Electricity 11

Knowledge of the basic principles of electricity is necessary for understanding lighting circuitry, electrical distribution, power consumption, operating costs, switch control, and dimming control.

PRINCIPLES OF ELECTRICITY

Electrically charged particles called *electrons*, which orbit the nucleus of an atom, can be made to flow from one point to another. This is observable in objects charged by friction and in natural phenomena: lightning is a huge spark of electricity.

A flow of electricity is called an *electric current*; the rate of flow of an electric current is measured in *amperes* (*amps*, A). The potential of the flow of electricity is called *voltage*; it is measured in units called *volts* (V).

Water provides a helpful analogy to these concepts. The amount of pressure that moving water exerts inside a pipe is analogous to volts; amperes are similar to the "gallons-per-second" measurement, the rate at which water passes through the pipe. The pipe is the conductor or wire, the wall of the pipe is the insulator, and the faucet is the resistance or dimmer. The larger the pipe, the greater the flow it can carry.

The path through which an electric current flows is called a *circuit*. When no gap exists in the path, it is called a *complete circuit* (figure 11.1). When a gap occurs, it is called a *break in the circuit*.

Resistance impedes the flow of current and is determined by the composition of a material. This results in the production of light or heat or both. A *resistor* is a device placed in the path of an electric current to produce a specific amount of resistance. If electricity flowing along a path is slowed by

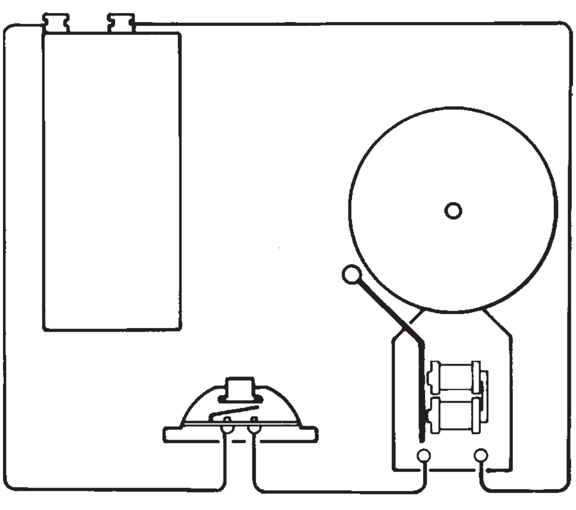

Figure 11.1 Complete circuit.

resistance or interrupted by an open switch, there will be little or no current (amps) even though the potential to produce it (volts) is high.

Wiring

Materials that electricity flows easily through are called *conductors*. Materials through which it does not flow easily are called *poor conductors,* or *insulators*. All metals are good conductors: silver is the best conductor, but it is too costly for most wiring purposes; copper is an excellent conductor and is used widely.

Almost all wire is encased within an insulator, which confines the current to its metallic conductor. Wire that is wrapped with a poor conductor, such as rubber or synthetic polymers, is called *insulated wire*. Before connections are made with insulated wire, the wrapping is removed from the ends of the wire.

Insulated circuit wires are sometimes covered by a mechanically protective conduit for installation in buildings. Flexible, nonmetallic sheathed cable ("romex") and flexible, metal sheathed cable ("BX") are often used in single-family homes. Commercial installations use wires inserted in flexible metal conduit ("greenfield"), or in rigid electrical metal tubing ("EMT") for long runs.

Circuits

Direct current (dc) is electric current that always flows in one direction. *Alternating current* (ac) also moves in a single direction; however, that direction is reversed at regular intervals. Alternating current is the prevailing electrical current in use today (figure 11.2).

A *cycle* includes the complete set of values through which the alternating current passes. The unit *Hertz* (Hz) is used to measure the number of times the cycle occurs each second, which is also called the *frequency* of the cycle. Power distribution systems operate at 60 Hz in the United States and 50 Hz in most other parts of the world.

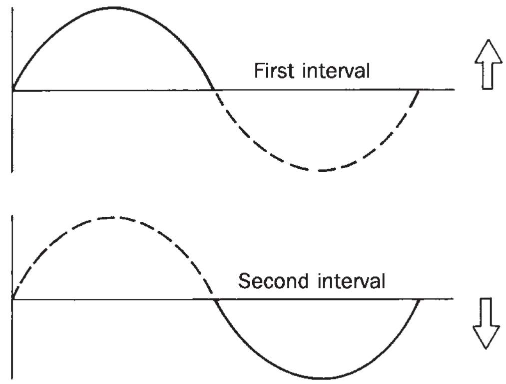

Figure 11.2 Alternating current.

Series circuit

If one lamp fails in an inexpensive strand of Christmas tree lights, the remaining lamps in the strand go out. When the tungsten wire in one lamp breaks, it causes a break in the circuit because its filament is part of the conductive path carrying current to other lamps.

Lamps connected in this way are wired in *series*. All lamps in a series circuit must be of the same wattage; if a lamp of different wattage is substituted, the remaining lamps will grow brighter or dimmer due to the substituted lamp's resistance. A series circuit is therefore said to be *load-sensitive* (figure 11.3).

Parallel circuit

If one lamp in figure 11.4 goes off, all of the others remain lighted; the current still flows to the other lamps and the circuit remains complete. These lamps are wired in *parallel*. Since the voltage of the circuit is present across all branches of the circuit, several different *loads* (for example, a 60 W lamp and a 100 W lamp) may be connected to the

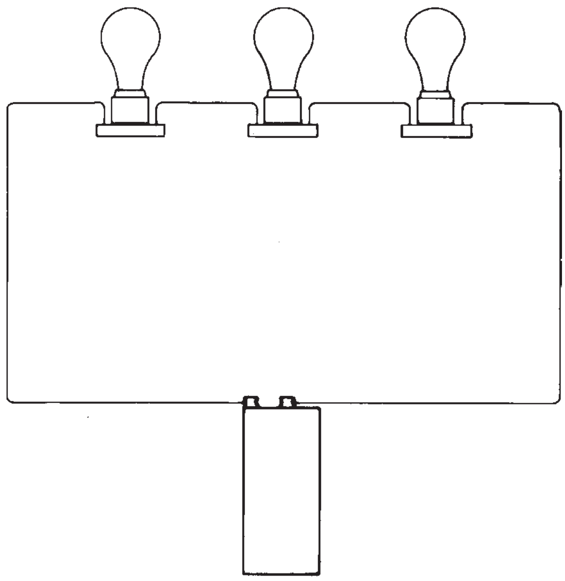

Figure 11.3 Series circuit.

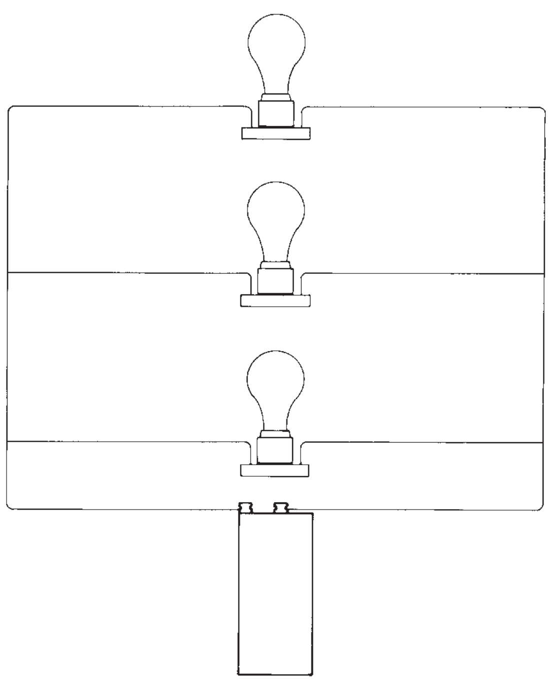

Figure 11.4 Parallel circuit.

same circuit. Parallel circuits are therefore not load-sensitive.

