once these manual estimates have been completed, a computer calculation will help refine the design. See RP-33⁸ for additional information on floodlighting process.

LANDSCAPE LIGHTING

Landscape lighting includes a wide variety of outdoor areas including both natural and built environments. Projects may include natural meadows or woods, parks, corporate offices, hotels, theme parks, golf courses, residential gardens or boulevards, and entry features. In every setting, lighting can add aesthetic beauty, expand the number of usable hours, improve safety, increase security, and develop a desired image. Luminaire types, sources, wattages, and lighting techniques chosen vary based on project size, usage, needs, and expectations of the owner. Considerations must be given to the requirements and appearance of plant materials in landscape lighting installations.¹⁰ In all cases, the lighting designer's main task is to create a safe, attractive nighttime environment using an energy-efficient low-brightness system.

Design Considerations

Designs should begin with a thorough site survey. Give careful consideration to the landscape elements present. These include softscape (trees, shrubs, flowers, and other plant material), hardscape (rocks, cliffs, sidewalks, stairs, plazas, benches, planters, and other site furnishings), and water features. In every case, the designer must take into account the surroundings so that the lighting of individual elements blends with the rest of the lighting composition. Designers should then take the following steps:

- Determine the intended use of the space and the nature of the audience.
- Realize that the significant areas in daytime may not be (and are not required to be) the same as the significant nighttime areas.
- Locate major and minor focal points.

The designer's knowledge should include the characteristics of all plant material being lighted, and those not being lighted, because these factors dictate the selection and location of equipment. Information concerning plant characteristics can be obtained from the project landscape architect, agricultural extension services of local governments and universities, or the American National Standards Institute (ANSI). Plant characteristics vary with both plant type and region.¹⁰ Consider the following characteristics:

- Overall shape, height, width, maturing, and type
- Foliage characteristics (shape, color, reflectance, texture, translucency, and density)
- Branching pattern (open, closed, dense, upright, or weeping)
- Trunk and bark condition (striped, thorny, peeling, cracked, multicolored, or flaking)
- Root depth, spread
- Growth rate (how quickly, how much)

- Evergreen or deciduous
- Seasonal changes for the location

Luminaire Types and Usage

Lighting professionals must be familiar with the luminaires and sources available for landscape and architectural feature lighting. There are eight basic luminaire types used for landscape and architectural feature lighting:

- Uplights (well lights, below-grade open recessed luminaires with a louver or grill, direct burial luminaires, sealed luminaires with the lens at grade level, bullet uplights, and grade-level adjustable accent lights)
- Downlight (typically shielded bullet-type luminaires)
- Floodlights (using reflectors with both spot and flood distributions)
- Pathway
- Decorative (sconces and lanterns)
- Bollards
- Wall packs
- Pole- or post-mounted area lights

For the purpose of this section, luminaires are combined into three basic functional categories: uplighting, downlighting, and general or area lighting.

Uplights are used to illuminate plant material, signs, sculptures, or other structures upward from their base. Because illuminated surfaces and shadowed areas are different from natural patterns generated by the sun and moon, uplighting is quite dramatic. The type of luminaire chosen should be based on its location (e.g., grass, groundcover, mulch, or concrete) and the effect desired. Well lights can be adjusted to match the height of the groundcover. Direct burial luminaires are more appropriate for concrete installations than well lights. Bullets offer better directional control than in-ground units and can be easily aimed around obstacles.

Downlights are used to illuminate plant material, objects, or walkways from above. They can be either tree or structure mounted. Illumination created by downlights facilitates pedestrian traffic and reduces safety and security concerns. Bullet luminaires with integral full shields are the tools of choice for downlighting. Well-designed, shielded bullets can minimize or eliminate light trespass concerns.

Other luminaire types are used to provide general illumination and establish borders. They are typically used in hardscape rather than softscape applications. Regardless of the application, luminaire selection is critical. Corrosion is a concern for luminaires located in areas exposed to weather. Harsh environments do not recognize the difference between residential and commercial projects. Although aluminum luminaires are low cost and can be painted a variety of colors, they are subject to corrosion. To ensure proper performance, choose luminaires constructed of low-copper

aluminum alloy with either polyester powder coat or anodized finish. Although copper alloys such as brass or bronze are corrosion resistant, they are quite expensive. To achieve the corrosion resistance of copper alloys at an aluminum price, consider luminaires constructed of corrosion-proof composite materials.¹⁰

Sources

Lamp information (efficacy, life, and CCT) is thoroughly covered in Chapter 6, Light Sources, and earlier sections of this chapter. However, within the landscape a few generalizations apply. Cool colors (mercury vapor and some metal halide) work well on some foliage. The warmer tones of incandescent and halogen lamps (both line and low-voltage) and some metal halide lamps work well on most foliage, flowering plants, people, food, and hardscape. Compact fluorescent lamp CCTs can be matched to the object being illuminated. High-pressure sodium (HPS) and low-pressure sodium are not typically used because they do not flatter plant appearance; however, HPS is appropriate for some architectural features.

Using different sources can add depth and texture, and contrast creates areas of interest. Different colors also create different moods or feelings. Many manufacturers provide color filters to further expand the range of colors available. Remember that color is a very subjective issue; less is usually better. Scenes with multiple sources with different CCTs are difficult to photograph for publicity or advertising purposes.

Typically, low-voltage lamps and luminaires are small and easily concealed. Low voltage is appropriate for the smaller spaces and plant material often found in residential applications; however, voltages drop with the distance between the luminaires and the transformers.

Due to electrical resistance, the voltage measured at the end of a low-voltage cable is lower than voltage measured at the start of the cable (i.e., at the transformer). This difference is known as voltage drop. Luminaires closer to the transformer produce more light than those at the end of the run of the cable. To minimize the effects of voltage drop:

- Use heavier gauge cable
- Shorten cable runs
- Use lower wattage lamps
- Use fewer luminaires on each run
- Use multiple transformers

Techniques for Illuminating Trees

There are four basic approaches to illuminating trees:

- Uplighting, the most common landscape lighting technique, creates different effects depending upon luminaire placement.
- Frontlighting shows or creates shapes, highlights de-

tails and colors, and reduces or emphasizes texture, depending on how far the luminaire is from the plant(s).

- Backlighting (silhouetting) shows only form, adds depth by separating the plant(s) from the background, and creates drama by eliminating colors and details.
- Sidelighting emphasizes plant textures and creates shadows that can be used to tie areas together.¹⁰

Perhaps the most important uplighting effect is anchoring the tree to the landscape. If the trunk is not included when accenting the tree, the canopy appears unnaturally detached from the ground. Luminaire placement also depends on the overall shape of the tree, its branch structure, and its foliage type.¹⁰

- Open spreading trees. Place luminaires one-third to one-half the distance between the trunk and the edge of the canopy to highlight it from within. Flood-type distributions are appropriate for broad canopies (oaks, willows). Tilted optics and crossing beam patterns enhance both depth and texture.
- Open vertical trees. Place luminaires closer to the trunk and aim them vertically. Narrower distributions are appropriate for vertical trees (palms, poplars).
- Dense spreading trees. Luminaires should be placed outside the branch structure. Luminaires placed close to the foliage and aimed up (grazing) emphasize texture; luminaires placed farther away highlight shape.

Downlighting involves lighting areas, trees, or plant material from above. Aiming downlights through a tree's leaves and branches creates soft subtle shadow patterns on the ground. This is called "moonlighting" when using clear mercury vapor and "dappled light" when using a white light source such as incandescent or metal halide. Luminaires should always be placed as high in the tree as possible. Luminaires positioned toward the center of the tree generally create more shadows, while luminaires placed toward the edge of the tree (filtered by fewer leaves) result in higher light levels.

High levels are not required to be effective. For comparison, a full moon produces only 0.1 lux of illumination. In general, the luminance ratios between focal points and their surroundings should range from 3:1 to 5:1 or, at most, 10:1 for special effect.

Installation Guidelines

All installations should meet National Electrical Code (NEC)¹¹ requirements. Luminaires should be suitable for wet locations. Make sure adequate drainage is provided for areas with grade-mounted luminaires. Wiring for downlights

must be shielded from mechanical damage from the ground to 2.5 m (8 ft) above grade. Never aim downlights at an angle greater than 35° from vertical, or glare is likely to be a problem.¹⁰ Take advantage of the variety of shields offered by many manufacturers to control glare. Always use a mounting device that accommodates the growth of the tree. Plan and coordinate a maintenance and pruning schedule with the landscape architect or the landscape maintenance contractor.¹⁰

Design Guidelines for Water Features

Light interacts with water in three different ways: refraction, reflection, and dispersion (Figure 21-16). Light is refracted (changes direction) when passing from air into water or vice versa. This is why the apparent location of a submerged object can shift. Refraction also causes rainbows or sparkle in water droplets or in turbulent water.

In addition to refraction, reflection also occurs when light strikes the water's surface; light is redirected back into the air or into the water in which it had been traveling. As with a mirror, the angle of incidence equals the angle of reflection. This is an important consideration for determining equipment location because it is possible to see luminaires as reflected images in a pool. Reflection can also play a role in displaying the lighted structure. When lighting objects from underwater sources in calm water, total internal reflection

occurs at the water surface if the angle of incidence is greater than the critical angle (about 48°).

Depending on the particulates and air bubbles suspended in a body of water, a certain amount of light diffusion takes place. This occurs because the light traveling through the water strikes the particles or bubbles and is reflected in a different direction. This may be a help or a hindrance, depending on the desired effect. For example, if the designer is lighting ornate tile at the bottom of a fountain, diffusion may make the water appear murky, thus obscuring the tile.

Water features include both natural and built environments. Waterfalls, ponds, streams, and ocean fronts comprise a surrounding's earth features. A designer should evaluate these surroundings and determine if a specific earth feature is to be a focal point, transition area, or background element in the scene. When locating equipment, several factors should be considered, including critical angles, viewing angles, and whether the equipment is above or under water. Check local building codes carefully for any restrictions on equipment locations. When positioning equipment, make sure the luminaires are aimed so that the source cannot be seen directly or indirectly as a result of reflection and refraction angles. If placing equipment under water, the effect of light and heat on the organisms living there must be considered. All such equipment must be listed for submersible use, and all electrical codes for underwater lighting followed precisely. Fiber optics can simplify this situation because the

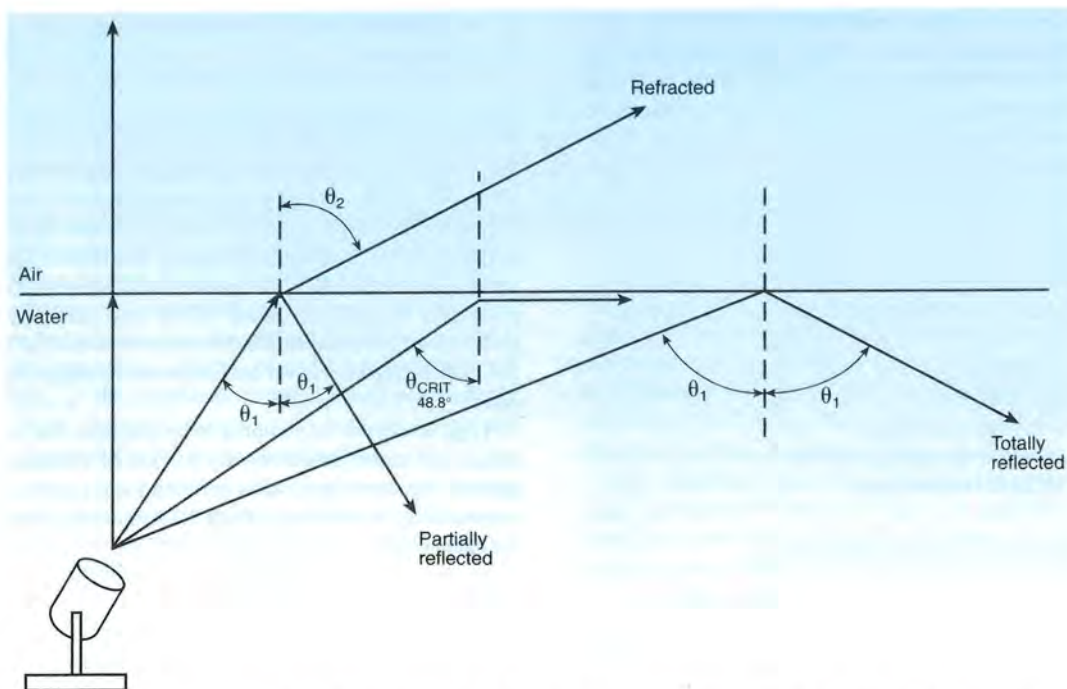


Figure 21-16. Underwater rays can be refracted or reflected depending on the incident angle with which they strike the surface of the water. Dispersion (not shown) also occurs whenever a light ray strikes a particle or air bubble in the water.

electrical equipment is separated from the water and only requires seals to prevent water leakage out of the fountain and capillary action along the fiber. Note that all submersible equipment is about three to five times more expensive than normal wet-location outdoor equipment.

Equipment not placed under water can be installed in trees, on nearby structures, in the ground surrounding the fountain, or on the fountain structure. Maintenance and access issues should always be kept in mind. This approach may yield a less dramatic solution than that produced by submerged equipment, but the result may be far more practical and considerably less expensive. See Figure 21-17 for an example of an illuminated fountain at night.

For general notes on equipment and source selection, refer to the lighting equipment and maintenance section. As when lighting natural-water features, all safety codes should be met as set forth by the National Electrical Code (NEC)¹¹ and local authorities. Underwater luminaires need strong locking mechanisms to maintain their aiming angle.

The following guidelines cover each specific water feature:

- **Fountains.** Determine which parts of the fountain need to be lighted, the water or the structure. Ascertain the viewing geometry and the type of lighting that will surround the fountain. If color is desired, other lighting must not overpower or wash out the colored effects.
- **Waterfalls.** To light a waterfall, determine the type of edge (weir) over which the water falls. If the weir is rough, the water will be agitated and aerated. Luminaires placed directly below the point where the water hits the surface allow light to travel up the falls, react with the bubbles, and give the water a glow. The water will take on the color of the light shining into it. If the weir is smooth, the water will fall in sheets. This type of waterfall should be lighted from the front with the luminaires placed

back far enough to cover the entire height of the falls.¹⁰

- **Streams and ponds.** While streams and ponds rarely represent the most important element in landscape composition, it is usually best to light them externally. Internal lighting can draw too much attention away from other areas.
- **Oceanfront/Beach.** The only part of the ocean that can be lighted is the foam on the surf. A great deal of light must be thrown at the ocean because most of it will be absorbed. Because oceanfront lighting could cause considerable light pollution, its use should be restricted to the occasional special event. Time control use is essential. Oceanfront lighting is not recommended near sea turtle nesting areas and requires permission from the coast guard.
- **Other features.** Lighting for geysers, rock faces, and other special natural features of the type often found in national parks (Figure 21-18) should be designed by a professional. All the basic design principles previously discussed should be applied. Light pollution, surround luminance, and light disturbance to the environment must also be considered.

HARDSCAPE LIGHTING

Beyond softscape and water features, the lighting designer must be concerned with illuminating a wide variety of sculptures, statues, flags, and other architectural features (hardscape). The section focuses on outdoor sculptures, vertical displays, and gazebos.

Outdoor Sculptures

A three-dimensional sculpture must be lighted from more than one direction to provide the essential highlights and shadows that reveal shape or texture (Figure 21-19). This



Figure 21-17. An illuminated fountain can provide nighttime theme lighting.



Figure 21-18. Rock face illumination should avoid hot spots or excessive spill light.



Figure 21-19. Highlight and shadow can reveal the shape and texture of outdoor sculptures, from the typical garden statue (a) to a monumental structure (b).

can be accomplished by using different lamps, color filters, or beam patterns from different angles. For example, a bronze sculpture with patina may appear light blue, green, or gray, depending on the light source. Directional lighting models sculptures, expressing depth and highlighting some areas while allowing others to fall into shadow.

Shadows are indicators of surface form and texture, providing they are not so dark as to conceal important details. High-lights also give good visual clues about surface characteristics, but they should not dazzle or cause uncomfortable glare.

If a sculpture at eye level (or lower) is lighted from above on all sides, there should be few problems for the viewer. When the sculpture is tall, however, there may be glare. Listed here are some solutions:

- If lighting the sculpture from above with structure-, pole-, or tree-mounted lights, angle the luminaires sharply downward and relieve shadows with a high-reflectance pedestal.
- Keep light beams entirely within the mass of the display by using shielded luminaires and selecting lamps with the correct beam spread.
- Illuminate the sculpture from below if that does not distort its appearance.

- Combine ambient, diffuse lighting (fill light) in the space with narrow-beam lighting (key light) on important parts of the sculpture.

Vertical Displays

It is often necessary to illuminate large vertical displays uniformly. See the discussion of floodlighting earlier in this chapter.

Floodlights mounted far from a vertical surface mute a vertical display's texture; floodlights mounted close accentuate texture. Carefully select floodlight luminaires that do not create hot spots on the display (Figure 21-20). Occasionally one feature of the display may need to be highlighted. This can be accomplished with spotlighting.