A current will always follow the easiest path that is available. If the wires of a circuit are uninsulated and touch each other, the current will pass from one to the other because this is a shorter and easier path than the one intended: there will be a *short circuit*.

In the drawing on the left in figure 11.5, the current will take a shortcut back to the cell without going through the push button; the bell will ring continuously whether the switch is open or closed. In the drawing on the right, the bell will not ring at all; the current will take a shortcut back to the cell without going through the bell.

A short circuit allows a stronger-than-usual flow of electricity through the wires; this excessive current causes the wires to overheat. A *fuse* or *circuit breaker* is a safety device that opens the circuit before the wire becomes a fire hazard. Because the fuse is part of the circuit, it also overheats and a metal strip in the fuse melts and breaks the circuit. If the protective device is a circuit breaker, the excess current of the short circuit causes the breaker to flip open, interrupting the path of the current.

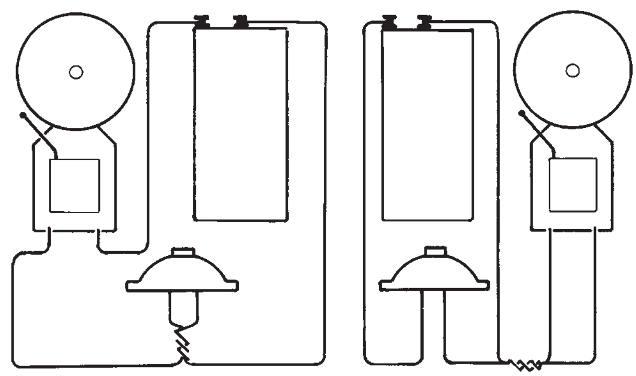

Figure 11.5 Two short circuits. The wire in these circuits is bare wire. Where the wires are twisted together, the current would flow from one to the other.

Electrical Distribution

Electric current generated and delivered by an electric utility enters a building through a *service panel*. In the United States, three kinds of systems are common:

1. 120/240 V, single-phase, three-wire.
2. 120/208 V, three-phase, four-wire.
3. 277/480 V, three-phase, four-wire.

The 120/240 V, single-phase, three-wire system is commonly used in single-family homes and small commercial buildings. Wire conductors leading from the entrance panel distribute the power throughout the building. Because the wire has resistance, the longer the distance that power is carried, the greater the voltage *losses*, causing lights to dim and appliances to operate sluggishly. This is corrected by using larger-diameter wires, which have less resistance.

Distributing current at higher voltages reduces losses occurring because of the wire's resistance. Therefore, in large commercial buildings, 120/208 V, three-phase, four-wire and 277/480 V, three-phase, four-wire systems are used to reduce resistance losses.

In commercial buildings, running each circuit from the entrance panel will create a substantial voltage loss or require the use of large-diameter, expensive wires. To avoid voltage loss, *feeder circuits* conduct power from the entrance panel to secondary distribution panels, called *panel boards*, located throughout the building. The wires that distribute power locally between the panel board and the luminaires or receptacles are called *branch circuits*.

Power Consumption

A *watt* (W) indicates the rate at which electricity is changed into another form of power—light or heat. Power consumption in watts is calculated by multiplying volts times amps ($W = V \times A$).

Theoretically, a 20-amp circuit operating at 120 V will handle a possible maximum load of 2,400 W (that is, $20 \times 120 = 2{,}400$). In practice, the National Electrical Code limits the possible load of a branch circuit to 80 percent of the branch circuit ampere rating: a 15 A, 120 V circuit to 1,440 W; a 20 A, 120 V circuit to 1,920 W; a 20 A, 277 V circuit to 4,432 W.

Energy is the amount of electric power consumed over a period of time; it is measured in *kilowatt-hours* (kWh). One kilowatt (kW) = 1,000 W. Hence, kWh = kW × hours used. For example, a 150 W lamp is equivalent to 0.15 kW. When operated for 40 hours it uses 6 kWh (0.15kW × 40 hrs = 6 kWh). Utility rates are based on monthly kWh usage.

In estimating the connected load for discharge and low-voltage incandescent sources, the power consumed by the ballast or transformer must be included.

To obtain lighting *watts per square foot* for an installation, divide the total luminaire watts by the area of the space in square feet.

Life Cycle Costs

The cost of lamps and luminaires plus their installation is a minor part of the total cost over the life of a lighting system. The cost of electricity (*operating costs*) is the single largest cost in lighting. Except in homes, maintenance (*labor costs*) to replace lamps and clean luminaires is the second greatest expenditure. Lighting systems, therefore, must be evaluated in terms of *life cycle costs.*

A typical *cost analysis* will include initial lamp and luminaire costs; installation costs; electricity costs based on burning hours per year; labor costs, including those incurred because of dirt conditions; and interest costs on the original capital investment.

When comparing the life cycle costs of one system with those of another, the greater initial cost of an energy-effective system will almost always be recouped after a period of time because of the saving in energy costs. This *payback period* varies with different systems.

In comparing dissimilar systems, it is impossible to place a dollar value on the quality of light. A direct system, for example, is usually less costly than an indirect one that produces the same quantity of light on a horizontal workplane, but the *quality* of light is vastly different.

Cost comparisons are made on equal illuminance values of equivalent quality. If there is a difference in the connected load, the additional air-conditioning required to handle the larger load must also be counted.

SWITCH CONTROL

An electric current is the flow of electrons between two points along a path. If the path is interrupted, the current cannot flow. A switch *breaks* the flow of electricity in a circuit when it is open ("off") and it allows unimpeded flow when closed ("on").

Manual Switches

The manually operated *toggle switch* makes contact by snapping one metal piece against another. *Mercury switches* contain a vial of mercury; contact is made between two electrodes when the vial is tripped to the "on" position. These switches operate silently. The toggle designates "on" in the up position and "off" in the down position. A *rocker switch* and a *push-button switch* operate in the same manner (figure 11.6).

A *single-pole, single-throw* switch is connected at any point between the luminaire and the power supply. It opens only one side of the circuit and is therefore called a "single-pole"; it moves only between an open and a closed position and is therefore called a "single-throw." This is the switch most frequently used to control electric luminaires and wall receptacles.