Gazebos

Usually rendered as small, raised, polygonal platforms open on the sides (Figure 21-21), gazebos typically have pitched roofs supported by perimeter columns which provide an excellent opportunity for interior lighting by mounting a centrally located pendant luminaire. This luminaire should light the ceiling so that the gazebo softly glows as seen from the



Figure 21-20. Good vertical surface illuminance without hot spots.

outside. For larger gazebos, column- or perimeter-mounted uplights can provide additional lighting for the platform area. Wall sconces on the columns add pedestrian-level lightings if required.



Figure 21-21. Nighttime illumination of a gazebo showing soft lighting of the structure.

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Roadway Lighting

22

Fixed lighting of public ways for both vehicles and pedestrians can create a nighttime environment in which people can see comfortably and can quickly and accurately identify objects on the roadway being traveled. Roadway lighting can improve traffic safety, achieve efficient traffic movement, and promote the general use of the facility during darkness and under a wide variety of weather conditions.

As a supplement to vehicular headlight illumination, fixed lighting can enable the motorist to see details more distinctly, locate them with greater certainty, and react safely to roadway and traffic conditions present on or near the roadway facility. Pedestrians must be able to see with sufficient detail to readily negotiate the pedestrian facility and recognize the presence of other pedestrians, vehicles, and objects in their vicinity. When fixed-lighting principles and techniques are properly applied, the visibility provided on these public ways can provide economic and social benefits to the public, including:

- Reduction in nighttime accidents
- Aid to police protection
- Facilitation of traffic flow
- Promotion of business and industry during nighttime hours
- Inspiration for community spirit and growth

This chapter considers only fixed lighting for the different kinds of public roads, pedestrian walkways and bikeways of a quality considered appropriate to modern requirements for night use. See Chapter 23, Transportation Lighting, for information on vehicle headlighting.

CLASSIFICATION DEFINITIONS¹

Roadway: Pedestrian Walkway and Bikeway Classifications

Freeway. A divided major roadway with full control of access and with no crossings at grade. This definition applies to toll as well as nontoll roads as follows:

Freeway A. Roadways with visual complexity and high traffic volumes. Usually this type of freeway is found in major metropolitan areas in or near the central core and operates through much of the early evening hours of darkness at or near design capacity.

ROADWAY LIGHTING DESIGN ISSUES

- Appearance of Space and Luminaires
- Direct Glare
- Illuminance (Vertical)
- Light Distribution on Surfaces
- Light Pollution/Trespass
- Peripheral Detection
- Reflected Glare
- Shadows
- Source/Task/Eye Geometry

Freeway B. All other divided roadways with full control of access where lighting is needed.

Expressway. A divided major roadway for through traffic with partial control of access and generally with interchanges at major crossroads. Expressways for noncommercial traffic within park areas are generally known as parkways.

Major. The part of the roadway system that serves as the principal network for through traffic flow. The routes connect areas of principal traffic generation and important rural highways entering the city.

Collector. The roadways serving traffic between major and local roadways. These are roadways used mainly for traffic movements within residential, commercial, and industrial areas.

Local. Roadways used primarily for direct access to residential, commercial, industrial, or other abutting property. They do not include roadways carrying through traffic. Long local roadways are generally divided into short sections by a system of collector roadway systems.

Alley. Narrow public ways within a block, generally used for vehicular access to the rear of abutting properties.

Sidewalk. Paved or otherwise improved areas for pedestrian use, located within public street rights-of-way that also contain roadways for vehicular traffic.

Pedestrian Walkway. A public walk for pedestrian traffic, not necessarily within the right-of-way for a vehicular traffic roadway. Included are skywalks (pedestrian overpasses), subwalks (pedestrian tunnels), walkways giving access to parks or block interiors, and midblock street crossings.

Isolated Interchange. A grade-separated roadway crossing that is not part of a continuously lighted system, with one or more ramp connections with the crossroad.

Isolated Intersection. The general area where two or more discontinuously lighted roadways join or cross at the same level. The intersection includes the roadway and roadside facilities for traffic movement in that area. A special type is the channelized intersection, in which traffic is directed into definite paths by islands with raised curbing.

Bikeway. Any road, street, path, or way that is specifically designated as being open to bicycle travel, regardless of whether such facilities are designed for the exclusive use of bicycles or are to be shared with other transportation modes.

Type A: Designated bicycle lane. A portion of roadway or shoulder that has been designated for use by bicyclists. It is distinguished from the portion of the roadway for motor vehicle traffic by a paint stripe, curb, or other similar device.

Type B: Bicycle trail. A separate trail or path from which motor vehicles are prohibited and which is for the exclusive use of bicyclists or the shared use of bicyclists and pedestrians. Where such a trail or path forms a part of a highway, it is separated from the roadways for motor vehicle traffic by an open space or barrier.

Area Classifications (Abutting Land Uses)

Certain land uses, such as office and industrial parks, may fit into any of the classifications below. The classification selected should be consistent with the expected night pedestrian activity.

Commercial. A business area of a municipality where ordinarily there are many pedestrians during night hours. This definition applies to densely developed business areas outside, as well as within, the central part of a municipality. The area contains land use that frequently attracts a heavy volume of nighttime vehicular and pedestrian traffic.

Intermediate. Those areas of a municipality characterized by frequent moderately heavy nighttime pedestrian activity, as in blocks having libraries, community recreation centers, large apartment buildings, industrial buildings, or neighborhood retail stores.

Residential. A residential development, or a mixture of residential and small commercial establishments, characterized by few pedestrians at night. This definition includes areas with single-family homes, town houses, and small apartment buildings.

Pavement Classifications

The calculation of pavement luminance requires information about the surface reflectance characteristics of the pavement. Studies have shown that most common pavements can be grouped into a limited number of standard road surfaces

having specified reflectance data given by reduced luminance coefficient tables (*r* tables). In this section, pavement reflectance characteristics follow the established CIE document.² A description of road surface classifications is given in Figure 22-1. The *r* tables quantifying the pavement class are shown in Figure 22-2.

Luminaire Light Distribution Classifications

Proper distribution of the light flux from luminaires is one of the essential factors in efficient roadway lighting. The light emanating from the luminaires is directionally controlled and proportioned in accordance with the roadway width, the spacing between luminaires, and the mounting locations where the luminaires are expected to be used. Therefore, there is a need for a luminaire light distribution classification system to aid the engineer or designer to narrow down the selection of luminaires that might meet the requirements specified for a given roadway system.

Several methods have been devised for showing the light distribution pattern from a luminaire (Figures 22-3 through 22-7). For practical operating reasons, the range in luminaire mounting heights may be limited. Therefore, it becomes necessary to have several different light distributions in order to light different roadway widths effectively, while using various luminaire spacing distances at a fixed luminaire mount-

Figure 22-1. Road Surface Classifications

Class	Q_o	Description	Mode of Reflectance
R1	0.10	Portland cement, concrete road surface. Asphalt road surface with a minimum of 15 percent of the aggregates composed of artificial brightener and aggregates	Mostly diffuse
R2	0.07	Asphalt road surface with an aggregate composed of a minimum 60 percent gravel (size greater than 10 millimeters). Asphalt road surface with 10 to 15 percent artificial brightener in aggregate mix. (Not normally used in North America).	Mixed (diffuse and specular)
R3	0.07	Asphalt road surface (regular and carpet seal) with dark aggregates (e.g., trap rock, blast furnace slag); rough texture after some months of use (typical highways).	Slightly specular
R4	0.08	Asphalt road surface with very smooth texture.	Mostly specular

Note: Q_o = representative mean luminance coefficient.

Figure 22-2. The r -Tables for Standard Surfaces: (a) R1, (b) R2, (c) R3, (d) R4. All values must be multiplied by 10,000. Angles are shown in (e). (Adapted from reference 2.)

β tan γ	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	135	150	165	180
0	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655
0.25	619	619	619	619	610	610	610	610	610	610	610	610	610	601	601	601	601	601	601	601
0.5	539	539	539	539	539	539	521	521	521	521	521	503	503	503	503	503	503	503	503	503
0.75	431	431	431	431	431	431	431	431	431	431	395	386	371	371	371	371	371	386	395	395
1	341	341	341	341	323	323	305	296	287	287	278	269	269	269	269	269	269	278	278	278
1.25	269	269	269	260	251	242	224	207	198	189	189	180	180	180	180	180	189	198	207	224
1.5	224	224	224	215	198	180	171	162	153	148	144	144	139	139	139	144	148	153	162	180
1.75	189	189	189	171	153	139	130	121	117	112	108	103	99	99	103	108	112	121	130	139
2	162	162	157	135	117	108	99	94	90	85	85	83	84	84	86	90	94	99	103	111
2.5	121	121	117	95	79	66	60	57	54	52	51	50	51	52	54	58	61	65	69	75
3	94	94	86	66	49	41	38	36	34	33	32	31	31	33	35	38	40	43	47	51
3.5	81	80	66	46	33	28	25	23	22	22	21	21	22	22	24	27	29	31	34	38
4	71	69	55	32	23	20	18	16	15	14	14	14	15	17	19	20	22	23	25	27
4.5	63	59	43	24	17	14	13	12	12	11	11	11	12	13	14	14	16	17	19	21
5	57	52	36	19	14	12	10	9.0	9.0	8.8	8.7	8.7	9.0	10	11	13	14	15	16	16
5.5	51	47	31	15	11	9.0	8.1	7.8	7.7	7.7										
6	47	42	25	12	8.5	7.2	6.5	6.3	6.2											
6.5	43	38	22	10	6.7	5.8	5.2	5.0												
7	40	34	18	8.1	5.6	4.8	4.4	4.2												
7.5	37	31	15	6.9	4.7	4.0	3.8													
8	35	28	14	5.7	4.0	3.6	3.2													
8.5	33	25	12	4.8	3.6	3.1	2.9													
9	31	23	10	4.1	3.2	2.8														
9.5	30	22	9.0	3.7	2.8	2.5														
10	29	20	8.2	3.2	2.4	2.2														
10.5	28	18	7.3	3.0	2.2	1.9														
11	27	16	6.6	2.7	1.9	1.7														
11.5	26	15	6.1	2.4	1.7															
12	25	14	5.6	2.2	1.6															

$Q_0 = 0.10; S1 = 0.25; S2 = 1.53$

a

β tan γ	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	135	150	165	180
0	390	390	390	390	390	390	390	390	390	390	390	390	390	390	390	390	390	390	390	390
0.25	411	411	411	411	411	411	411	411	411	411	379	368	357	357	346	346	346	335	335	335
0.5	411	411	411	411	403	403	384	379	370	346	325	303	281	281	271	271	271	260	260	260
0.75	379	379	379	368	357	346	325	303	281	260	238	216	206	206	206	206	208	206	206	206
1	335	335	335	325	292	291	260	238	216	195	173	152	152	152	152	152	141	141	141	141
1.25	303	303	292	271	238	206	184	152	130	119	108	100	103	106	108	108	114	114	119	119
1.5	271	271	260	227	179	152	141	119	108	93	80	76	76	80	84	87	89	91	93	95
1.75	249	238	227	195	152	124	106	91	78	67	61	52	54	58	63	67	69	71	73	74
2	227	216	195	152	117	95	80	67	61	52	45	40	41	45	49	52	54	56	57	58
2.5	195	190	146	110	74	58	48	40	35	30	27	24	26	28	30	33	35	38	40	41
3	160	155	115	67	43	33	26	21	18	17	16	16	17	17	18	21	22	24	26	27
3.5	146	131	87	41	25	18	15	13	12	11	11	11	11	11	12	14	15	17	18	21
4	132	113	67	27	15	12	10	9.4	8.7	8.2	7.9	7.6	7.9	8.7	9.6	11	12	13	15	17
4.5	118	95	50	20	12	8.9	7.4	6.6	6.3	6.1	5.7	5.6	5.8	6.3	7.1	8.4	10	12	13	14
5	106	81	38	14	8.2	6.3	5.4	5.0	4.8	4.7	4.5	4.4	4.8	5.2	6.2	7.4	8.5	9.5	10	11
5.5	96	69	29	11	6.3	5.1	4.4	4.1	3.9	3.8										
6	87	58	22	8.0	5.0	3.9	3.5	3.4	3.2											
6.5	78	50	17	6.1	3.8	3.1	2.8	2.7												
7	71	43	14	4.9	3.1	2.5	2.3	2.2												
7.5	67	38	12	4.1	2.6	2.1	1.9													
8	63	33	10	3.4	2.2	1.8	1.7													
8.5	58	28	8.7	2.9	1.9	1.6	1.5													
9	55	25	7.4	2.5	1.7	1.4														
9.5	52	23	6.5	2.2	1.5	1.3														
10	49	21	5.6	1.9	1.4	1.2														
10.5	47	18	5.0	1.7	1.3	1.2														
11	44	16	4.4	1.6	1.2	1.1														
11.5	42	14	4.0	1.5	1.1															
12	41	13	3.6	1.4	1.1															

$Q_0 = 0.07; S1 = 0.58; S2 = 1.80$

b

Figure 22-2. Continued.

β tan γ	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	135	150	165	180
0	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294
0.25	326	326	321	321	317	312	308	308	303	298	294	280	271	262	258	253	249	244	240	240
0.5	344	344	339	339	326	317	308	298	289	276	262	235	217	204	199	199	199	199	194	194
0.75	357	353	353	339	321	303	285	267	244	222	204	176	158	149	149	149	145	136	136	140
1	362	362	352	326	276	249	226	204	181	158	140	118	104	100	100	100	100	100	100	100
1.25	357	357	348	298	244	208	176	154	136	118	104	83	73	70	71	74	77	77	77	78
1.5	353	348	326	267	217	176	145	117	100	86	78	72	60	57	58	60	60	60	61	62
1.75	339	335	303	231	172	127	104	89	79	70	62	51	45	44	45	46	45	45	46	47
2	326	321	280	190	136	100	82	71	62	54	48	39	34	34	34	35	36	36	37	38
2.5	289	280	222	127	86	65	54	44	38	34	25	23	22	23	24	24	24	24	24	25
3	253	235	163	85	53	38	31	25	23	20	18	15	15	14	15	15	16	16	17	17
3.5	217	194	122	60	35	25	22	19	16	15	13	9.9	9.0	9.0	9.9	11	11	12	12	13
4	190	163	90	43	26	20	16	14	12	9.9	9.0	7.4	7.0	7.1	7.5	8.3	8.7	9.0	9.0	9.9
4.5	163	136	73	31	20	15	12	9.9	9.0	8.3	7.7	5.4	4.8	4.9	5.4	6.1	7.0	7.7	8.3	8.5
5	145	109	60	24	16	12	9.0	8.2	7.7	6.8	6.1	4.3	3.2	3.3	3.7	4.3	5.2	6.5	6.9	7.1
5.5	127	94	47	18	14	9.9	7.7	6.9	6.1	5.7										
6	113	77	36	15	11	9.0	8.0	6.5	5.1											
6.5	104	68	30	11	8.3	6.4	5.1	4.3												
7	95	60	24	8.5	6.4	5.1	4.3	3.4												
7.5	87	53	21	7.1	5.3	4.4	3.6													
8	83	47	17	6.1	4.4	3.6	3.1													
8.5	78	42	15	5.2	3.7	3.1	2.6													
9	73	38	12	4.3	3.2	2.4														
9.5	69	34	9.9	3.8	3.5	2.2														
10	65	32	9.0	3.3	2.4	2.0														
10.5	62	29	8.0	3.0	2.1	1.9														
11	59	26	7.1	2.6	1.9	1.8														
11.5	56	24	6.3	2.4	1.8															
12	53	22	5.6	2.1	1.8															

 $Q_0 = 0.07; S1 = 1.11; S2 = 2.38$

c

β tan γ	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	135	150	165	180
0	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264
0.25	297	317	317	317	317	310	304	290	284	277	271	244	231	224	224	218	218	211	211	211
0.5	330	343	343	343	330	310	297	284	277	264	251	218	198	185	178	172	172	165	165	165
0.75	376	383	370	350	330	304	277	251	231	211	198	165	139	132	132	125	125	125	119	119
1	396	396	396	330	290	251	218	198	185	165	145	112	86	86	86	86	86	87	87	87
1.25	403	409	370	310	251	211	178	152	132	115	103	77	66	65	65	63	65	66	67	68
1.5	409	396	356	284	218	172	139	115	100	88	79	61	50	50	50	50	52	55	55	55
1.75	409	396	343	251	178	139	108	88	75	66	59	44	37	37	37	38	40	41	42	45
2	409	383	317	224	145	106	86	71	59	53	45	33	29	29	29	30	32	33	34	37
2.5	396	356	264	152	100	73	55	45	37	32	28	21	20	20	20	21	22	24	25	26
3	370	304	211	95	63	44	30	25	21	17	16	13	12	12	13	13	15	16	17	19
3.5	343	271	165	63	40	26	19	15	13	12	11	9.8	9.1	8.8	8.8	9.4	11	12	13	15
4	317	238	132	45	24	16	13	11	9.6	9.0	8.4	7.5	7.4	7.4	7.5	7.9	8.6	9.4	11	12
4.5	297	211	106	33	17	11	9.2	7.9	7.3	6.6	6.3	6.1	6.1	6.2	6.5	6.7	7.1	7.7	8.7	9.6
5	277	185	79	24	13	8.3	7.0	6.3	5.7	5.1	5.0	5.0	5.1	5.4	5.5	5.8	6.1	6.3	6.9	7.7
5.5	257	161	59	19	9.9	7.1	5.7	5.0	4.6	4.2										
6	244	140	46	13	7.7	5.7	4.8	4.1	3.8											
6.5	231	122	37	11	5.9	4.6	3.7	3.2												
7	218	106	32	9.0	5.0	3.8	3.2	2.6												
7.5	205	94	26	7.5	4.4	3.3	2.8													
8	193	82	22	6.3	3.7	2.9	2.4													
8.5	184	74	19	5.3	3.2	2.5	2.1													
9	174	66	16	4.6	2.8	2.1														
9.5	169	59	13	4.1	2.5	2.0														
10	164	53	12	3.7	2.2	1.7														
10.5	158	49	11	3.3	2.1	1.7														
11	153	45	9.5	3.0	2.0	1.7														
11.5	149	41	8.4	2.6	1.7															
12	145	37	7.7	2.5	1.7															

 $Q_0 = 0.08; S1 = 1.55; S2 = 3.03$

d

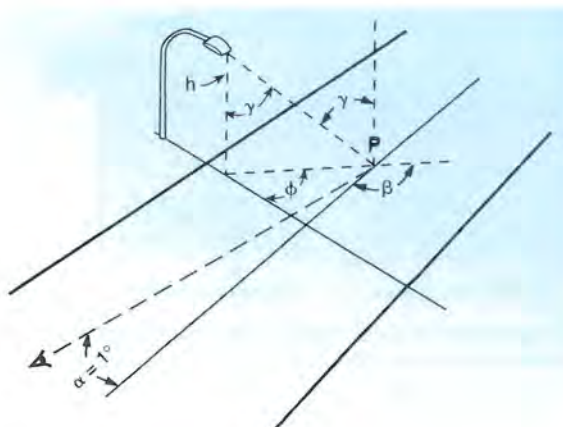


Figure 22-2e. Continued.

ing height. All luminaires can be classified according to their lateral and vertical distribution patterns. Different lateral distributions are available for different ratios of street width to mounting height. Different vertical distributions are available for different ratios of spacing to mounting height.

Distributions with higher vertical angles of maximum intensity emission are necessary to obtain the required uniformity of illuminance where longer luminaire spacings are used (as on residential and light-traffic roadways). These higher vertical emission angles produce a more favorable pavement luminance, which may be desired for silhouette seeing where the traffic volume is low. Distributions with lower vertical angles of maximum intensity emission are used in order to reduce system glare. This becomes more important when using high-lumen-output lamps. The lower the emission angle, the closer the luminaire spacing must be to obtain required illuminance uniformity.

Luminaire light distribution may be classified in respect to three criteria:

- Vertical light distribution
- Lateral light distribution
- Control of light distribution above maximum intensity

Classification of the light distribution should be made on the basis of an isointensity diagram which, on its rectangular coordinate grid, has superimposed a series of longitudinal roadway lines (LRL) in multiples of the mounting height (MH), and a series of transverse roadway lines (TRL), also in multiples of the MH. The relationship of LRL and TRL to an actual street and the representations are shown in Figures 22-3 through 22-7. The minimum information that should appear on such an isointensity diagram for classification is as follows:

1. LRL lines at 1.0, 1.75, and 2.75 MH
2. TRL lines at 1.0, 2.25, 3.75, 6.0, and 8.0 MH
3. Maximum-intensity location and half-maximum-intensity trace
4. Intensity lines at the numerical values of 2.5, 5, 10, and 20% of the rated bare lamp lumens

Following are several types of luminaire light distributions. Other variations from these distributions may be useful for special applications.

Vertical Light Distributions. Vertical light distributions are divided into three groups: short (S), medium (M), and long (L) (Figures 22-3 and 22-6).

Short Distribution. A luminaire is classified as having a short light distribution when its maximum-intensity point lies in the S zone of the grid, which is from the 1.0-MH TRL up to the 2.25-MH TRL. The maximum luminaire spacing is generally less than 4.5 times the mounting height (Figures 22-3 and 22-4).

Medium Distribution. A luminaire is classified as having a medium light distribution when its maximum-intensity point lies in the M zone of the grid, which is from the 2.25-MH TRL up to the 3.75-MH TRL. The maximum luminaire spacing is less than 7.5 times the mounting height (Figures 22-3 and 22-4).

Long Distribution: A luminaire is classified as having a long light distribution when its maximum-intensity point lies in the L zone of the grid, which is from the 3.75-MH TRL up to the 6.0-MH TRL. The maximum luminaire spacing is less than 12 times the mounting height (Figures 22-3 and 22-4).

Lateral Light Distributions. Lateral light distributions (Figures 22-5 and 22-6) are divided into two groups based on the location of the luminaire in relation to the area to be lighted. Each group may be subdivided into divisions with regard to the width of the area to be lighted in terms of the MH ratio. Only the segments of the half-maximum-intensity isointen-

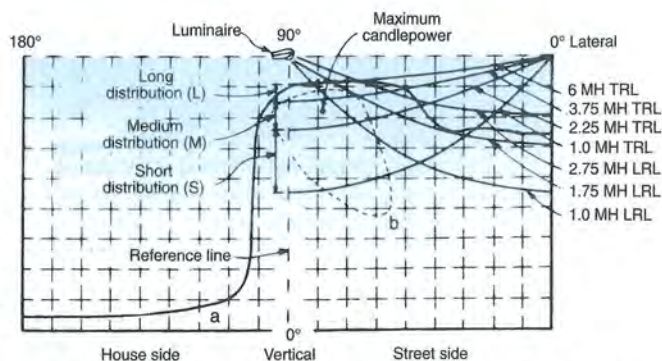


Figure 22-3. Recommended vertical light distribution boundaries on rectangular coordinate grid (representation of a sphere). Lines a and b are isointensity traces.

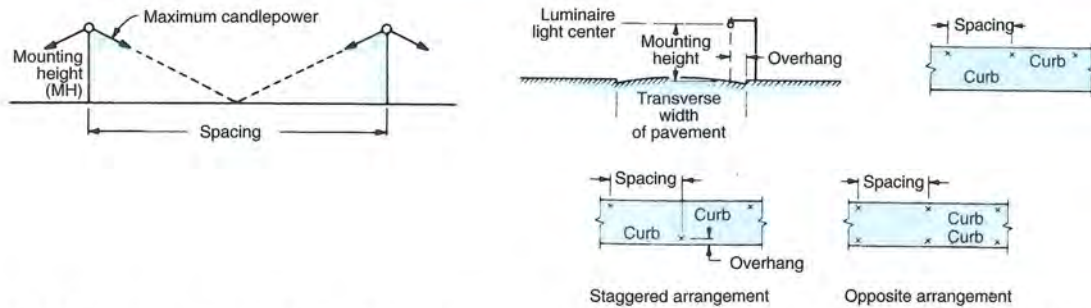


Figure 22-4. Typical lighting layouts showing spacing-to-mounting height relationships and terminology with respect to luminaire arrangement and spacing. Short Distribution—for luminaires designed to be located less than $4.5 \times \text{MH}$ between luminaires. Medium Distribution—for luminaires designed to be located in the range of $4.5 \times \text{MH}$ to $7.5 \times \text{MH}$ between luminaires. Long Distribution—for luminaires designed to be located in the range of $7.5 \times \text{MH}$ to $12 \times \text{MH}$ between luminaires.

sity trace that fall within the longitudinal distribution range, as determined by the point of maximum intensity (S, M, or L), are used for establishing the luminaire distribution width classification.

Luminaires At or Near Center of Area. The group of lateral width classifications that deals with luminaires intended to be mounted at or near the center of the area to be lighted has similar light distributions on both the house side and the street side of the reference line.

Type I. A distribution is classified as Type I when its half-maximum-intensity isointensity trace lies within the Type I width range on both sides of the reference line which is

bounded by 1.0-MH house side LRL and 1.0-MH street side LRL within the longitudinal distribution range (S, M, or L) where the point of maximum intensity falls (Figure 22-6a).

Type I Four-way. A distribution is classified as a Type I four-way when it has four beams of the width as defined for Type I above (Figure 22-6b).

Type V. A distribution is classified as Type V when it has circular symmetry, being essentially the same at all lateral angles around the luminaire (Figure 22-6c).

Luminaires Near Side of Area. The lateral width classifications that deal with luminaires intended to be mounted near the side of the area to be lighted vary as to the width of

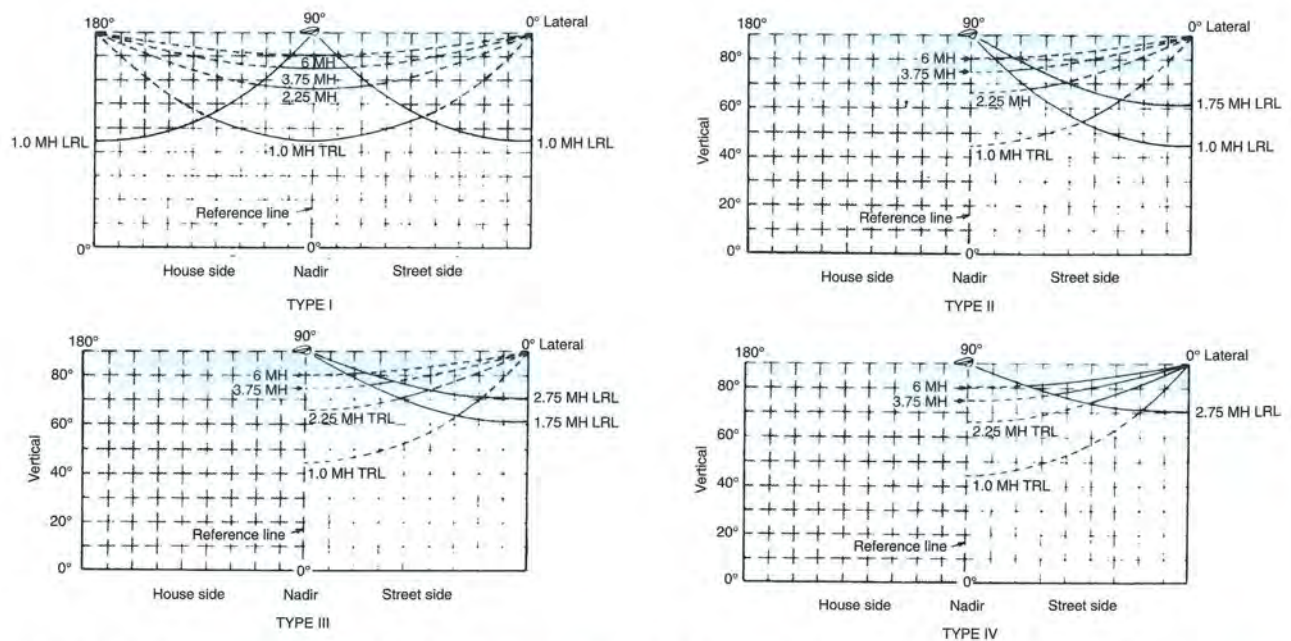


Figure 22-5. Recommended lateral light distribution boundaries on a rectangular coordinate grid (representation of a sphere). Some information omitted for clarity. See Figure 22-3 for a complete diagram.

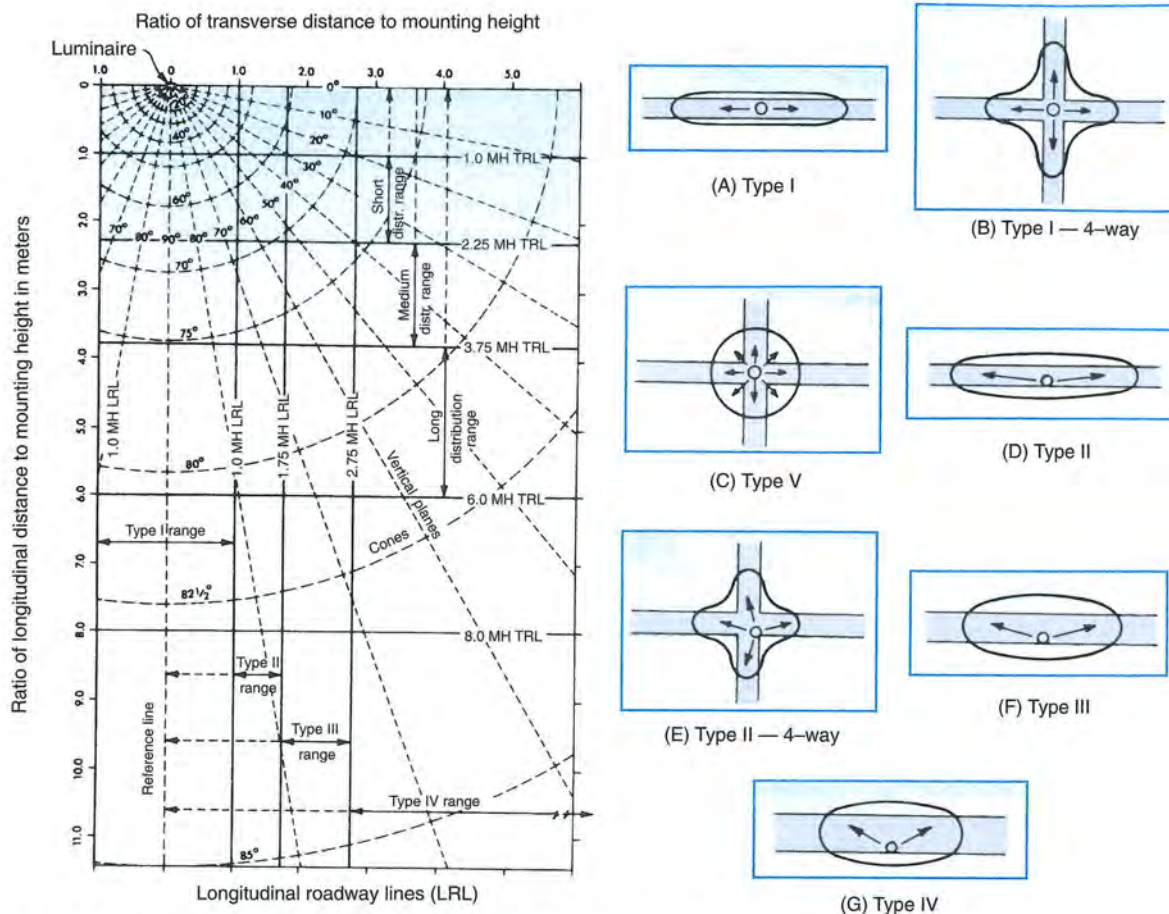


Figure 22-6. Plan view of roadway coverage for different types of luminaires.

distribution range on the street side of the reference line. The house side segment of the half-maximum-intensity isointensity trace within the longitudinal range in which the point of maximum intensity falls (S, M, or L) may or may not cross the reference line. In general it is preferable that the half-maximum-intensity isointensity trace remain near the reference line. The variable width on the street side is as defined by the following.

Type II. A distribution is classified as Type II when the street side segment of the half-maximum-intensity isointensity trace within the longitudinal range in which the point of maximum intensity falls (S, M, or L) does not cross the 1.75-MH street side LRL (Figure 22-6d).

Type II Four-way. A distribution is classified as a Type II four-way when it has four beams, each of the width on the street side as defined for Type II above (Figure 22-6e).

Type III. A distribution is classified as Type III when the street side segment of the half-maximum-intensity isointensity trace within the longitudinal range in which the point of maximum intensity falls (S, M, or L) lies partly or entirely

beyond the 1.75-MH street side LRL, but does not cross the 2.75-MH street side LRL (Figure 22-6f).

Type IV. A distribution is classified as Type IV when the street side segment of the half-maximum-intensity isointensity trace within the longitudinal range in which the point of maximum intensity falls (S, M, or L) lies partly or entirely beyond the 2.75-MH street side LRL (Figure 22-6g).

Control of Distribution Above Maximum Intensity. Although the pavement luminance generally increases on increasing the vertical angle of light flux emission, it should be emphasized that the disability and discomfort glare also increase. However, since the rates of increase and decrease of these factors are not the same, design compromises become necessary in order to achieve balanced performance. Therefore, varying degrees of control of intensity in the upper portion of the beam above maximum intensity are required. This control of the intensity distribution is divided into three categories.