A *single-pole, double-throw* switch directs the current in either of two directions. It is used to alternately turn on two different luminaires with a single switch action, such as a safelight and the general light in a darkroom. The up position will designate "on" for one luminaire, the down position "on" for the

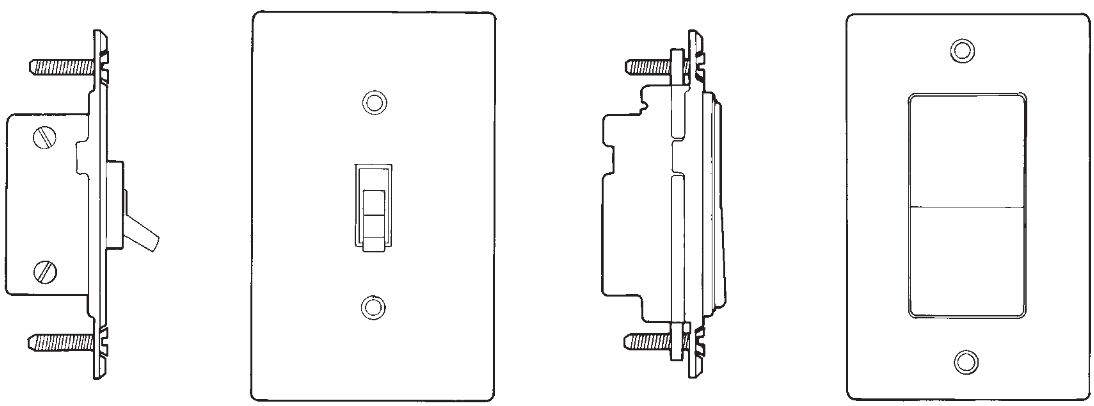

Figure 11.6 Toggle switch and rocker switch.

other; an optional center position will turn both "off."

A *double-pole, single-throw* switch is able to direct the current to two paths at once. It is used to control two devices simultaneously, such as a luminaire and an exhaust fan; it functions as if two separate toggle switches were operated by the same handle.

A *three-way* switch controls an electrical load from two locations. This allows the circuit to use one of two alternate paths to complete itself. (Several explanations exist for why a switch that provides control from *two* locations is called "three-way." Although these explanations are hypothetical and flawed, the term is still customary.)

A *four-way* switch controls a circuit from three locations, a *five-way* switch controls a circuit from four locations, and so forth. For control from many different locations, a low-voltage switching system is used.

Timers

A *timer* automatically turns on electric lighting when it is needed and turns it off when it is not needed. Timers range in complexity from simple integral (spring-wound) timers to microprocessors that can program a sequence of events for years at a time. With a simple integral timer, the load is switched on and held energized for a preset period of time, usually within a range between a few minutes and twelve hours.

An *electromechanical time clock* is driven by an electric motor, with contacts actuated by mechanical stops or arms affixed to the clock face. *Electronic time clocks* provide programmable selection of many switching operations and typically provide control over a seven-day period. Electromechanical and electronic time clocks have periods from twenty-four hours to seven days and often include astronomical correction to compensate for seasonal changes.

Occupancy Sensors

Occupancy sensors (also called *motion sensors*) automatically switch luminaires on and off to reduce energy use. They operate in response to the presence or absence of occupants in a space. Electrical consumption is reduced by limiting the number of hours that luminaires remain in use.

Occupancy is sensed by one of four methods: audio, ultrasonic, passive infrared, or optical. Occupancy sensors can be mounted in several ways: they can be recessed or surface-mounted on ceilings, corners, or walls; they can replace wall switches; and they can plug into receptacles. The floor area covered by individual sensors can range from 150 sq ft in individual rooms, offices, or workstations to 2,000 sq ft in large spaces. Larger areas are controlled by adding more sensors.

Occupancy sensors can be used in combination with manual switches, timers, daylight sensors, dimmers, and central lighting control systems. Careful product selection and proper sensor location are critical to avoid the annoying inconvenience of false responses to movement by inanimate objects inside the room or people outside the entrance to the room.

Photosensors

Photosensors (also called *daylight sensors*) use electronic components that transform visible radiation from daylight into an electrical signal, which is then used to control electric lighting. The photosensor comprises different elements that form a complete system. The word "photocell" (short for "photoelectric cell") refers only to the light-sensitive component inside the photosensor. The term "photosensor" is used to describe the entire product, including the housing, optics, electronics, and photocell.

The photosensor output is a control signal that is sent to a device that controls the quantity of electric light. The control signal can activate two modes of operation: (1) a simple on-off switch or relay, or (2) a variable-output signal sent to a controller that continuously adjusts the output of the electric lighting.

Different photosensors are manufactured for indoor or outdoor use. In the northern hemisphere, photosensors used in outdoor applications are usually oriented to the north. This orientation ensures more constant illumination on the sensor because it avoids the direct sunlight contribution.

Wireless Remote Control

Radio-controlled systems

Some systems allow wireless remote control and can interface to audiovisual and other systems in both commercial and residential applications. *Radio-controlled* systems eliminate the need for wiring between the sensor, processor, and controller. Radio transmitters communicate with controllers via *r*adio *f*requency (RF) signals. Controllers, in turn, regulate and adjust electric lighting. These systems can employ multiple transmitters for multiple-location control and multiple controllers for multiple areas.

Radio frequencies from many sources can interfere with proper operation of this equipment, however. These systems are also relatively expensive, but they are useful where the controlled luminaires are difficult to access. They are also suited to retrofit applications where control wiring would be difficult or expensive to install.

Infrared preset controls

Infrared preset controls allow you to create and recall settings for electric lighting the same way you set and recall AM and FM stations on a stereo tuner/receiver. The handheld remote control sends an infrared (IR) signal to wall-mounted switches and dimmers that have a receiving IR window. An unlimited number of dimmers may be connected in the same room.

Typically, infrared preset controls have an IR range of up to 50 ft along the line of sight. They use standard wiring and can be retrofitted to replace switches or dimmers, using the existing wires for installation. Good-quality infrared controls will minimize chances of interference from radio, audio, and video equipment.

DIMMING CONTROL

A *dimmer* provides variation in the intensity of an electric light source. *Full-range dimming* is the continuous variation of lighting intensity from maximum to zero without visible steps.

All dimming systems operate on one of two principles for restricting the flow of electricity to the light source: (1) varying the voltage or (2) varying the length of time that the current flows during each alternating current cycle.

Resistance Dimmers

Historically, *resistance* dimmers were the first dimming method; they were used mainly in theatres in the early part of the twentieth century. A resistance dimmer, or "rheostat," controls voltage by introducing into the circuit a variable length of high-resistance wire. The longer the length of the wire, the greater the resistance, the lower the voltage, and the lower the intensity of the lamp.

In order to absorb a sufficient amount of energy, the resistance wire must be quite long; for this reason it is often coiled. Current flows into one end of the coil and an arm slides along the resistance wire in increments. Dimming is thus achieved in a series of steps, often a minimum of 110 to appear "flicker-less."

A large drawback to this kind of dimmer is that the portion of the current that would otherwise produce light is instead converted to heat. Also, no savings in energy is realized: although light output is reduced, connected wattage remains unchanged. In addition, these dimmers are bulky; consequently, they are no longer used.

Autotransformer Dimmers

Autotransformer dimmers avoid these problems by using an improved method of dimming. Instead of converting the unused portion of the current into heat, the autotransformer *changes* the standard-voltage current into low-voltage current, with only a 5 percent power loss.

A transformer has two coils of wire; the ratio of the number of turns in one coil to the other produces the ratio of the voltage change induced by the transformer. An autotransformer is simply a variable transformer: the primary coil remains fixed, while the number of turns in the secondary coil is varied by a rotating arm that controls successive turns of the coil. Because electrical power can be drawn from different points along the secondary coil, different voltages are achieved from the same transformer.

Because autotransformers do not convert energy to heat as light intensity is reduced, they are therefore cooler and more compact than resistance dimmers. Autotransformer dimmers are widely available in sizes up to many thousands of watts.