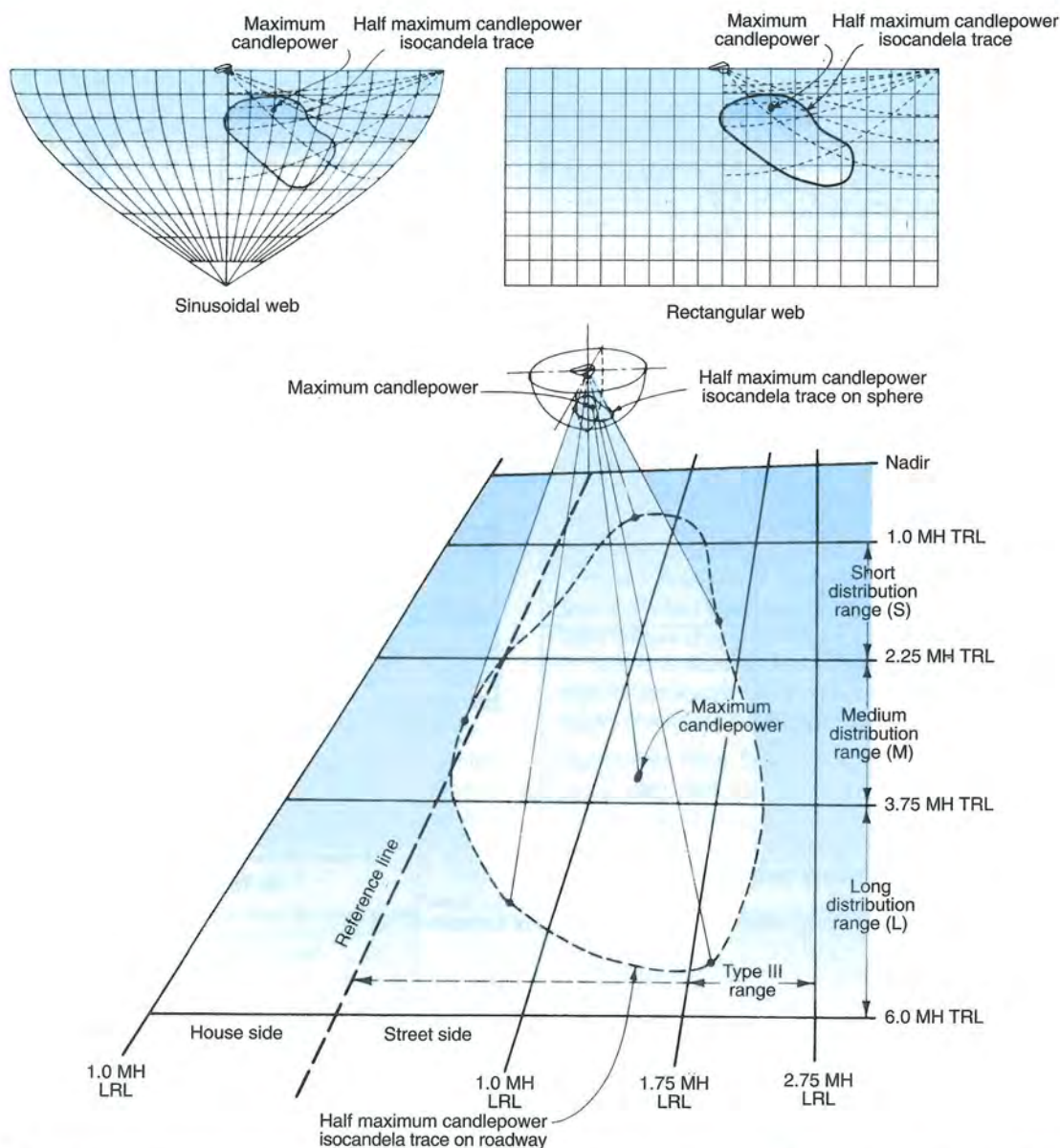


Figure 22-7. Diagram showing projection of maximum candlepower and half-maximum candlepower isocandela trace from a luminaire having a Type III—Medium distribution, on the imaginary sphere and the roadway. Sinusoidal web and rectangular web representation of sphere are also shown with maximum candlepower and half-maximum candlepower isocandela trace.

Full Cutoff. A luminaire light distribution where zero candela intensity occurs at an angle of 90° above nadir, and all greater angles from nadir. Additionally, the candela per 1000 lamp lumens does not numerically exceed 100 (10%) at an angle 80° above nadir. This applies to all lateral angles around the luminaire.

Cutoff. A luminaire light distribution is designated as cutoff when the intensity per 1000 lamp lumens does not numeri-

cally exceed 25 (2.5%) at an angle of 90° above nadir (horizontal), and 100 (10%) at a vertical angle of 80° above nadir. This applies to any lateral angle around the luminaire. (In some cases the cutoff distribution may meet the requirements of the semicutoff distribution.)

Semicutoff. A luminaire light distribution is designated as semicutoff when the intensity per 1000 lamp lumens does not numerically exceed 50 (5%) at an angle of 90° above

nadir (horizontal), and 200 (20%) at a vertical angle of 80° above nadir. This applies to any lateral angle around the luminaire. (In some cases the semicutoff distribution may meet the requirements of the noncutoff distribution.)

Noncutoff. This is the category in which there is no intensity limitation in the zone above maximum intensity.

Variations. With the variations in roadway width, type of surface, luminaire mounting height, and spacing found in actual practice, there are a large number of ideal lateral distributions. For practical applications, however, a few types of lateral distribution patterns may be preferable to many complex arrangements. This simplification of distribution types is more easily understood, and consequently there is greater assurance of proper installation and more reliable maintenance.

When luminaires are tilted upward, the angle of the street side light distribution is raised. Features such as cutoff or width classification may be changed appreciably. When the tilt is planned, the output of the luminaire should be measured and the light distribution classified in the position in which it will be installed.

Type I, II, III, and IV lateral light distributions can vary across transverse roadway lines (except for the line that includes the maximum intensity) so as to provide adequate coverage of the rectangular roadway area involved. The width of the lateral angle of distribution required to adequately cover a typical width of roadway varies with the vertical angle or length of distribution as shown by the TRL. For a TRL at 4.5 MH, the lateral angle of distribution for roadway coverage is obviously narrower than that required for a TRL at 3.0 MH or 2.0 MH.

Luminaire Selection

Luminaire light distribution classification helps to determine the optical and economical suitability of a luminaire for lighting a particular roadway from the proposed mounting height and location. A wide selection of light distribution systems is available.

Simply because a luminaire is assigned a particular classification, there is no assurance that it produces the recommended quantity and quality of lighting for all roadway configurations and mountings shown in Figure 22-4. The relative amount and control of light in areas other than the cone of maximum intensity are equally important in producing good visibility in the final system but are not considered in the classification system.

LIGHTING DESIGN

The lighting system of a specific road section should accommodate the visual needs of night traffic (vehicular and pedestrian) and be expressed in terms clearly understandable by lighting designers, traffic engineers, and highway administrators.

The visual environmental needs along the roadway can be described in terms of pavement illuminance and luminance, uniformity, and direct glare produced by the system light sources. Figure 22-8a provides recommended luminance design requirements and uniformity. It also specifies the relationship between the average luminance L_{avg} , which is the average of all of the luminances values calculated for the section of roadway under consideration, and the veiling luminance L_v , which is defined later in this chapter.

The visual needs along the roadway can also be satisfied by the use of illuminance criteria. Figure 22-8b provides the recommended illuminance design requirements, considering the differences in roadway reflectance characteristics. The designer should not expect the lighting systems designed under the two sets of criteria to provide identical results.

The design of a roadway lighting system involves consideration of visibility, economics, aesthetics, safety, and environmental conditions, as well as appropriate material and equipment. The design process follows these major steps:

1. Determination of roadway classification and adjacent area classification along the specific road section to be lighted. There are three types of area classification: commercial, intermediate, and residential. If the pavement classification is unknown, use the R3 values of Figure 22-8.
2. (a) Selection of the level and uniformity of pavement luminance and assessment of the relationship between the veiling luminance and the average pavement luminance, as recommended in Figure 22-8a for each different area classification along the section, or
(b) Determination of the roadway pavement classification, desired average horizontal illuminance, and uniformity for design as recommended in Figure 22-8b.
3. Preliminary selection of several luminaires and light sources.
4. Preliminary selection of one or more lighting system geometries, including mounting heights and lateral luminaire positions, that may provide an acceptable design based on recommended illuminance, uniformity, and glare.
5. Calculation of either pole spacing for the various luminaire and lamp combinations under study, if for a new system, or lamp output requirements, if existing poles are to be reused, based on illuminance values. Mounting height and lateral luminaire positions can also be considered to verify meeting the requirements of Figure 22-8a or b.
6. When luminaires have been selected, borderline situations quickly become evident during the application stage. In most cases, skilled judgment must be exercised when considering luminaires for a specific system. It may not be appropriate to specify only one light distribution when it is obvious that several

Figure 22-8. Recommended Maintained Luminance and Illuminance Values for Roadways

(a) Maintained Luminance Values (L_{avg}) in Candelas per Square Meter*					
Road and Area Classification		Average Luminance	Luminance Uniformity		Veiling Luminance Ratio (maximum)
		L_{avg}	L_{avg} to L_{min}	L_{max} to L_{min}	L_v to L_{avg}
Freeway Class A		0.6	3.5 to 1	6 to 1	0.3 to 1
Freeway Class B		0.4	3.5 to 1	6 to 1	0.3 to 1
Expressway	Commercial	1.0	3 to 1	5 to 1	0.3 to 1
	Intermediate	0.8	3 to 1	5 to 1	
	Residential	0.6	3.5 to 1	6 to 1	
Major	Commercial	1.2	3 to 1	5 to 1	0.3 to 1
	Intermediate	0.9	3 to 1	5 to 1	
	Residential	0.6	3.5 to 1	6 to 1	
Collector	Commercial	0.8	3 to 1	5 to 1	0.4 to 1
	Intermediate	0.6	3.5 to 1	6 to 1	
	Residential	0.4	4 to 1	8 to 1	
Local	Commercial	0.6	6 to 1	10 to 1	0.4 to 1
	Intermediate	0.5	6 to 1	10 to 1	
	Residential	0.3	6 to 1	10 to 1	

(b) Average Maintained Illuminance Values (E_{avg}) in Lux†					
Road and Area Classification		Pavement Classification			Illuminance Uniformity Ratio E_{avg} to E_{min}
		R1	R2 and R3	R4	
Freeway Class A		6	9	8	3 to 1
Freeway Class B		4	6	5	
Expressway	Commercial	10	14	13	3 to 1
	Intermediate	8	12	10	
	Residential	6	9	8	
Major	Commercial	12	17	15	3 to 1
	Intermediate	9	13	11	
	Residential	6	9	8	
Collector	Commercial	8	12	10	4 to 1
	Intermediate	6	9	8	
	Residential	4	6	5	
Local	Commercial	6	9	8	6 to 1
	Intermediate	5	7	6	
	Residential	3	4	4	

Notes1. L_v = veiling luminance

2. These tables do not apply to high mast interchange lighting systems, e.g., mounting heights over 20 meters. See Fig. 24-9.

3. The relationship between individual and respective luminance and illuminance values is derived from general conditions for dry paving and straight road sections. This relationship does not apply to averages.

4. For divided highways, where the lighting on one roadway may differ from that on the other, calculations should be made on each roadway independently.

5. For freeways, the recommended values apply to both mainline and ramp roadways.

* For approximate values in candelas per square foot, multiply by 0.1.

† For approximate values in footcandles, multiply by 0.1.

- different luminaire light distributions provide improved performance for a specific application.
7. Selection of final decision or reentry of the design process at any step above to achieve an optimal design.

8. Selection of luminaire supports (pole and bracket) that result in an acceptable aesthetic appearance, adherence to traffic safety practice, low initial construction cost, and minimal operation and maintenance expenses.

The formation of a preliminary design involves many variables not explicitly described here. The choice of light source, the extent to which available electrical distribution facilities are used, and the types of poles, brackets, and luminaires selected are some of the factors that influence the economics of lighting. Any consideration of appearance must be resolved by professional judgment and can be justified only if the basic requirements of good visibility have first been attained. It is important that roadway lighting be planned on the basis of traffic and past accident information, which includes the factors necessary to provide for traffic safety and nighttime pedestrian security.

Roadway conditions may also affect the final design. These include the width of the pavement and location of curbs adjacent and within the roadway (island and medians); pavement reflectance; severe grades and curves; location and width of sidewalks and shoulders; type and location of very high volume driveways, intersections, and interchanges; underpasses and overpasses; and trees.

Lighting System Depreciation

The recommended values of Figures 22-8, 22-9, and 22-10 represent the lowest in-service luminance or illuminance values for the type of maintenance to be given to the system. Prior to beginning the design of a lighting system it is necessary to determine the expected light losses. Since luminance or illuminance values can depreciate by 50% or more between relamping and luminaire washing cycles, it is imperative to use lamp lumen depreciation (LLD) and luminaire dirt depreciation (LDD) factors that are valid and based on realistic information or judgment. See Chapter 9, Lighting Calculations, for the use of light loss factors in calculations.

Changes in Pavement Reflectance

Pavement luminance values can be changed by wear on the road surface, resulting in modifications of the reflectance

Figure 22-9. Recommended Maintained Illuminance Design Levels for High Mast Lighting* in Lux†

Road Classification	Horizontal Illuminance (E_{avg}) in Lux		
	Commercial Area	Intermediate Area	Residential Area
Freeways	6	6	6
Expressways	10	8	6
Major	12	9	6
Collector	8	6	6

* Recommended uniformity of illumination is 3 to 1 or better; average-to-minimum for all road classifications at the illuminance levels recommended above. These design values apply only to the travelled portions of the roadway. Interchange roadways are treated individually for purposes of uniformity and illuminance level analysis.

† For approximate values in footcandles, multiply by 0.1.

Figure 22-10. Recommended Average Maintained Illuminance Level for Pedestrian Ways* in Lux†

Walkway and Bikeway Classification	Minimum Average Horizontal Levels (E_{avg})	Average Vertical Levels For Special Pedestrian Security (E_{avg})‡
Sidewalks (roadside) and Type A bikeways:		
Commercial areas	10	22
Intermediate areas	6	11
Residential areas	2	5
Walkways distant from roadways and Type B bikeways:		
Walkways, bikeways, and stairways	5	5
Pedestrian tunnels	43	54

* Crosswalks traversing roadways in the middle of long blocks and at street intersections should be provided with additional illumination.

† For approximate values in footcandles, multiply by 0.1.

‡ For pedestrian identification at a distance. Values at 1.8 meters (6 feet) above walkway.

coefficient. For example, asphalt tends to lighten because of exposure of aggregate, and Portland cement darkens because of carbon and oil deposits.

Quality

Quality lighting relates to the ability of the lighting system to provide target and obstacle contrast so that people can make decisions based on fast and accurate obstacle detection and recognition. If the quality of one lighting installation is higher than that of a second installation for the same average luminance (or illuminance) level, then visual detection of typical tasks are faster and easier under the first installation. Important lighting quality considerations for roadways are source/task/eye geometry, shadows, direct glare, reflected glare, peripheral detection, light distribution on surfaces, appearance of spaces and luminaires, light pollution/trespass, and vertical illuminance.

Uniformity

Uniformity is usually expressed in one of three ways: the average-to-minimum, minimum-to-maximum, or maximum-to-average ratio. In roadway lighting, the average-to-minimum and maximum-to-minimum ratios are usually used. The average-to-minimum point method uses the average luminance of the roadway design area between two adjacent luminaires, divided by the lowest value at any point in the area. The maximum-to-minimum point method uses the maximum and minimum values between the same adjacent luminaires.

The luminance values provided in Figure 22-8a are considered to be satisfactory only if the average-to-minimum and maximum-to-minimum uniformity ratios do not exceed the limits specified in this figure. The illuminance values given in Figure 22-8b are satisfactory if the average-to-minimum uniformity ratios are not exceeded. The luminance uniformity (average-to-minimum and maximum-to-minimum) considers the traveled portion of the roadway, except for divided highways, which may have different design requirements on each side of the roadway.

It is important in the actual design of the roadway lighting system that actual photometric data be used for the calculations rather than generic data. This assures that the lighting results achieved match the predicted values, within the normal limits of the calculations.

Luminaire Mounting Height

Mounting heights of luminaires have, in general, increased substantially during the past several decades. The advent of more efficient, higher-lumen lamps has been the primary reason. Designers have increased mounting heights in order to obtain economic and aesthetic gains in addition to increased uniformity of luminance and illuminance values when utilizing modern, high-wattage lamps. Mounting heights of 12 m (40 ft) and higher are used along roadways, and the cluster mounting of luminaires is used at interchanges. The advent of suitable servicing equipment and lowering devices has made this practical.

During this same period, there has been another trend to lower mounting heights in some cases. In general, this has been due to aesthetic considerations. An example is the use of pole top-mounted luminaires in residential areas.

When designing a system, mounting height should be considered in conjunction with spacing and lateral positioning of the luminaires as well as the luminaire type and distribution (Figure 22-11). Uniformity and levels of luminance

and illuminance should be maintained as recommended regardless of the mounting height selected.

Increased mounting height may, but does not necessarily, reduce discomfort glare and veiling luminance. It increases the angle between the luminaires and the line of sight to the roadway; however, luminaire light distributions and intensity also are significant factors. Glare is dependent on the flux reaching the observer's eyes from all luminaires in the visual scene.

High-Mast Interchange Lighting

High-mast interchange lighting is defined as the use of a group of luminaires mounted more than 20 m (60 ft) in height. It is intended to light multiple sections of the paved roadway of an interchange.