Solid-State Dimmers

Solid-state dimmers are predominant today; they use the second of the two methods of limiting current flow. A power control device—such as a silicon-controlled switch (SCS) under 6 kW, or a silicon-controlled rectifier (SCR) over 6 kW—allows electric current to flow at full voltage, but only for a portion of the time. This causes the lamp to dim just as if less voltage were being delivered (figure 11.7).

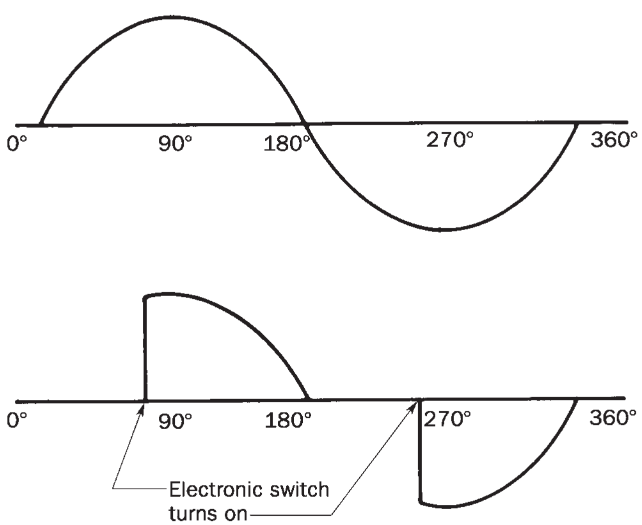

Figure 11.7 Solid state dimming control.

Square Law Dimming Curve

The manner in which light output responds to changes in the control setting is called the *dimming curve*. If a change in the setting of the dimming control, from full bright to full dim, approximates the change in the amount of electricity allowed to reach the light source, the dimmer is said to have a linear curve.

The eye is more sensitive to changes in low intensities of light than to changes in high intensities. This relationship between light perceived and light measured is called the "square law" curve (figure 11.8).

Electric lamps also respond in a nonlinear way: at 81 percent of the voltage, the light output is 50 percent. If the electrical output of a dimmer changes in a linear manner, then a light source will appear to dim faster at low intensities and slower at high intensities.

To correct this, good-quality dimmers feature a "square law" dimming curve. Here the dimmer control moves at constant speed, but causes the light to dim faster at high intensities and slower at low intensities. To the eye, the result is a consistent rate of change in the light intensity.

Incandescent Lamps

Dimming incandescent sources increases the life of the lamp. Yet both incandescent

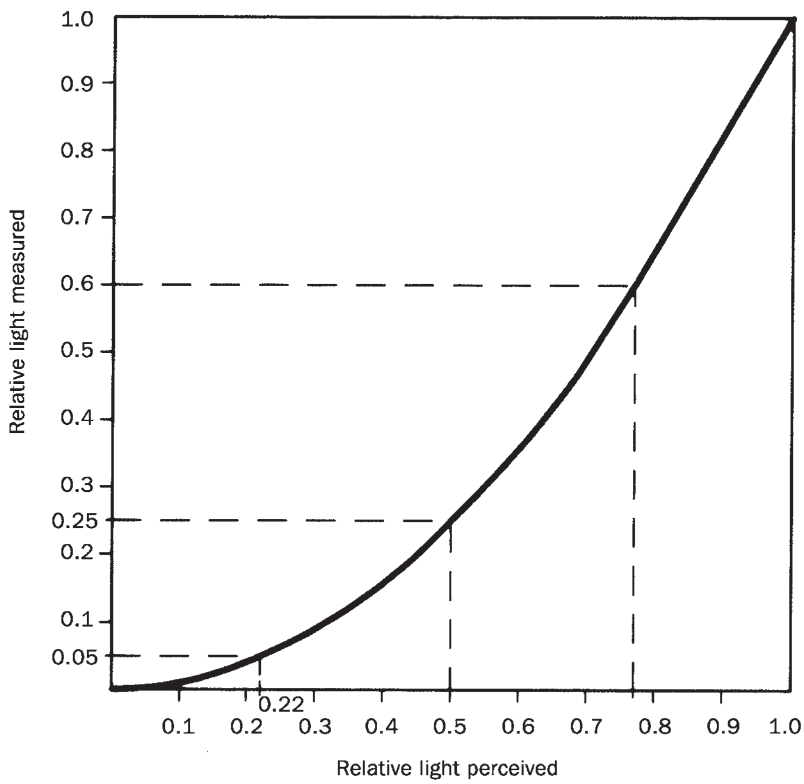

Figure 11.8 "Square law" curve: the relationship between perceived illuminance and measured illuminance.

and tungsten-halogen lamps undergo considerable shifts toward the orange-red end of the spectrum when they are dimmed. Although this increases the warm appearance of the lamps at lower light intensities, it is a positive result because people prefer warmer colors of light at lower intensities (figure 11.9).

The efficiency of an incandescent lamp is reduced when the source is operated at less than its designed voltage because the temperature of the filament is reduced. Even though the lamps are less efficient at producing light, much energy is still being saved (figure 11.10).

In some applications, normal operation of dimmers causes lamp filaments to "buzz." Lower-wattage lamps, physically smaller lamps, rough service (RS) lamps, low-noise stage lamps, and lamp debuzzing coils help to decrease this noise.

The lamp *debuzzing coil* is a separate component. It, too, will hum during operation, so it is remotely located in an area where this noise will be acceptable (for example, a closet or adjacent room).

Low-voltage lamps

Dimmers for incandescent low-voltage luminaires are installed on the 120 V side of the low-voltage transformer. Two kinds of transformers are manufactured for low-voltage lighting: magnetic (core-and-coil) and electronic (solid-state).

Before selecting a dimmer control, it is necessary to determine which kind of trans-

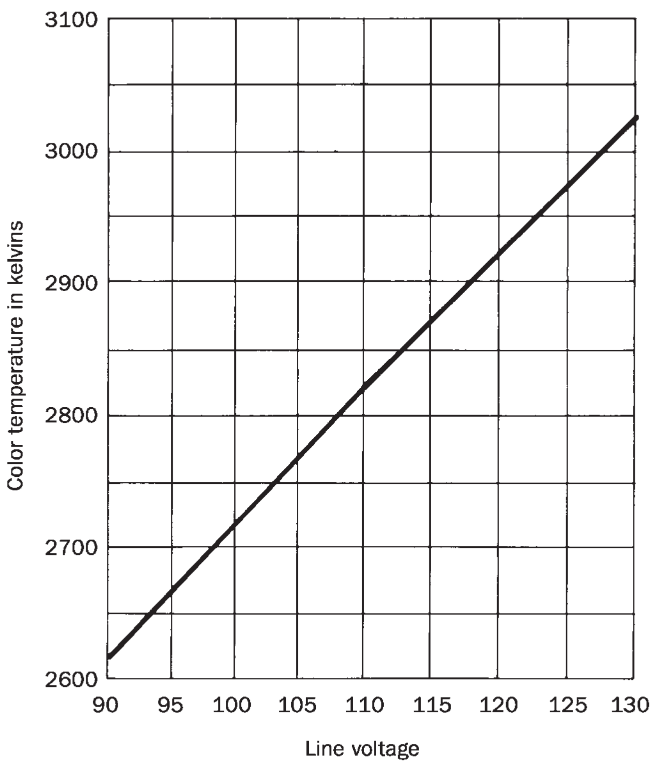

Figure 11.9 Dimming incandescent and tungsten-halogen lamps moves light toward the warmer end of the color spectrum.

former is connected to the luminaire. Each kind of transformer requires a compatible dimmer.

Magnetic-transformer low-voltage dimmers are used for dimming luminaires equipped with magnetic transformers. These dimmers protect the lighting system from the dc voltages and current surges to which magnetic transformers are sensitive. Magnetic low-voltage dimmers are specially designed to prevent dc voltage from being applied to the transformer and to withstand voltage "spikes" and current "surges."

Equipment supplied with electronic transformers requires the use of *electronic-transformer* low-voltage dimmers. Electronic low-voltage dimmers are designed specifically for electronic transformers. They eliminate the problems that occur in the interaction between the transformer and the dimmer when a magnetic low-voltage dimmer is used with electronic transformers: dimmer buzz, transformer buzz, lamp flickering, and radio frequency interference.

Electronic low-voltage dimmers combined with electronic transformers have the virtue of silent operation, although these dimmers have a smaller capacity (up to 150 W) than magnetic low-voltage ones (up to 10,000 W).

Fluorescent Lamps

Dimming fluorescent lamps requires the use of special dimming ballasts, which replace the standard ballast and must be compatible with the dimming control device. Only rapid-

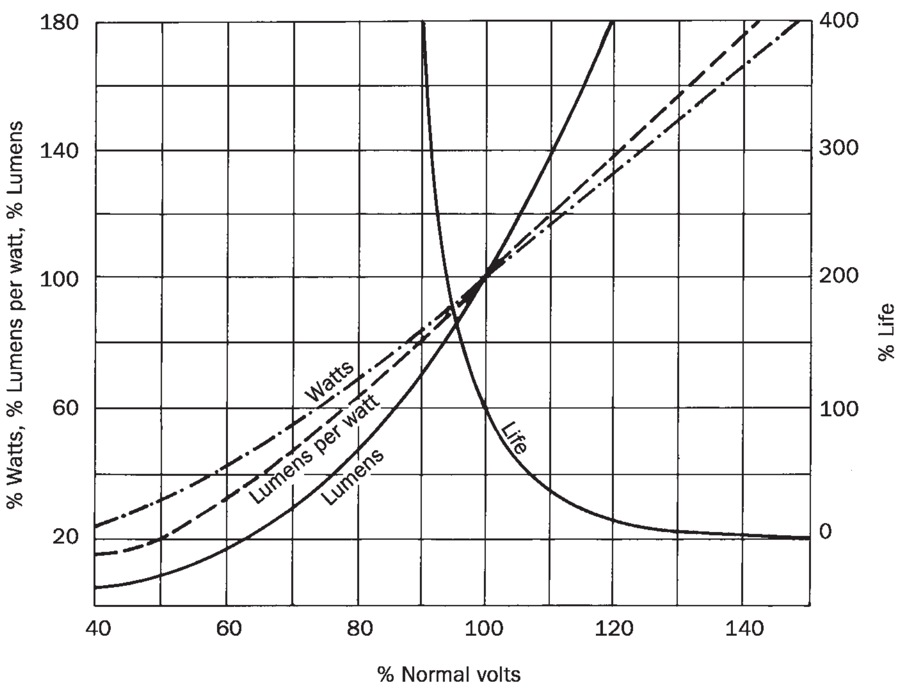

Figure 11.10 Effect of voltage variation on incandescent efficiency.

start fluorescent lamps can be dimmed because voltage is supplied continuously to the cathodes. When dimmed, the special ballast maintains the cathode voltage so that the cathodes remain heated to ensure proper lamp operation. Because instant-start and preheat lamp electrodes are turned off after the lamps are started, they cannot be dimmed.

Fluorescent lamps cannot be dimmed all the way to "off." If they are allowed to dim too far, a flicker or spiraling light pattern becomes visible inside the tube.

Many systems dim only 3- and 4-ft lamps. For optimal performance, different kinds of lamps (T4, T5, T8, or T12) are not mixed on the same circuit. It is also advisable for all lamps that are controlled by a single dimmer to be of the same length; different lengths dim at different rates.

Dimming fluorescent lamps that operate either in a cold atmosphere or in an air-handling luminaire sometimes results in variations in light output and color, which are caused by the changes in bulb wall temperature. The color shift is slight; dimmed lamps usually appear cooler in color.

Fluorescent lamp life is reduced by dimming systems. Considering that a fluorescent lamp consumes up to one hundred times its cost in energy, a slight loss in lamp life is offset greatly by the savings achieved through dimming.

HID Lamps

It is technically possible to dim high-intensity discharge lamps over a wide range of light output, but HID dimming ballasts are uncommon: the long warm-up, restrike delay, and color shift associated with HID lamps limit their applications. *Multilevel* ballasts are more frequently used, allowing the light output to be changed in steps.

A discernible color shift occurs with dimmed HID lamps. In mercury lamps, however, this slight change will be negligible; the color is already inadequate. Clear metal halide lamps shift rapidly toward a blue-green color similar to that of a mercury lamp. Phosphor-coated metal halide lamps exhibit the same trend, but less distinctly. HPS lamps slowly shift toward the yellow-orange color that is characteristic of LPS lamps.

HID lamps have a shorter life as a result of dimming. As with fluorescent lamps, the shorter life is offset by energy savings achieved through dimming.

CENTRAL LIGHTING CONTROL SYSTEMS

Local, single-room systems typically consist of one *control station* with switches or manual sliders that control large amounts of power. The dimmable wattage is limited only by the capacity of the system. These local systems are easily expanded to multiple rooms and customized to offer many combinations of manual, preset, assigned, and time-clock control. They can incorporate energy-reduction controls such as occupancy sensors and photosensors, and can handle emergency power functions.

Whole-building systems use local or small modular dimmers, a central computer, and master control stations to control all of the luminaires in a home or commercial building. Many of these systems also operate other electrical systems, such as motorized shades, fans, air-conditioning, heating, and audio systems, and they interface easily with burglar alarms, "smart" building systems, and other electrical control systems.

In centralized systems, a microprocessor assimilates the data, determines the required change, and initiates action to complete the change. More sophisticated processors can respond to a number of complex lighting conditions in the space, collect power and energy-use data, and supply summary reports for building management and tenant billing. Processors range in complexity from a microchip in a controller to a large computer.

Three kinds of processors are used: local, central, and distributed. With the local kind, the processor is located in or adjacent to the device it controls; sensor inputs go to a signal conditioner and are then fed to the processor. The central processor receives all inputs, analyzes the data, and then sends instructions to controllers located throughout a facility, allowing coördinated control of all system elements. In distributed processing, the ongoing decision making is left to local processors, but a central processor orchestrates the entire system, with the advantage that the entire system does not fail if any one processor does, and only the local processor has to be reprogrammed to accommodate changes.

Low-Voltage Control Systems

Low-voltage switching and dimming control is achieved with low-voltage wires that operate a relay installed in the luminaire wiring circuit. The relay is either mounted near the luminaire or installed in a remote location. Since the low-voltage wires are small and consume little electric power, it is possible to use many of them; they can be placed where needed without being enclosed in metal conduit, except where required by local codes.