The design levels of Figure 22-8 have not been proven to apply to high-mast interchange lighting systems. This is due to a lack of applicable experience in the design of such lighting on a luminance basis. Experience indicates that a system designed to the illuminance criteria in Figure 22-9 gives satisfactory results.

Luminaire Spacing

The spacing of luminaires is often influenced by the location of utility poles, block lengths, property lines, and roadway geometry. It is generally more economical to use lamps with high lumen output at longer intervals and higher mounting heights than to use lamps with lower lumen output at more frequent intervals with lower mounting heights. Higher mounting is usually in the interest of good lighting, provided the spacing-to-mounting-height ratio is within the range of lighting distribution for which the luminaire is designed. Terminology with respect to luminaire arrangement and spacing is shown in Figure 22-4.

Other factors to be considered are:

- Access to luminaires for servicing
- Vehicle-pole collision probabilities
- System glare aspects
- Visibility (both day and night) of traffic signs and signals
- Aesthetic appearance
- Trees
- Locations of poles at intersections to allow joint use for traffic signals

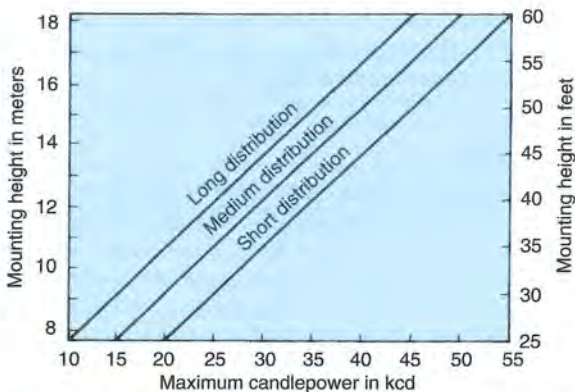


Figure 22-11. Minimum luminaire mounting heights based on current practice and veiling luminance calculations.

Situations Requiring Special Consideration

Roadways have many areas where the problems of vision and maneuvering of motor vehicles are complex, such as grade intersections, abrupt curves, underpasses, converging traffic lanes, diverging traffic lanes, and various types of complicated traffic interchanges. The values in Figure 22-8 are for roadway sections that are continuous and nearly

level. Intersecting, merging, or diverging roadway areas require special consideration. The luminance or illuminance levels for these areas should be at least equal to the sum of the recommended values associated with each roadway that forms the intersection. Very high volume driveway connections to public streets and midblock pedestrian crosswalks should be lighted to a level at least 50% higher than the average route value.

The lighting of such areas, at first glance, appears to be a very complicated problem. It becomes apparent upon analysis, however, that all such areas consist of one of several basic types of situations or a combination of these.

Grade Intersections, Balanced Heavy Traffic. These intersections (Figure 22-12a) may have unrestricted traffic flow on both roadways, restriction by means of stop signs on one or both of the roadways, or control of the traffic by signal lights, traffic officers, or other means. Some intersections are complicated by pedestrian traffic as well as vehicular traffic. The lighting problems on all of these, however, are fundamentally the same. The luminance level in these areas should be higher than that on either intersecting road. See also the subsections on converging and diverging traffic lanes below.

Luminaires should be located so that illumination is provided on vehicles and pedestrians in the intersection area, on the pedestrian walkways, and on the adjacent roadway areas. Of particular importance here is the amount of light falling on the vertical surfaces of such objects that differentiates them from the pavement background against which they are seen.

Figure 22-12b shows a larger, more complex grade intersection. The lighting problems and techniques here are similar to those at the smaller intersections. The size, however, may make the use of more and larger luminaires mandatory.

Curves and Hills. The visual problems in motor vehicle operation increase on curves and hills. In general, gradual large-radius curves, roadways with appropriate super elevation (the vertical distance between the inner and outer edges of the roadway), and gently sloping grades are lighted satisfactorily if treated like straight, level roadway surfaces (Figure 22-13). Sharper curves and steeper grades, especially at the crests of hills, warrant closer spacing of luminaires in order to provide higher pavement luminance and improved uniformities (Figure 22-13e and f).

The geometry of abrupt curves, such as those found on traffic interchanges and many roadway areas, requires careful analysis. Headlighting is not effective in these situations, and silhouette seeing (a condition where the target, or obstacle, has a lower luminance than the background) cannot be provided in some instances. Luminaires should be located to provide ample illumination on vehicles, road curbing and berms, guard rails, and so on. Poles should be located to provide adequate, safe clearance behind guardrails or any natural barriers that may exist. There is some evidence that poles are more likely to be involved in accidents if placed on the outside of curves. Many vehicle operators may be unfa-

miliar with these areas, and illumination on the surround greatly helps their discernment of the roadway path (Figure 22-13c and d).

Proper horizontal orientation of luminaire supports and poles on curves is important to assure balanced distribution of the light flux on the pavement (Figure 22-13a). When luminaires are located on grade inclines, it is desirable to orient the luminaire so that the light beams strike the pavement equidistant from the luminaire. This assures maximum uniformity of light distribution and keeps glare to a minimum (Figure 22-13b).

Underpass-Overpass. Short underpasses such as those encountered where a roadway goes beneath a two- or four-lane roadway generally can be lighted satisfactorily with standard luminaires if they are properly positioned (Figure 22-12e). Luminaires on the lower roadway should be positioned so that there are not large discontinuities in the pavement lighting from that on either side of the overpass and so that the recommended levels are provided. Care should be taken so that the uniformity does not fall below the minimum values recommended in Figure 22-8. These luminaires should also provide adequate vertical illumination on the supporting structures.

Longer underpasses, where such overlapping of the illumination from the street luminaires cannot be accomplished, require special treatment. Such underpasses also greatly reduce the entrance of daylight, warranting illumination during the daytime. Very high luminance levels can be justified in order to reduce the required adaptation, particularly during daylight hours. In many cases, the techniques used for tunnel lighting can be used effectively for lighting these longer underpasses.

Diverging Traffic Lanes. Diverging traffic lanes warrant extremely careful consideration because these are areas where motorists are most frequently confused. Luminaires should be placed to provide illumination on curbs, abutments, guardrails, and vehicles in the area of traffic divergence (Figure 22-12c). Poles should be located to provide adequate safety clearance for vehicles that may cross the gore area. Lighting also should be provided in the deceleration zone. Diverging roadways frequently have all the problems of abrupt curves and should be treated accordingly.

Converging Traffic Lanes. Converging traffic lanes (Figure 22-12d) frequently have all the problems of abrupt curves. Here, automobile headlighting is ineffective, and silhouette seeing cannot be provided for many of the situations. It is also essential to provide good direct side illumination on the vehicles entering the main traffic lanes.

Interchanges: High-Speed, High-Traffic-Density Roadways. Interchanges at first glance appear to be complex lighting problems. Analysis, however, shows that they are composed of one or more of the basic problems that are discussed in previous sections of this chapter and can be treated accordingly.

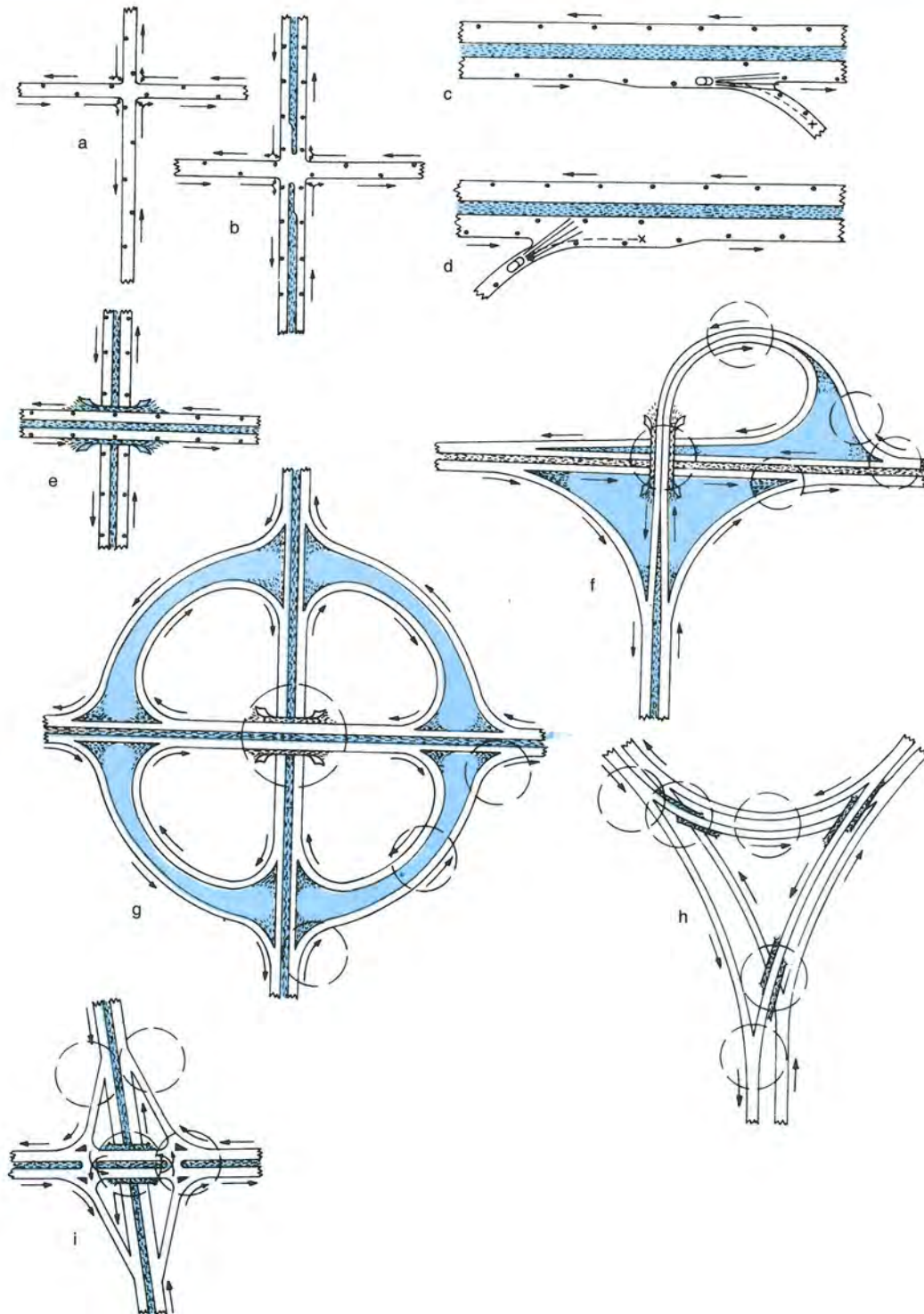


Figure 22-12. Roadway complexities. (a) Grade intersection, balanced heavy traffic. (b) Larger, more complex grade intersection. (c) Diverging traffic lanes. (d) Converging traffic lanes. (e) Underpass—overpass. (f) to (i) Traffic interchanges. Note: Arrows indicate traffic flow directions. Pole location will depend on local practice and physical conditions of the area.

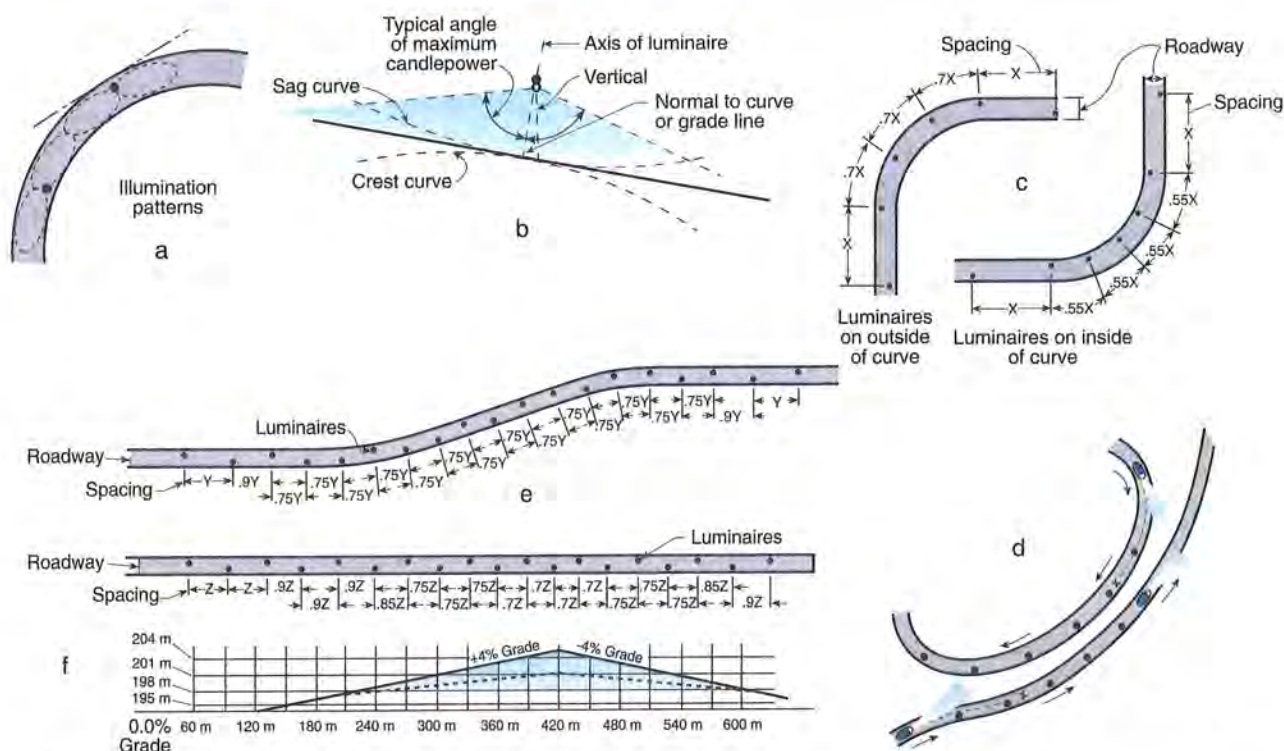


Figure 22-13. Typical lighting layouts for horizontal curves and vertical curves. (a) Luminaires oriented to place reference plane perpendicular to radius of curvature. (b) Luminaire mounting on hill (vertical curves and grade). (c) Short radius curves (horizontal). (d) Vehicle illumination will fall outside the roadway when approaching a curve. Roadway luminaires must be located to compensate for the illumination lost when this occurs. (e) Horizontal curve, radius 305 meters (1000 feet), super elevation six percent per foot. (f) 380-meter (1250-foot) vertical curve with four-percent grade and 230-meter (750 foot) sight distance. (In this illustration, 30 m = 100 ft.)

When designing lighting for interchanges (Figure 22-12f through i), the regular roadway lighting system usually provides sufficient surround illumination in the field of view to reveal features of the entire scene and to allow drivers to know at all times where they are and where they are going. An inadequately lighted interchange with too few luminaires may lead to confusion for the driver by giving misleading clues due to the random placement of the luminaires. (This does not apply to high-mast lighting.)

When continuous illumination for the entire interchange area cannot be provided, it may be desirable to illuminate intersections, points of access and egress, curves, hills, and similar areas of geometrical and traffic complexity. In these cases, illumination should be extended beyond the critical areas. There are two fundamental reasons for this:

- The eyes of the driver, adapted to the level of the lighted area, need about 1 s to adjust to changes in the illumination upon leaving the lighted area and must maintain vision during this period of dark adaptation. There is no evidence that a gradual reduction at the levels used in roadway lighting has

any practical advantage over a sudden ending of the lighted area. This end, however, should be beyond the end of the maneuver area.

- Traffic merging into a major roadway from an access road is often slow in accelerating to the speed on the major roadway. The lighting along this area for a distance beyond the access point extends visibility and facilitates the acceleration and merging process.

The placement of luminaires should be carefully considered so as to minimize glare for the drivers and, especially, so as not to detract from sign legibility or block the view of signs.

Railroad Grade Crossings. Railroad grade crossings should be adequately lighted to allow identification of the crossing, any irregularities in the pavement surface, and the presence or absence of the train in or approaching the crossing, and to allow recognition of unlighted objects or vehicles at or near the railroad crossing. Grade crossings are normally identified by means of signs with the message on a vertical face, as well as markings on the pavement surface. The lighting direction and level should permit visual recog-

dition of such signs and markings. Minor variation of the basic lighting layouts shown in Figure 22-14 may be desirable, depending on the exact locations of the signs or markings.

General principles to be followed in selecting and locating equipment are as follows:

- The illuminance level on a track area starting 30 m (100 ft) before the crossing and ending 30 m (100 ft) beyond it should be in accordance with Figure 22-8, but never less than a luminance of 0.8 cd/m^2 or an illuminance of 8 lx (0.8 fc) (Figure 22-14a).
- Pole location should provide uniformity (Figure 22-14b through f) as outlined above in the section "Uniformity."
- Vertical illumination of a train in a crossing is important for adequate visibility. However, care must be used in locating the luminaire so that glare is not a problem to the drivers approaching the crossing from the opposite direction.