With low-voltage switching systems, the branch circuit wiring goes directly to the luminaires; this eliminates costly runs of conduit to wall switch locations. Where switching occurs from three or more locations, the savings are considerable. Many switches can control a single luminaire, or one switch (a "master") can control many circuits of luminaires.

Power Line Carrier Systems

Power line carrier systems (also called *carrier current* systems) are low-cost, simple-to-install control systems that operate by sending a signal through the building wiring ("power line"). The switch functions as a transmitter that generates the signal. A receiver located at the luminaire or electric appliance turns a circuit on or off when it senses the appropriate signal.

As long as the transmitter and the receiver are connected to the same electric service in the building, no control wiring is required. Any number of luminaires can be attached to one receiver or to any number of receivers; any number of transmitters can control any one receiver. Great flexibility is inherent in this kind of system.

Power line carrier systems are subject to malfunction, however. Automatic garage door openers and communication systems in airplanes flying overhead may operate on the same frequency as the power line carrier system, causing luminaires and appliances to turn on and off when unintended.

Existing wiring systems in older buildings can significantly reduce the effective range of communication between the sensor, processor, and controller. Additionally, the overall capacity and speed of this kind of system is limited.

Energy Management Controls

In offices of the past, lighting controls were used to provide lighting flexibility. Today, their major application is energy management. Simple controls, such as photocells, time clocks, and occupancy sensors will automatically turn lights on when needed and off when unnecessary. For larger facilities, *energy management control* systems are designed to integrate the lighting with other building energy systems such as those used for heating and cooling.

The key to proper application of these controls is not only the selection of the proper control device, but also the careful planning of where and when the control is needed. Two basic control strategies are available: (1) control in space by electrically positioning (switching) the light *where* it is needed and (2) control in time or supplying lighting *when* it is needed.

Daylighting controls have photosensors that automatically adjust the electric lighting to preset values. When daylight is available and suitable (reaching task areas without causing glare, for example), luminaires are dimmed or turned off.

Lumen-maintenance controls compensate for the natural deterioration of the lighting system and the room surfaces over time. They automatically increase the power to the system so that the light output is kept at a constant value.

It is advisable to use control systems for daylighting, worker area individualization, and window energy management. Individual controls in office spaces go a long way toward conserving energy and, equally important, toward giving occupants a sense of control over their immediate environment.

12 Luminaires

Almost all lamps require a method to curtail glare; in addition, many need a method to modify distribution.

A *luminaire* provides physical support, electrical connection, and light control for an electric lamp. Ideally, the luminaire directs light to where it is needed while shielding the lamp from the eyes at normal angles of view.

Luminaires are composed of several parts that provide these different functions: the housing, the light-controlling element, and the glare-controlling element. Depending on the design requirements and optical control desired, some of these functions may be combined.

HOUSINGS

The electrical connection and physical support for the light source are provided by the luminaire *housing*. Often its electrical auxiliary equipment, when required, is also incorporated. Housings are divided into five categories based on how they are supported: recessed, semi-recessed, surface-mounted, pendant-mounted, and track-mounted.

Recessed housings are mounted above the finished ceiling, are entirely hidden from view, and have an *aperture* (opening) at the ceiling plane to allow light to pass through. Some recessed housings are designed to be mounted into the wall, the floor, or the ground.

The electrical connection between the building wiring and the luminaire is made at the *junction box*, which is often attached to the housing (figure 12.1). UL standards require that the connection ("splices") of luminaire wires to branch circuit wires be accessible for field inspection after the lighting fixture is installed. This access is usually accomplished through the aperture of the luminaire.

Semi-recessed housings are mounted partially above the ceiling with the remainder visible from below (figure 12.2). Sometimes the semi-recessed housing is mounted partially in the wall with the remainder projecting, and in rare cases it is mounted partially below the floor with the remainder visible from above.

Surface-mounted housings are mounted to the surface of a ceiling, a wall, or, in rare cases, a floor. If the ceiling or wall construction permits, the junction box is recessed into the mounting surface, giving a cleaner appearance (figure 12.3); otherwise, the junction box is mounted against the surface of the ceiling or wall (figure 12.4).

In both cases, the housing serves to partially or entirely conceal the junction box.

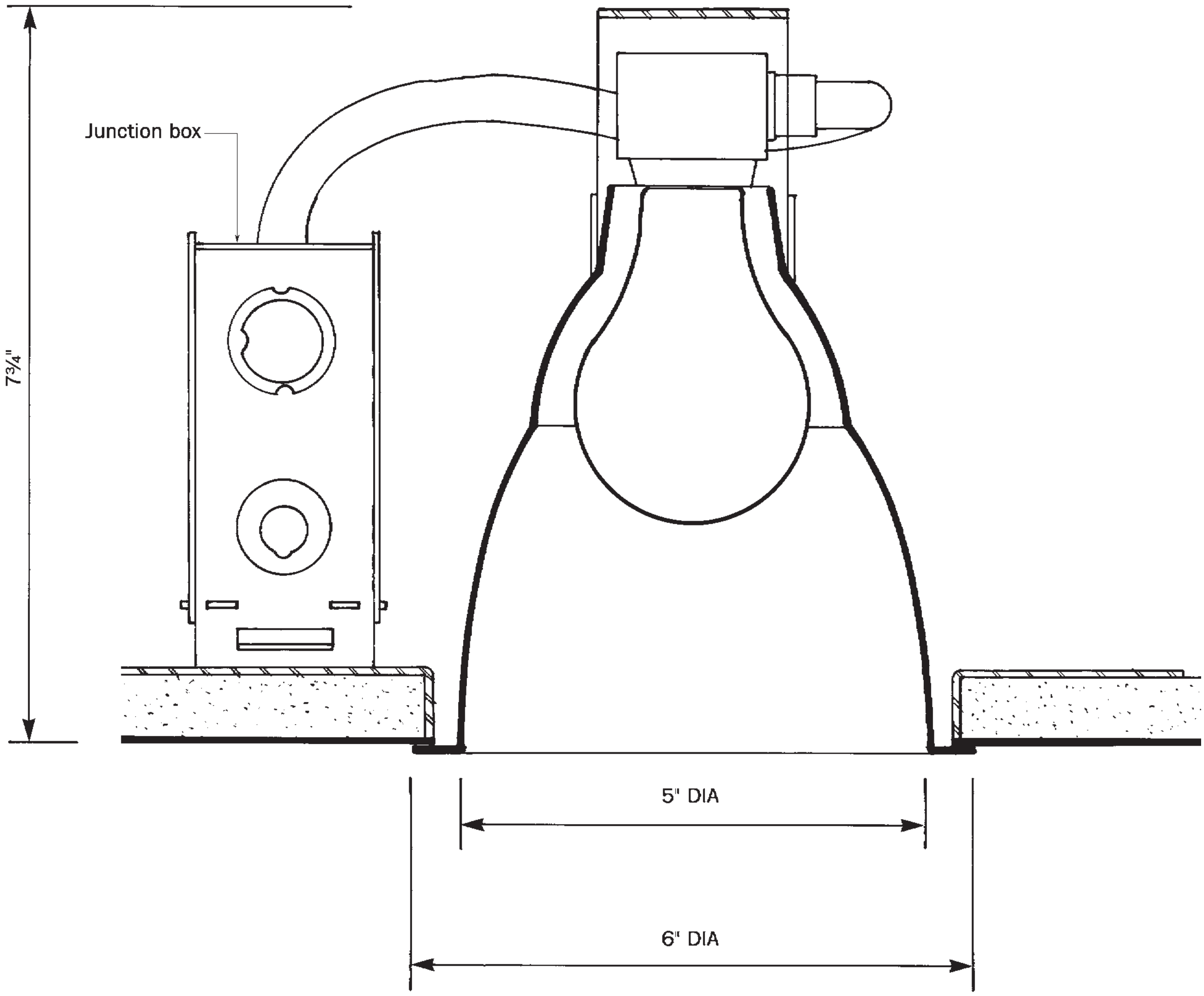

Figure 12.1 Recessed incandescent downlight with junction box.