Trees. Trees are important community assets. Careful placement of luminaires and regular tree pruning not only enhance traffic safety and pedestrian security but also preserve the character and appearance of a neighborhood. In order for the lighting designer to determine suitable overhang distances of luminaires for different mounting heights, the characteristics of the different types of trees must be known.

Most tree growers or municipal arborists can provide specifications of selected trees such as shape, height, and growth circumference, which help develop a spacing pattern for street lights and trees. Large round-headed trees require more spacing between the street light and tree than a pyramidal, oval, or columnar tree. A successful result requires cooperation between the lighting designer, landscape architect, developer, and local forestry division early in the design process. In the long run, proper spacing between street lights and trees allows more light on the street and sidewalk, and the trees are allowed to grow naturally with little or no pruning. Mismatched, as well as misplaced, trees and street lights usually become a detriment to the local municipal authority, the community, and the adjacent property owner.

Because of the recent trend to use ornamental post-top lights in urban, suburban, and subdivision designs, reasonable spacing (e.g., at least one mounting height between tree and street light) should become part of the design scheme. When using a mast-arm pole, similar concerns should be made to assure that pedestrians have adequate lighting on the sidewalk. For mast-arm designs, see Figure 22-15.

Deviations from ideal luminaire spacing may be necessary to accommodate trees. Generally, a 10 to 20% deviation in longitudinal spacing of luminaires does not seriously affect lighting uniformity, depending on the luminaire photometrics. If more than two consecutive luminaires are involved, care should be taken not to create unacceptable

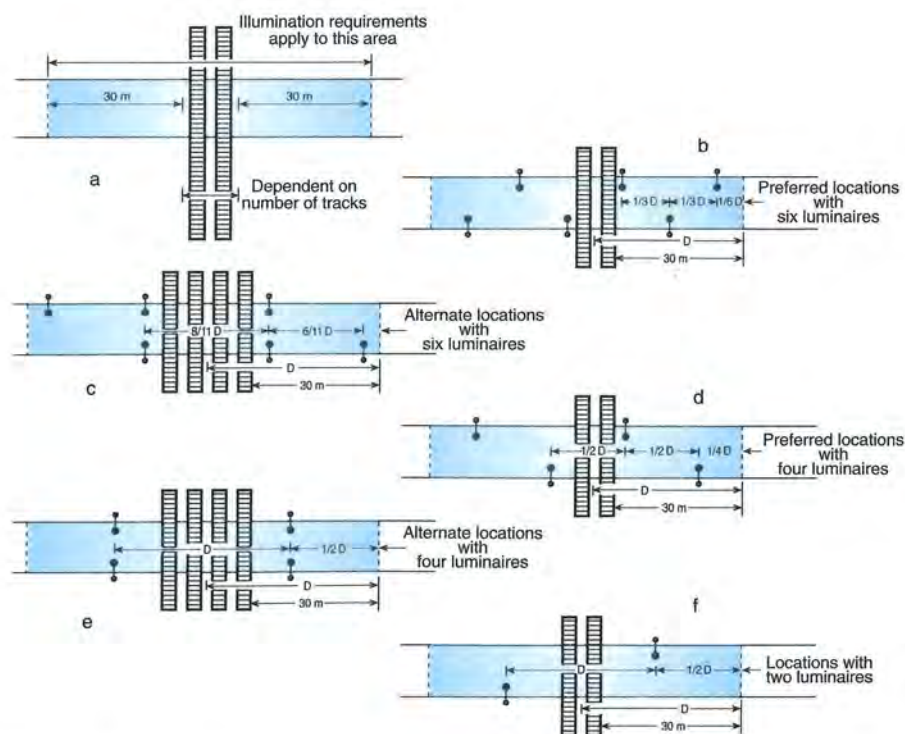


Figure 22-14. Railroad grade crossings.

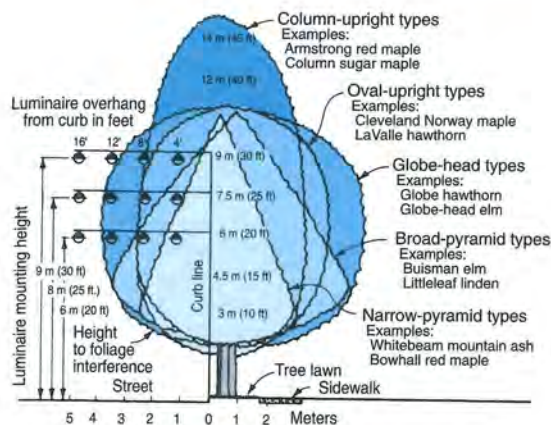


Figure 22-15. Height of foliage interference for different types of trees. Luminaire overhang must be selected to assure luminaire distribution will not be obstructed by the foliage as the tree matures. (Tree examples by E. H. Scanlon.)

shadows or dark spots. Only as a last resort should deviation be permitted in the transverse overhang of the luminaires. This positioning is important for effectiveness of the lighting and appearance of the system. This latter point can be very important in regard to local residential streets.

In most cities trees are trimmed on a select basis as opposed to a formal tree trimming plan and in these cases the trimming is accomplished by the local utility. The method and manner for trimming trees should be supervised by an arborist. Most cities and large utilities have an arborist as part of the tree trimming crews.

Roadside Border Areas

Visibility for drivers can be improved if areas beyond the roadway proper are illuminated. It is desirable to widen the narrow visual field into the peripheral zone in order to reveal adjacent objects. Such conditions also improve depth perception and perspective, thereby facilitating the judgment of speed and distance. The luminance of border areas should diminish gradually and uniformly away from the road. Of course, these points must be considered in the context of local property owners; the design must eliminate objectionable light trespass.

Transition Lighting

Transition lighting is a technique intended to provide the driver with a gradual reduction in illuminance when traveling from one roadway area into another. Factors that may influence the decision to provide a transition lighting area are:

- Significant reduction in roadway cross section
- Severe horizontal or vertical curvature of the roadway

- Change from a very high lighting level to a lower level

The use of transition lighting is the option of the designer after a study of the conditions at a specific location.

Gradual decreases in pavement luminance are usually accomplished by extending the lighting system beyond the normal limits and partially interrupting the required geometric arrangement of luminaires. For example, a two-side opposite or staggered spacing arrangement could be continued to the normal lighting limits, where luminaires would be omitted from the exiting side of the roadway but continued for one to six cycles beyond the normal limits on the approach side, depending on road speed and luminaire coverage. Designer judgment should be used, and various geometric arrangements should be considered.

Alleys

A well-lighted alley increases the perception of safety and reduces criminals' opportunities to operate and hide under the cover of darkness. Alleys should be lighted to facilitate police patrolling from sidewalks and cross streets, especially in commercial areas. Generally, such lighting also meets the vehicular traffic needs in these low-traffic areas.

Pedestrian Walkways and Bikeways

Proper lighting of walkway and bikeway areas is essential to the safe and comfortable use of pedestrian areas (herein assumed to include bicyclists) at night. Many walkways and bikeways are located adjacent to lighted roadways, and no specific or separate lighting is required. Often, however, the roadway spill light is inadequate for the comfort and safety of pedestrians on the walkway or bikeway. Important lighting criteria for walkways and bikeways are source/task/eye geometry, color appearance, shadows, direct and reflected glare, peripheral detection, modeling of faces and objects, light pollution/trespass, and vertical illuminance.

It is recommended that all lighting designs conform to the illuminance requirements shown in Figure 22-10. If the roadway illumination does not provide the recommended walkway or bikeway levels, revisions or additions to the roadway lighting are necessary. The photometric data provided by the supplier of the roadway luminaires can be used for evaluating Type A or Type B sidewalk or roadway bikeway illuminance recommendations.

The recommended levels of walkway and bikeway illuminance listed in Figure 22-10 represent average maintained illuminance levels and should be considered as minimum, particularly when security and pedestrian identification at a distance is important. Visual identification of other pedestrians and objects along walkways is dependent to a great degree on vertical surface illuminance; therefore, different values are shown in the table. To provide well-lighted surroundings for such pedestrian ways as walkways and bike-

ways through parks, additional information is provided in Chapter 21, Exterior Lighting.

The average-to-minimum uniformity ratio in illuminating pedestrian ways where special pedestrian security is not essential should not exceed 4:1, except for residential sidewalks and Type A bikeways in residential areas, where a ratio of 10:1 is acceptable. Where increased pedestrian security is desired, the uniformity ratio should not exceed 5:1 for any walkway or bikeway.

Tunnels^{3,4}

Tunnel lighting should provide good visibility for drivers, both day and night. The many factors that contribute to or detract from visibility need to be identified and their specific importance determined for each tunnel. Important lighting criteria for tunnels are shadows, direct glare, reflected glare, peripheral detection, and vertical illuminance.

Physical Characteristics. For lighting purposes a tunnel is an enclosure over a roadway that restricts the normal illumination of the roadway by daylight, thus requiring an evaluation of the need for supplemental lighting. This enclosure may be created either by boring through natural materials such as earth and rock, or by construction using materials such as steel and concrete. The terminology associated with tunnels for the purpose of lighting design is described in Figure 22-16.

Depending on the length and the safe-stopping sight distance (SSSD), tunnels can be classified in two categories (Figure 22-17):

- Short tunnel. A tunnel having an overall length, from portal to portal along the centerline, equal to or less than the SSSD.
- Long tunnel. A tunnel with an overall length greater than the SSSD.

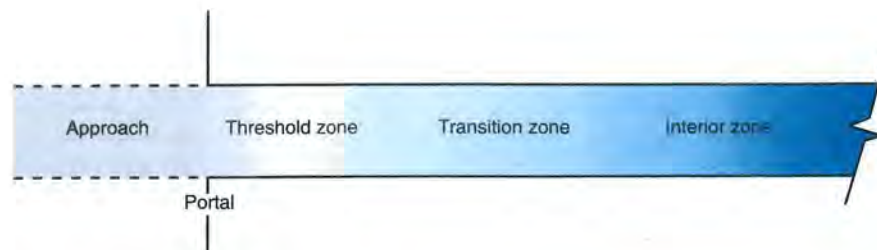


Figure 22-16. Descriptive terms associated with tunnel lighting.:

Approach: The external roadway area leading to the tunnel;

Portal: The plane of entrance into the tunnel;

Threshold Zone: The first part of the tunnel where, during daytime, the highest level of the lighting is provided;

Transition Zone: The area where a transition is made from the high lighting level of the threshold to the lower lighting level of the interior.

Interior Zone: The innermost part of the tunnel where the lowest level of lighting is provided.

Note: Lengths of zones will vary with the design parameters.

Figure 22-17. Safe Stopping Sight Distance*

Traffic Speed		Minimum Safe Stopping Sight Distance (SSSD)†	
Kilometers per Hour	Miles Per Hour	Meters	Feet
48	30	60	200
64	40	90	300
80	50	140	450
88	55	165	540
96	60	200	650
104	65	220	720

* Based on American Association of State Highway and Transportation Officials (AASHTO) recommendations. See *A Policy on Geometric Design of Highways and Streets*, 1984, AASHTO, 444 No. Capitol Street N.W., Suite 225, Washington, DC 20001.

† Assumes average prevailing speeds in a straight and level tunnel approach roadway are at, or near, the posted speed limit of the facility. For other geometric conditions, refer to the AASHTO standard as referenced.

The critical task facing the driver approaching the tunnel entrance portal during the daytime is to overcome the “black hole” effect created by the high ratio of external to internal luminance. The use of dark finish material on the approach road surface to the tunnel portal, and light finish material on the road surface inside the portal, for a distance at least equal to the SSSD, reduces the difference between external and internal luminances. The darkening of these external surfaces reduces the luminance level to which the eye is adapted prior to entering the tunnel, thus shortening the time to adapt to the lower luminance levels within the tunnel. For tunnels with a prominent sky background immediately above their entrance portals, objects such as plants, screens, and panels can increase the size of the darkened area above the portals.

To use daylight and supplemental electric lighting effectively, it is recommended that interior wall surfaces be of an

easily maintained, high-reflectance, nonspecular finish having a reflectance of at least 50% initially. In tunnels having curved roadways or having curved approach roadways, development of high wall luminance is of great value in meeting visibility needs. Relatively narrow tunnels, where the width-to-height ratios are approximately 3 or less, normally develop good tunnel visibility as a result of reflected light from high-reflectance walls. Tunnels having greater width-to-height ratios normally require supplemental lighting of the roadway surface.

The amount and extent of daylight penetration into the tunnel entrance is largely dependent on the orientation of the tunnel with respect to the sun's path in the sky. Since the orientation of a tunnel is generally directed by criteria other than illumination considerations, the tunnel lighting system must be able to accommodate the entrance orientation conditions. In entrance portal areas, sunlight penetration can be improved by use of wall, ceiling, and roadway surface texture control.

Lighting Design Considerations. Tunnel lighting design should take into account the following considerations:

- Volume and speed of traffic
- External luminance
- Tunnel classification
- Tunnel luminances during both daytime and nighttime conditions
- Lighting and electrical equipment

Volume and Speed of Traffic. Tunnels with high traffic volume and with high-speed traffic require higher luminance levels than those with lower volume and slower traffic to aid the motorist in performing more difficult driving

tasks. High-volume traffic increases the probability of having to stop quickly or take evasive action. Higher speeds reduce the time available for eye adaptation and reaction to driving difficulties.

External Luminance. Since approaching drivers are looking at the tunnel entrance prior to entering the tunnel, they are adapted to the luminance of the portal area and the surrounding visual scene.

Tunnel Classification. Short tunnels, with a length of less than the SSSD and having straight, level approach alignment and a straight and level tunnel roadway, may have adequate visibility without supplemental daytime lighting. In these cases, visibility can be provided by negative contrast (silhouette), with high luminance values provided by the exit portal. In tunnels with curved roadways, where the exit portal is not visible, supplemental lighting may be required. These short tunnels should have a single lighting zone equal in luminance to the threshold zone as shown in Figure 22-18. Long tunnels require several zones of lighting.

Tunnel Luminance. Tunnels have several different areas with different lighting requirements. In addition, the time of day plays an important role in the lighting of tunnels. Topics discussed below include the threshold zone, the interior zone, the transition zone, nighttime tunnel lighting, uniformity rules, and maintenance considerations.

Threshold Zone. Daytime tunnel luminance in the threshold zone must be relatively high to provide visibility during eye adaptation as the motorist enters the tunnel. Figure 22-18 gives appropriate daytime threshold zone luminances. During nighttime, the motorist's eyes are adapted to the low ambient exterior luminance; therefore, a nighttime minimum luminance of 2.5 cd/m² is recommended for the entire

Figure 22-18. Recommended Maintained Threshold Zone Average Payment Luminance Values for Tunnel Roadways during Daylight

Characteristics of Tunnel	Traffic Speed		Traffic Volume AADT*			
	Kilometers per Hour	Miles per Hour	< 25,000	25–89,999	90–150,000	> 150,000
			Candelas per Square Meter†			
Mountain tunnels, gradual slopes where snow can accumulate or river tunnels with few surrounding buildings.	≥ 81	50	210	250	290	330
	61–80	38–49	180	220	260	300
	≤ 60	37	140	185	230	270
East/west tunnel orientation						
Mountain tunnels with steep, dark slopes or climate conditions where snow cannot accumulate. Portal surroundings have medium brightness year round.	≥ 81	50	145	175	205	235
	61–80	38–49	130	160	190	220
	≤ 60	37	105	140	170	200
Concealed portals, dark surfaces, or buildings surrounding entrance. Artificial measures taken to reduce exterior brightnesses. North/south orientation.	≥ 81	50	80	100	115	130
	61–80	38–49	70	90	105	120
	≤ 60	37	60	80	95	110

* Average Annual Daily Traffic in both directions.

† For approximate values in candelas per square foot, multiply by 0.1.

length of the tunnel, including the threshold. Since the illuminance required at the tunnel threshold during nighttime hours is significantly lower than that required during daytime hours, it may be appropriate to provide for dimming or switching the tunnel lighting system to permit adjusting the threshold illuminance to provide appropriate daytime and nighttime levels. As indicated, the required luminance level is dependent on both the characteristics of the tunnel and the traffic speed and volume in the tunnel. The length of the threshold zone lighting should be 15 m (50 ft) less than the SSSD. At approximately 15 m (50 ft) before the portal, the tunnel dominates the visual scene.

Interior Zone: Daytime lighting in the interior of a long tunnel can be reduced, since the motorist's eyes will have adapted to the lower luminance of the threshold zone. Luminance of the tunnel interior zone should be a minimum of 5 cd/m² with a uniformity ratio below 3:1, average-to-minimum.

Transition Zone: Daytime luminance in the transition zone should taper from the threshold zone luminance to the interior zone luminance over a length equal to the SSSD. Transition zone lighting can be accomplished in various ways: greater spacing between luminaires, fewer lamps per luminaire (in the case of fluorescent lamps), lower-wattage lamps, or combinations of the above. The number of sections within the transition zone using different lighting arrangements should be such that an even transition occurs. The transition zone should first be divided into segments of equal length. The first segment after the threshold zone should have a pavement luminance of no less than 25% that of the threshold zone. Each subsequent section should have a pavement luminance no less than 33% that of the previous segment. The last segment before the interior zone should have a pavement luminance no greater than twice that of the interior zone.