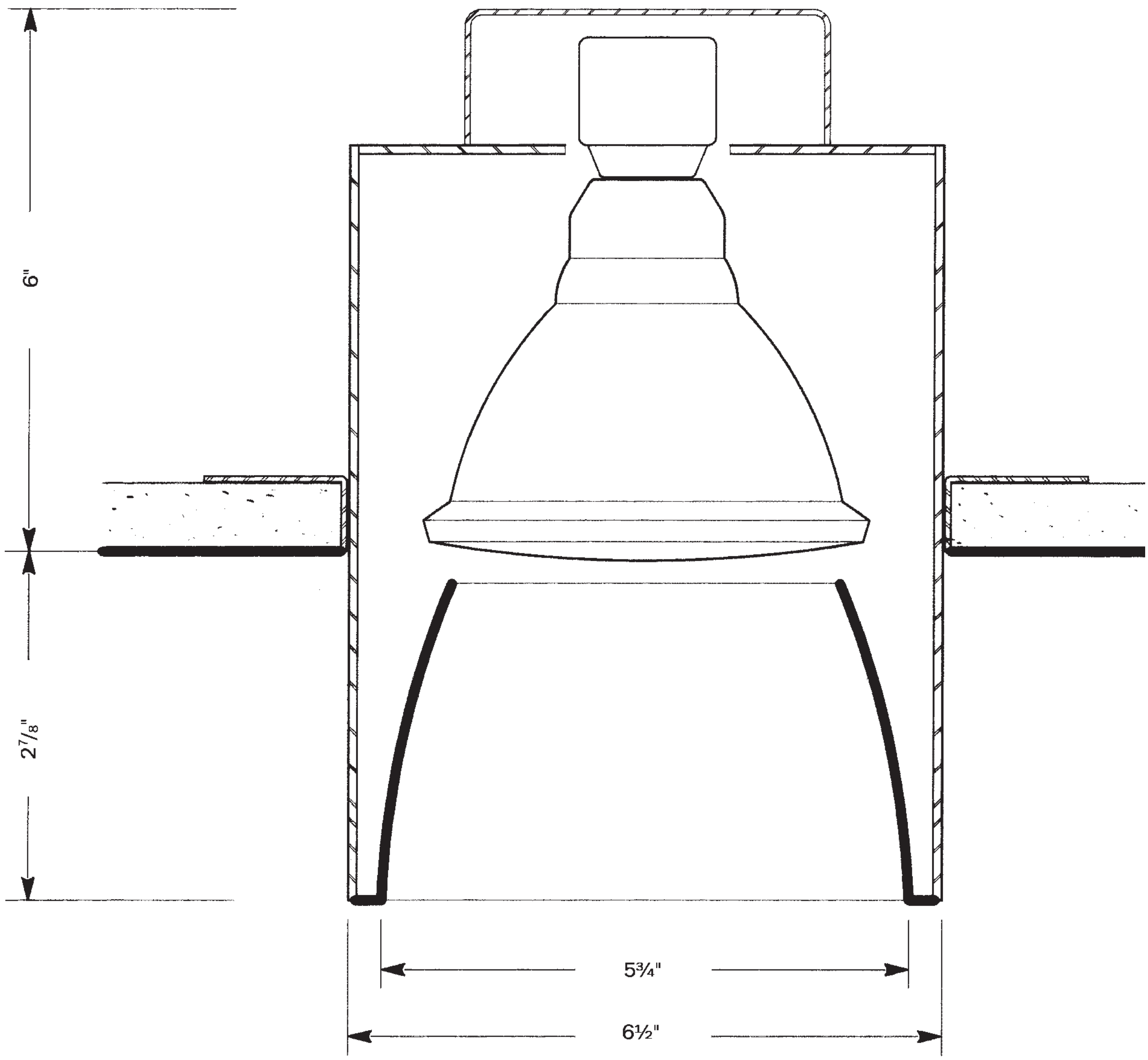

Figure 12.2 Semi-recessed incandescent downlight with junction box.