Nighttime. During nighttime, the motorist's eyes are adapted to the low ambient exterior luminance; therefore, a nighttime minimum luminance of 2.5 cd/m² is recommended for the entire length of the tunnel.

Uniformity Ratios. Uniformity ratios within the tunnel zones should be the same as those used for general roadway lighting as shown in Figure 22-8.

Maintenance Considerations. The recommended luminance values given for tunnels in Figure 22-18 represent the lowest in-service values that should be allowed throughout the operating life of the system. Therefore, the initial luminance in the tunnel may have to be higher to compensate for lamp lumen depreciation, luminaire dirt depreciation, and tunnel surface dirt depreciation.

Lighting and Electrical Equipment. Fluorescent, HID, and low-pressure sodium lamps are the light sources used most commonly for tunnel lighting installations. Incandescent lamps are seldom used in new installations due to their low efficacy and short life.

Tunnel lighting luminaires must be ruggedly constructed to withstand the harsh environment found in most tunnels. Vibration, air turbulence caused by vehicles, vehicle exhaust fumes, road dirt, salt, and the periodic washing of tunnels with industrial detergents and high-pressure jet spray equipment are some of the conditions to which luminaires are exposed.

The power supply for tunnel lighting must be very reliable. Even a momentary loss of power cannot be tolerated, since it can lead to serious accidents if people enter complete darkness. Safety can be greatly improved by providing power from two separate sources to the entire tunnel lighting system with transfer devices that automatically switch from one power source to the other in the event of power failure. Consideration should be given to the installation of an emergency power supply to luminaires providing at least one-fifth of the design nighttime lighting level. Tunnel lighting requirements may vary during daily operation as a result of external luminances varying with weather or the position of the sun. Some installations have luminaires that can be switched or dimmed automatically with changes in the outdoor luminance or with changes in the luminaire's effective light output. Tunnel systems may also have a manned control room with closed-circuit television surveillance that allows monitoring of tunnel conditions and provides for manual override of the automatic operations.

Flicker Effect. In the interior of a lighted tunnel, where luminaires or their reflected images are in full or partial view of the vehicle occupants, the flicker effect of passing closely spaced light sources may produce undesirable behavioral sensations. The significance of this effect depends on the brightness of the source to the observer, the location of the source in the motorist's viewing field, and the frequency or rate at which successive light sources appear to be moving. The designer should avoid luminaire spacings that produce driveby frequencies of 5 to 10 Hz.⁵

Rest Areas⁶

Rest areas on limited access highways are an important feature to the motorist, and there is general agreement that for the public to obtain maximum benefits from the construction of a rest area, it must be available 24 hours a day and be considered safe to enter and stay in at least for short periods of time. To obtain this condition, these areas must be adequately lighted for nighttime use. Figure 22-19 shows a typical layout for a roadway rest area.

In designing a lighting system for a rest area, geographical location, topographical location, motorists' comfort and safety, landscaping and architectural treatment, and appearance to pedestrians must be considered. An important benefit to be derived from proper lighting is ease of policing these areas during nighttime hours. Important lighting quality criteria for rest areas include color appearance, shadows, direct glare, peripheral detection, modeling of faces and ob-

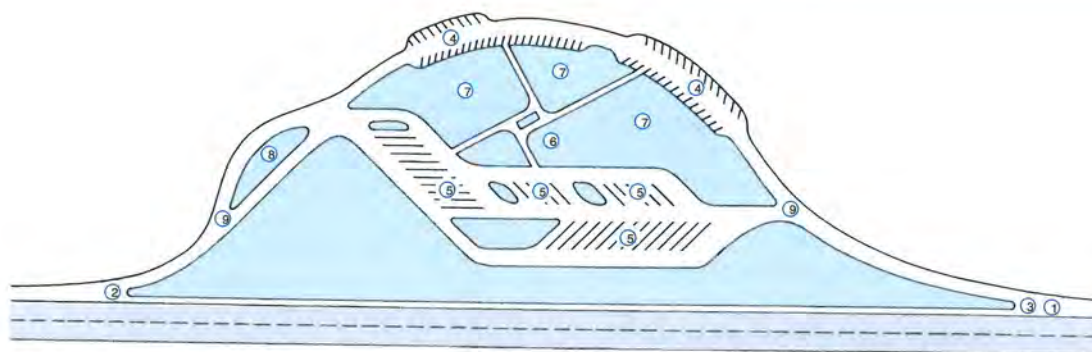


Figure 22-19. Typical layout of roadway rest area, (1) deceleration lanes; (2) acceleration lanes, (3) gore area; (4) automobile parking; (5) truck parking; (6) comfort station; (7) picnic area; (8) waste station; and (9) interior roadway.

jects, points of interest, appearance of space and luminaires, and horizontal and vertical illuminances.

One of the prime design considerations is the motorist's view while traveling along an unlighted main highway or in the rest area. The motorist should not be disturbed by glare or spill light from luminaires placed adjacent to the roadway within the rest areas. While traversing the entire length of the adjacent rest area, the motorist should be able to discern any vehicle leaving the rest area, as well as the traffic moving along the main roadway.

The overall design of the lighting is divided into general areas as follows:

- Entrance and exit
- Interior roadways
- Parking areas
- Activity areas

These have been defined for separate consideration because each is to be used for a different purpose. The illuminances recommended in Figure 22-20 are minimum maintained values.

Entrance and Exit. Entrance and exit areas are defined as the deceleration and acceleration lanes adjacent to the main roadway, leading to and from the gore area. These lanes should be lighted so that the driver entering or leaving the rest area can safely make the transition from the main roadway to the rest area and vice versa. At the same time, drivers electing to continue along the main roadway should be able to do so without impairment of their vision by luminaire brightness or spill light. Drivers should likewise be able to discern vehicles leaving or entering the roadway. The assumption is often made that access lanes to rest areas should be lighted in the same manner as ramps at interchanges; however, interchange ramps are usually designed for higher speeds and traffic densities. Rest area entrances and exits, with relatively low traffic density, are deceleration and acceleration lanes leading to and from low-speed roadways

within the area, and thus must be designed with this purpose in mind.

It is recommended that the illuminance along the deceleration lane be allowed to vary (Figure 22-20), but the maximum illuminance should occur at the gore point between the deceleration lane and the beginning of the interior roadways. Similarly, a high illuminance level should occur at the exit gore. Illumination may decrease from this point to a point where the motorist can be considered to have merged with the through traffic. The motorist on the through lanes must be able to see an exiting vehicle, make a proper decision, and adjust to the traffic flow. The decreased illuminance is desirable for the merging motorist because it facilitates adaptation from the illuminated rest area to the unlighted roadway.

It is recommended that luminaires be used that confine the main light to the deceleration and acceleration lanes and restrict high-angle brightness. In the event that the main

Figure 22-20. Recommended Illuminance Levels for Roadway Rest Areas*

Rest Area	Illuminances**		Uniformity† Ratio
	Lux	Footcandles	
Entrance and Exit			
Access Lanes	3 to 6	.3 to .6	6:1 to 3:1
Gores	6	.6	3:1
Interior Roadways	6	.6	3:1
Parking Areas‡	11	1.0	
Activity Areas			
Major	11	1.0	3:1
Minor	5	.5	6:1

* The illuminance values recommended represent the condition just prior to cleaning and/or group relamping as calculated and planned in the design procedure.

** Average.

† Average to minimum.

‡ = 6 lux [0.6 footcandles] minimum.

roadway is continuously lighted beyond the confines of the rest area, deceleration and acceleration lanes should be lighted to a level equal to that of the main roadway.

Interior Roadways. Interior roadways are those between the entrance or exit points and the parking areas. As these roadways are off the main highway, the designer may select another type of luminaire than that used on the highway. The designer should keep in mind, however, that there may be an added maintenance problem when several different types of luminaires and lamps are required within one area.

Parking Areas. Illumination of both automobile and truck parking areas should be designed so that, from the vehicle, the motorist can distinguish features of the area including pedestrians. The area should be lighted so that a motorist can read signage and be directed by it to various parts of the area. Careful attention should be paid to areas that may require special detailing, such as handicap ramps and sanitary disposal stations.

Activity Areas. Activity areas are those designed for pedestrian use. Major activity areas are those which include such structures as comfort stations and information centers, as well as the walkways between those locations and the parking area. Minor activity areas are those that include picnic tables and dog walks and their associated walkways and facilities. Generally, the illuminance in the major activity areas is higher than that in the minor areas.

Area floodlighting may be provided for architectural or other purposes. Care should be taken to ensure that stray light is not directed toward, or reflected from, the main roadway toward the passing motorist.

Maintenance. Rest areas are frequently in remote, isolated regions and require more rigid maintenance and supervision than facilities that can be visited more regularly by maintenance and security personnel.

Parking Facility Lighting⁷

Objectives. Parking facility lighting is important for vehicular and especially pedestrian safety, for protection against assault, theft, and vandalism; for the convenience of the user; and in some cases for business attraction. Important lighting design criteria for parking areas are source/task/eye geometry, shadows, direct and reflected glare, peripheral detection, modeling of faces and objects, light pollution and trespass, and vertical illuminance.

Types of Facilities. For lighting purposes, parking facilities can be classified as either a lot (open) or a garage (covered). Most facilities are one type or the other, but in a multilevel structure the roof is considered open while the lower levels are considered covered. Parking stalls with roofs only (open on all sides) may be treated as lots depending on the configuration of the space and the height of the spaces. The illuminance requirements for all parking facilities depend largely on pedestrian needs and perceived personal security issues.

Parking Lots. Illuminance recommendations for active lots open to the public, customers, or employees are given in Figure 22-21. The illuminance should be measured, or calculated, on a clear pavement, without any parked vehicles. The maximum and minimum values are maintained illuminances. This condition occurs just prior to lamp replacement and luminaire cleaning.

Basic lighting requirements tend to be similar for most types of land uses. Typical or average security needs are equally as great in a parking lot serving an apartment building, a regional shopping center, or a sports complex.

Exits, entrances, gate access, internal connecting roadways or ring roads, and cross-aisles should be given special consideration to permit ready identification and to enhance safety. Generally, higher illuminance should be placed along these routes by using appropriate locations of luminaires, larger light sources, and additional luminaires. Illuminance of the driveway access to streets should at least match any local public lighting. For high-volume drive-

Figure 22-21. Recommended Maintained Illuminance Values for Parking Lots

	Basic ¹	Enhanced Security ²
Minimum Horizontal Illuminance ³	lux ⁴ 2 fc ⁵ 0.2	5 0.5
Uniformity Ratio, Maximum-to-Minimum ⁶	20:1	15:1
Minimum Vertical Illuminance ⁷	lux ⁸ 1 fc ⁵ 0.1	2.5 0.25

¹ For typical conditions. During periods of nonuse, the illuminance of certain parking facilities may be turned off or reduced to conserve energy. If reduced lighting is to be used only for the purpose of property security, it is desirable that the minimum (low point) value not be less than 1.0 horizontal lux (0.1 hfc). Reductions should not be applied to facilities subject to intermittent night use, such as at apartments, hospitals, and transportation terminals.

² If personal security or vandalism is a likely and/or severe problem, a significant increase of the Basic level may be appropriate. Many retailers prefer even higher levels, with a specification of 10 lux. (1 fc) as the minimum value.

³ For preliminary design, an average value of 10 horizontal lux (1 hfc) for basic illuminance or 25 horizontal lux (2.5 hfc) for enhanced illuminance may be calculated. The minimum points (or areas) and maximum point are then calculated and the uniformity ratio checked for compliance with this table's values. Note that a 5:1 average-to-minimum ratio is the first step toward directing the design to achieve the maximum-to-minimum ratios presented in this table.

⁴ Measured on the parking surface, without any shadowing effect from parked vehicles or trees at points of measurement.

⁵ Rounded conversion of lux to footcandles.

⁶ The highest horizontal illuminance point divided by the lowest horizontal illuminance point or area should not be greater than the values shown.

⁷ Facial recognition can be made at levels as low as 2.5 lux (0.25 fc). The IESNA Security Lighting committee recommends that for facial identification, the minimum vertical illuminance should be 5.0 lux (0.5 fc).

⁸ Measured at 1.5 meters (5.0 ft.) above parking surface at the point of lowest horizontal illuminance, excluding facing outward along boundaries.

Note 1: The height of the measurement has been lowered from the previous 1.8 meters (6 ft.) of RP-20-84 to be in line with the average human observer's eye height of 1.5 meters (5 ft.)

Note 2: A survey of existing installations by the authoring committee found that a value of 1 lux (0.1 fc) minimum vertical illuminance was achievable using cutoff luminaires, but values greater than this may not be achievable.

ways, such as those at community or regional shopping centers, an increase of 50% in the average public road lighting level is desirable; however, this value should be compatible with local conditions. If the street has no lighting, the basic values in Figure 22-21 can be used and are applicable to the curb line.

For good visibility of objects such as curbs, poles, fire hydrants, and pedestrians, vertical illuminance is important. The values in Figure 22-21 obviously do not apply to a direction facing outward along a boundary, because this would require lighting equipment beyond the property line. Similarly, they do not apply to a direction facing inward between an outer line of luminaires and the boundary line. The values are for a location 1.5 m (5 ft) above the pavement.

The shadow effects of trees and fixed objects such as large signs or building walls also should be examined. It is sometimes practical to adjust luminaire locations to minimize or even eliminate such shadows.

Lighting for parking lots should provide not only the recommended minimum illuminance levels but also good color rendition, uniformity, and minimal glare.

Shielding lamps, reflectors, or lenses minimize glare and enhance visibility. Undesirable sky glow should be minimized by limiting the upward component of the luminaire light distribution. Spill light extending beyond the boundary of the parking lot may be undesirable if it falls onto a different land use. Spill light is unwelcome by residential owners and is sometimes prohibited by local ordinances.

Lamps typically used in parking lots include HID and some types of low-pressure sodium. The advantages and disadvantages of various lamp types are available in Chapter 6, Light Sources, and Appendix Table A-2 of IESNA RP-20.⁷ A variety of luminaires is used in parking lots, including floodlighting, area lighting, architectural, post-top, wall-mounted, high-mast, and roadway-lighting luminaires. Of these types, the floodlighting and roadway lighting luminaires are most commonly used (see Chapter 7, Luminaires).

All lighting installations depreciate with time and require a continuing maintenance program in order to provide the design illuminance. The designer must consider and assume the degree and frequency of maintenance. Vandalism can generally be reduced by mounting luminaires at least 3 m above ground level. High-impact materials such as tempered glass, acrylic, and polycarbonate, when incorporated into the design of shields, lenses, refractors or globes, are extremely useful for damage reduction.

Poles should be placed so as to reduce collision with automobiles. Poles should be set on pillars to minimize direct contact with an automobile.

Parking Garages. Illumination recommendations for parking garages are given in Figure 22-22. These apply to covered and enclosed facilities intended for use by the general public, and those used by residents, customers, and employees of apartment buildings or commercial developments. They are not intended to apply to garages used exclusively

for repair or storage of commercial vehicles, or where vehicles are parked by attendants.

From a security standpoint, and to reduce personal apprehension, garages need higher illuminances than open parking facilities. Good lighting uniformity should be provided to enhance pedestrian safety since access aisles are used by pedestrians for walking between cars and stairways or elevators. While Figure 22-22 specifies that the minimum vertical illumination be at least 50% of the minimum the horizontal illuminance, a higher percentage is desirable in garages to enhance visibility and security.

Driving ramps can be contained entirely within the structure or mounted along the perimeter. The latter are usually open to the sky and may require little or no daytime lighting. Ramps with parking along one or both sides are called sloping floor designs and require basic garage illumination.

The entrance area is defined as the drive aisle and any adjacent parking stalls, from the portal or physical building line to 20 m (60 ft) inside the structure. Where parking is not provided next to the drive lane, the width of entrance area should be defined by the adjacent walls, if any, but should not exceed 15 m (50 ft). Elevated illuminances during the day are needed for the transition from full daylight to the rel-

Figure 22-22. Recommended Maintained Illuminance for Parking Garages

	Minimum Horizontal ²		Maximum/Minimum Horizontal Uniformity Ratio ³		Minimum Vertical ⁵	
	Lux	fc ⁴			Lux	fc ⁴
Basic ¹	10	1.0	10:1		5	0.5
Ramps ⁶						
Day ⁷	20	2.0	10:1		10	1.0
Night	10	1.0	10:1		5	0.5
Entrance Areas ⁸						
Day ⁷	500	50			250	25
Night	10	1.0	10:1		5	0.5
Stairways	20	2.0			10	1.0

¹ For typical conditions. While these values are intended to address personal security issues, some retailers may increase them to further offset perceived concerns. Top levels of garages open to the sky should use the "Enhanced Security" column of Figure 22-21. Research has shown that, under certain conditions of limited contrast (such as concrete wheel stops on a concrete garage floor), this level is needed to provide good visibility of the wheel stop.

² Measured on the parking surface, without any shadowing effect from parked vehicles or columns. For preliminary design, an average value of 50 horizontal lux (5 ftc) for basic illuminance (and equivalent for other conditions) may be calculated.

³ The highest horizontal illuminance area, divided by the lowest horizontal illuminance point or area, should not be greater than the ratio shown.

⁴ Rounded conversion of lux to footcandles.

⁵ Measured at 1.5 meters (5.0 ft.) above parking surface at the point of lowest horizontal illuminance, excluding facing outward along boundaries.

⁶ Applies to clearway ramps (no adjacent parking) but not to sloping floor designs.

⁷ Daylight may be considered in the design calculation.

⁸ A high illuminance level for about the first 20 meters (66 ft.) inside the structure is needed to effect a transition from bright daylight to a lower internal level.

atively low interior illuminances. Ordinarily, entry to a garage involves a turn from a street or service road. Designs that involve a straight entry run of some distance (50 m [160 ft] or more) allow drivers to enter at higher speeds and may require correspondingly longer transition areas. In such cases, the illuminances can be stepped down in successive stages beyond the first 15 m (50 ft).

Light sources typically used today are metal halide and HPS. Luminaires for above-ground garages require many of the photometric and environmental considerations used in the design of lighting for parking lots. Open-wall structures are exposed to the same temperatures as open lots. Luminaires should be of a type designed for use in impact and corrosion- and emission-prone hostile outdoor environments requiring weather-proof, vandal-resistant construction. Luminaires for garages are categorized as cutoff and noncutoff. The cutoff type usually has a flat lens or enclosure to provide a shielded light source with resultant low brightness and glare. The noncutoff type is most commonly available with a dropped luminous diffusing lens or refractor allowing wider spacings. However, because of the typically low mounting heights, control of glare is essential, either by luminaire selection or placement. A lamp and luminaire maintenance program should be considered as part of the lighting design, including written instructions for maintenance personnel.

Emergency lighting units should be located in strategic positions to provide lighting in case of an interruption to the normal power supply. In general, they should provide approximately 10% of the lighting levels of Figure 22-22, with a minimum of 10 lx for pedestrian egress, or meet applicable local code requirements.

Special Considerations. Lighting of access roads to all types of parking facilities should match the local highway lighting as much as possible. The average maintained illuminance should be compatible with local conditions. The average-to-minimum illuminance uniformity ratio should not exceed 3:1.

In all parking facilities, consideration should be given to color rendition. Users sometimes have trouble identifying their cars under light sources with poor color rendering characteristics.

In many parking facilities, closed-circuit television is necessary. The illuminance, the light source, the photometric distribution, and the pattern of luminaires as well as the camera position must be considered to ensure effective results.

Special Considerations for Open Facilities. In open parking facilities, exits, entrances, loading zones, pedestrian crossings, and collector lanes should be given special priority to ensure safety and security. Outdoor pedestrian stairways require luminaires to illuminate changes in step elevation. Parking facilities for rest or scenic areas adjacent to roadways generally employ lower illuminances. See the section on "Rest Areas" earlier in this chapter for more information.

Special Consideration for Covered Facilities. In covered parking facilities, vertical illuminances of objects such as columns and walls should be equal to the horizontal values given in Figure 22-22. These vertical values should be for a location 1.8 m (6 ft) above the pavement.

In covered parking facilities the design should be arranged so that some lighting can be left on for security reasons. The low level from Figure 22-21 for open parking facilities can be used for this purpose.

Illuminated Roadway Signs⁸

Motorists may stop or reduce speed at roadway signs that are difficult to read, and thus create a hazardous condition. Proper sign lighting can aid rapid and accurate recognition of the sign shape, color, and message.

Lighting for roadway signs becomes more significant as the volume of traffic increases, the complexity of highway design increases, the likelihood of adverse weather increases, and ambient luminance increases. Important lighting design criteria for roadway signs are source/task/eye geometry, reflected glare, light distribution on surfaces, modeling of faces and objects, points of interest, surface characteristics of objects, appearance of area and luminaires, and vertical illuminance.

Ambient Luminance. The background luminance against which a sign is viewed by a motorist is called its ambient luminance. Three categories of ambient luminance (high, medium, and low) can be identified:

- **High:** Areas with high street lighting levels and brightly lighted advertising signs
- **Medium:** Areas with small commercial developments and lighted roadways and interchanges
- **Low:** Rural areas without lighting or areas with very low levels of lighting

High levels of ambient luminance can make sign lighting mandatory in order to ensure sign legibility for decisive driver action.

Light Source Selection. Energy consumption is a major consideration that must be balanced by other factors, such as color rendering, ambient temperature, and maintenance. Selection should be based on lamp efficacy and life in addition to its color rendering properties. Lighting must maintain the color rendering as close as practical to that seen under daylight conditions.

Illumination Recommendations. There are three types of lighted signs: externally lighted signs, internally lighted signs, and luminous source message signs (where the message is formed by lamps).

Externally Lighted Signs. Recommended illuminances for externally lighted signs are shown in Figure 22-23. A maximum-to-minimum illuminance uniformity ratio of 6:1

Figure 22-23. Recommended Maintained Levels for Externally Lighted Roadway Signs

Ambient Light Level	Sign Illuminance		Sign Luminance* Candelas per square meter
	lux	footcandles	
Low	100–200	10–20	22–44
Medium	200–400	20–40	44–89
High	400–800	40–80	89–178

* Based on maintained reflectance of 70 percent for white sign letters.

should not be exceeded for acceptable appearance of the sign face. Lower ratios will produce a more legible sign.

Internally Lighted Signs. Recommended luminances for internally lighted signs are shown in Figure 22-24. These luminance values are for a white translucent material forming the legend and the border. For colors other than white, higher luminance values may be required to obtain the same contrast with the background.

The maximum-to-minimum luminance ratio of the sign background should not exceed 6:1, and no adjacent areas 0.3 by 0.3 m (1 by 1 ft) should have a luminance difference greater than 20%. The maximum-to-minimum luminance ratio for the entire sign legend should not exceed 6:1. Lastly, the average luminance contrast between legend and background should be greater than 10:1.

Luminous Source Message Signs. Recommended levels have been established only for a variable message sign composed of a matrix of luminous sources that can be selectively lighted. These levels are the same as those given in Figure 22-24.

COMPUTATIONAL METHODS

The basic computations that follow apply to conventional roadway lighting systems mounted alongside the street or highway at heights of 5 to 20 m (15 to 60 ft) above the pavement. The data and techniques can also be applied to adjacent walkways, median strips, and other areas. Illuminance, light loss factors, and luminance are important in roadway lighting, but because of their general nature, illuminance calculations and light loss factors are discussed in Chapter 9,

Figure 22-24. Recommended Maintained Luminance for Internally Lighted Roadway Signs

	Ambient light level		
	Low	Medium	High
Candelas per square meter	240	520	1000
Candelas per square foot	24	52	100

Lighting Calculations. Roadway luminance calculations, because of their unique tables and roadway coordinate system, are included in this chapter. Special computations relating to area lighting with high-mast equipment over 20 m (60 ft) above the pavement, to walkways and bikeways, and to veiling luminance are also covered in this chapter.

The recommended design values, as well as uniformity ratios, are given in Figures 22-8, 22-9, and 22-10. These represent the lowest maintained values that are currently considered appropriate for the kinds of roadways or walkways in various areas. Numerous installations have been made at higher levels. Furthermore, the recommendations assume the use of applicable types of luminaire light distribution, lamp size, mounting heights, spacing, and transverse locations. These figures do not represent initial readings but should be the lowest in-service values of systems designed with the proper light loss factors. The tables indicate whether the values are averages or minimal for each area.

Light Loss Factors

Once design values for illuminance or luminance are established and a preliminary choice of a luminaire is made, light loss factors (LLF) can be evaluated. Several of these factors are affected by time-dependent depreciation effects. Others exist initially and continue through the life of the installation. However, all factors should be studied, and attempts should be made to improve LLFs wherever possible. Consult Chapter 9, Lighting Calculations, for details on LLFs that are not included in this chapter. The following LLFs are applicable to roadway lighting:

Lamp Lumen Depreciation. Consult the manufacturer.

Luminaire Dirt Depreciation. The accumulation of dirt on luminaires results in a loss in light output. This loss is known as the luminaire dirt depreciation (LDD) factor and is estimated by dirt category (very clean, clean, moderate, dirty, or very dirty) from definitions given in Figure 22-25. The LDD is found from the appropriate dirt category curve in Figure 22-25 and the proper elapsed time in years of the planned cleaning cycle.

Luminaire Ambient Temperature. Consult the manufacturer.

Voltage to Luminaire. Consult the utility.

Ballast and Lamp Factor.^{9,10} Consult the manufacturer.

Luminaire Surface Depreciation. Experience is the best predictor; no factors are available at present.

Burnouts. Routine maintenance is required.

Total Light Loss Factor. The total light loss factor is simply the product of all the contributing factors described above. Where factors are not applicable, they are omitted. If, at this point, it is found that the total light loss factor is excessive, it may be desirable to reselect the luminaire or lamp or to modify the cleaning and maintenance schedule.

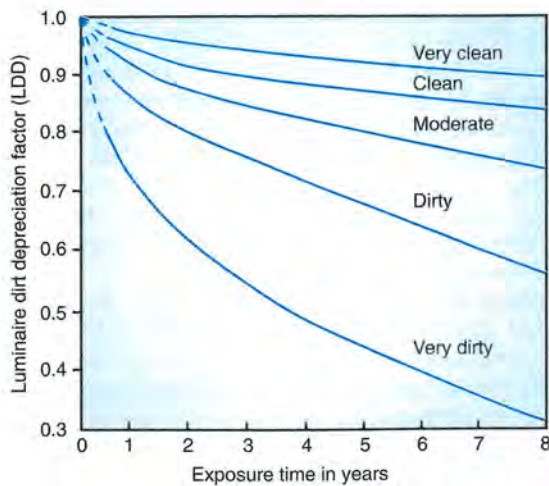


Figure 22-25. Chart for estimating roadway luminaire dirt depreciation factor for enclosed and gasketed luminaires.

Another factor that must be considered in the calculation is the change in the performance of individual components as a result of operation with a range of different associated luminaire components. For example, a lamp does not always have the same lumen output when used with ballasts of different manufacturers or when installed in luminaires of different design or manufacturer. This should be taken into account in the calculations for luminance or illuminance. The factor used for calculations can be in the range of 5 to 15%.

Determination of Average and Point Illuminance

The average illuminance over a large pavement area may be calculated by means of an average-footcandle calculation, a utilization curve (which is almost never used today), an isoilluminance (isofootcandle) curve, or by computing the illuminance at a large number of points and averaging the values found.

Average-Lux (Average-Footcandle) Computation. The formulas for determination of average horizontal illuminance in roadway lighting are the same ones used for average illuminance for parking lots in Chapter 9, Lighting Calculations.

Utilization Curves. Utilization curves, available for various types of luminaires, afford a practical method for the determination of average illuminance over the roadway surface where lamp size, mounting height, width of roadway, overhang, and spacing between luminaires are known or assumed. Conversely, the desired spacing or any other unknown factor may readily be determined if the other factors are given.

A coefficient of utilization is derived from the utilization

curve and is the percentage of rated lamp lumens that falls on either of two striplike areas of infinite length, one extending in front of the luminaire (street side) and the other behind the luminaire (house side), when the luminaire is level and oriented over the roadway in a manner equivalent to that in which it was tested. Since the roadway width is expressed in terms of a ratio of luminaire mounting height to roadway width, the term has no dimensions.

Isoilluminance (Isofootcandle) Diagram. An isoilluminance diagram is a graphical representation of points of equal illuminance connected by a continuous line. Such diagrams are convenient for making point illuminance determinations and are provided by the manufacturer of the luminaire under consideration. They have become less common since the introduction of powerful computer programs that can quickly and easily make point-by-point roadway lighting calculations.

Point-by-Point Calculation Method. For a complete description of the classical point-by-point calculation method and an example of its application, see Chapter 9, Lighting Calculations.

Determination of Luminance

Luminance values at a point may be calculated from photometric data obtained and provided by most manufacturers for luminaires associated with roadways. Parameters of position are important determinations that should be consistently applied for both luminance calculations and measurements.

The luminance of a point P (Figure 22-2e) can be written as a sum of contributions from all n luminaires:

$$L_P = \sum_{i=1}^n \frac{r(\beta_i, \gamma_i) I(\phi_i, \gamma_i)}{10,000h^2} \quad (22-1)$$

where all symbols, except luminous intensity (I), are defined in Figure 22-2. The factor 10,000 appears in the denominator because the values in Figure 22-2 should have been multiplied by 10,000. (If the values are taken directly from Figure 22-2 without multiplying by 10,000, the factor 10,000 in the denominator of Equation 22-1 should be omitted.) The value of I must be depreciated by the light loss factor times any equipment factors.

Calculation and Measurement Parameters (Figures 22-2 and 22-26).

- Observer eye height: 1.45 m (4.75 ft) above grade
- Line of sight of observer: downward 1° below horizontal over a distance of 83 m (272 ft); parallel to edge of roadway along lines 1/4 of the roadway line width from edges of each lane (two lines per lane)
- Lighting system to be measured: smooth and level, at least 10 mounting heights long

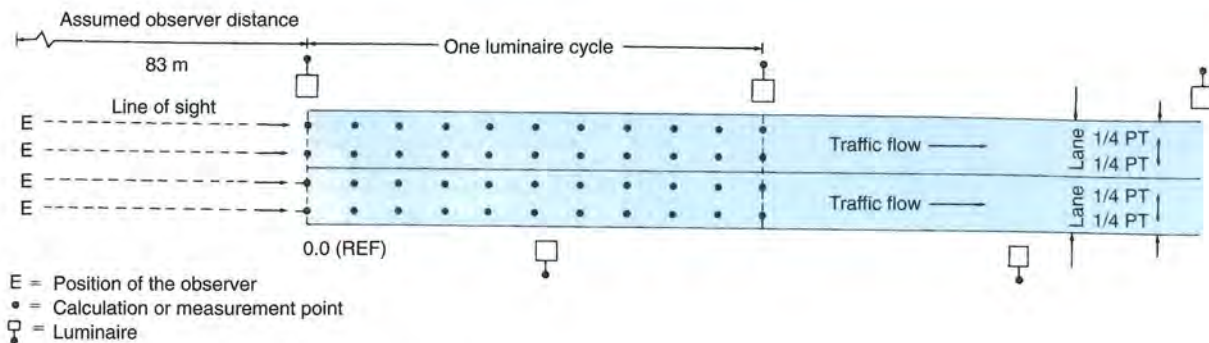


Figure 22-26. Luminance calculation points.

- Number of points per line: at least 10, not more than 5 m (16.5 ft) apart
- Area covered by measurement and calculations: all points between two luminaires on one side of roadway (Figure 22-26)
- Calculation-point location with respect to contributing luminaires: at least one luminaire behind, and at least three ahead of the calculation point P
- Luminaire light distribution data: based on initial installed values using actual lamp-luminaire performance
- Luminance values: to be calculated using the r tables in Figure 22-2
- Horizontal illuminance E_h : to be printed and recorded at the same points as the luminance values, as a reference
- Luminance L : to be printed and recorded at the same points as the horizontal illuminance values
- Average luminance L_{avg} : to be determined by averaging all values of the evaluated roadway section
- Longitudinal luminance uniformity: lane uniformity LL to be determined as the ratio of the maximum to the minimum luminance in any 1/4-lane line, taking the worst (highest) ratio as the rating for the roadway
- Average luminance uniformity: to be determined by rating the average luminance L_{avg} to the minimum found in any of the lines within the roadway
- Maximum luminance uniformity: to be determined by rating the maximum luminance found in any of the lines to the minimum found in any of the lines within the roadway

Veiling Luminance

The L_v (expressed in cd/m^2) of a roadway lighting system can be determined from the observer's position by using the following empirically derived formula¹¹ to calculate the L_v

contributed by each luminaire separately, and then summing the individual L values:

$$L_v = \frac{10 E_v}{\theta^2 + 1.50} \quad (22-2)$$

where

- E_v = vertical illuminance in the plane of the pupil of the observer's eye,
- θ = angle between the line of sight and the luminaire in degrees.

Note that the line of sight is a line parallel to the curb line of the roadway and located away from the edge of the roadway in one of the quarter-lane planes, at an eye height of 1.45 m (4.75 ft) above the road (Figure 22-27).

The number of luminaire cycles is to be the same as that for determining the pavement luminance. The L_v for an entire system of n luminaires is therefore

$$L_v = \sum_{i=1}^n \frac{10 E_{vi}}{\theta^2 + 1.50} \quad (22-3)$$

Walkway and Bikeway Lighting

The procedure to determine the horizontal illuminance values on pedestrian ways for safe and comfortable use is similar to that followed for roadways. Because the design of roadway lighting places greater emphasis on achieving proper illuminance on the roadway, it is customary for the lighting system to be initially selected to suit the needs of the roadway. Then, the system is checked to determine if the sidewalk illuminance levels and uniformity are adequate. If not, the designer may modify the luminaire type or spacing, may provide supplemental lighting primarily for the sidewalk area, or may do both in order to achieve proper illuminance on both roadway and sidewalk. See Chapter 21, Exterior Lighting, for additional walkway and bikeway lighting recommendations.