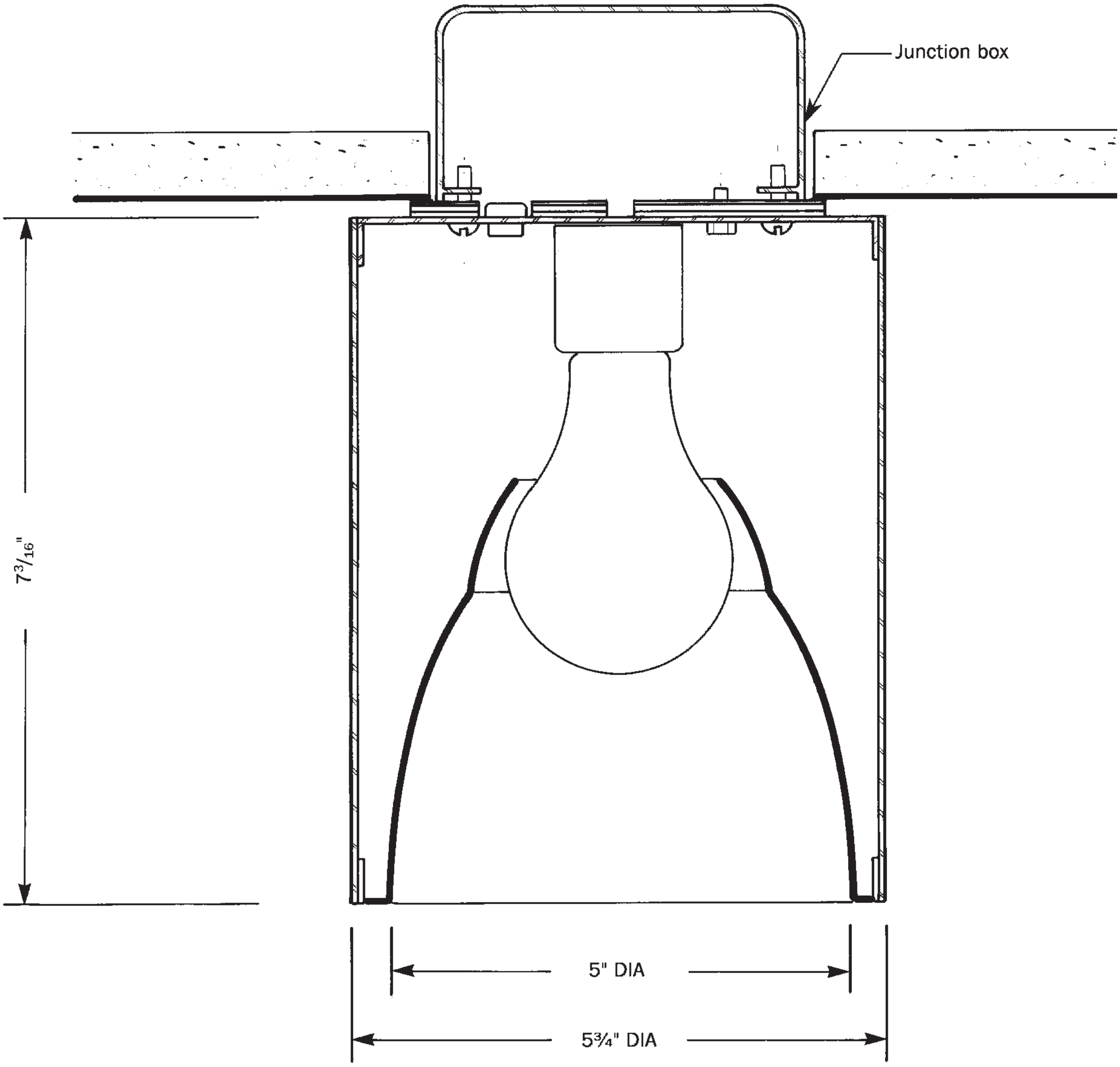

Figure 12.3 Surface-mounted incandescent downlight with recessed junction box.

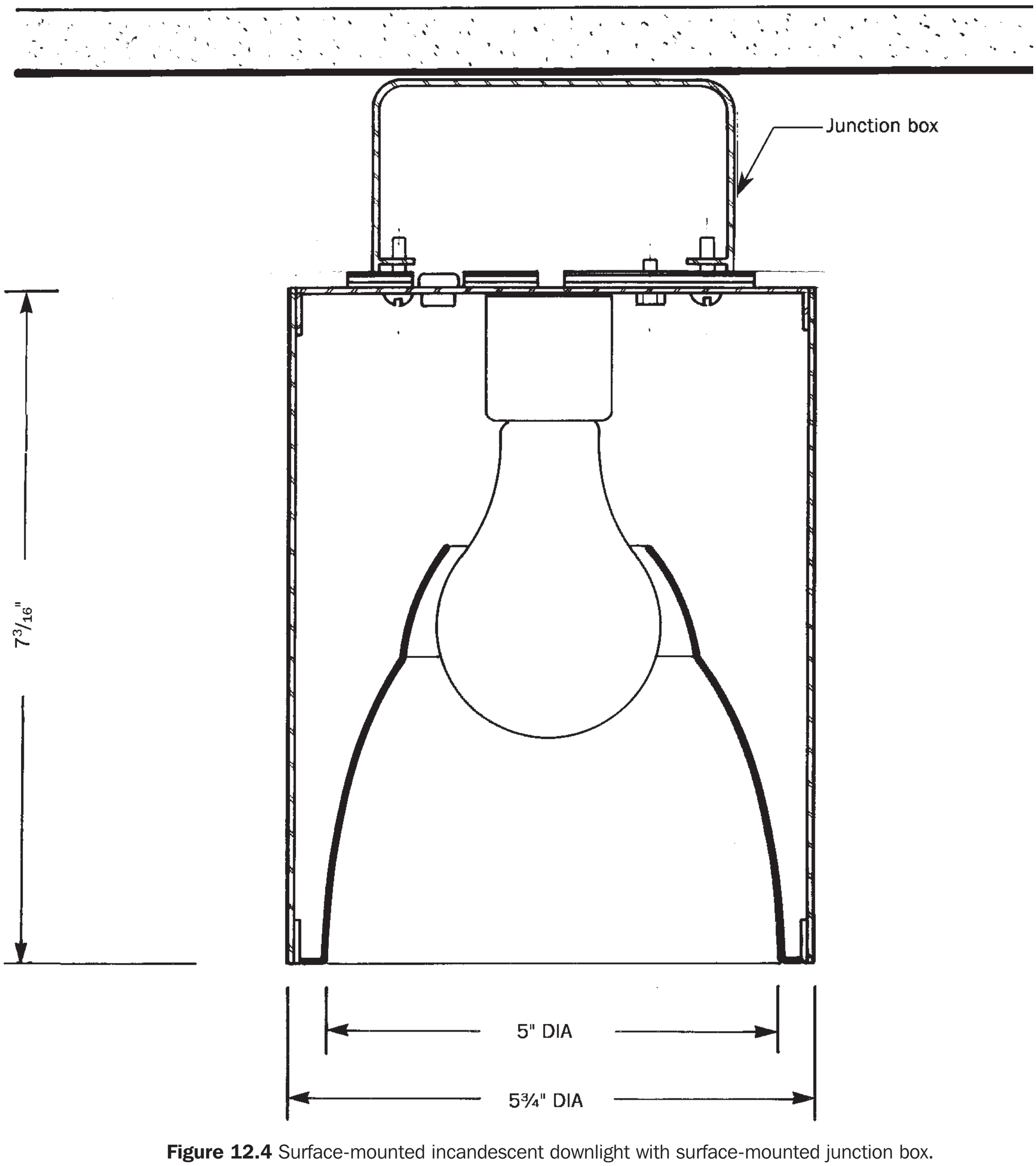

Figure 12.4 Surface-mounted incandescent downlight with surface-mounted junction box.

Because the housing of a surface-mounted luminaire is visible, it becomes a design element in the space.

Pendant-mounted housings also make use of a recessed or surface-mounted junction box located at the ceiling for electrical supply connection, but the luminaire is separated from the ceiling surface by a pendant such as a stem, chain, or cord. The junction box is concealed by a *canopy* (figure 12.5).

Pendant-mounted luminaires are used to provide uplight on the ceiling plane or to bring the light source closer to the task or activity in the space. At other times pendant-mounted luminaires are selected for decorative impact, as with a chandelier.

In high-ceiling spaces, bringing the light source down closer to the floor is often unnecessary. Instead of suspending the lighting element down into the space, where it becomes visually dominant, a more concentrated source at the ceiling plane is less conspicuous.

With *track-mounted* luminaires, a recessed, surface-mounted, or pendant-mounted lighting track provides both physical support and electrical connection through an adapter on the luminaire.

The main advantage of track is its flexibility. Track is often used where surfaces and objects to be lighted will be frequently or occasionally changed, or added or deleted, as in a museum or gallery. It also serves as an inexpensive way to bring electrical power to where it is needed in renovation and remodeling projects.

LIGHT AND GLARE CONTROL

Luminaires can be divided into five categories that describe their lighting function: downlights, wash lights, object lights, task lights, and multidirectional lights.

Downlights

Downlights, also called direct luminaires, produce a downward light distribution that is usually symmetrical. They are used in multiples to provide ambient light in a large space or for providing focal glow on a horizontal surface such as the floor or workplane (figure 12.6).

Point source downlights

A nondirectional, concentrated light source is often mounted in a reflector to control its distribution and brightness because the source would otherwise emit light in all directions. In an *open-reflector downlight*, a reflector made from spun or hydroformed aluminum accomplishes both purposes. A-lamp downlights allow for efficient use of inexpensive and readily available A-lamps (figure 12.7).

Tungsten-halogen (figure 12.8), compact fluorescent (figure 12.9), and HID open-reflector downlights (figure 12.10) operate under the same principle as the A-lamp downlight. Fluorescent and HID apertures are larger because the source is larger. For a given source, the larger the aperture, the greater is the efficiency of the luminaire.

Economy versions of the open-reflector downlight, often called “high hats” or “cans,” use an imprecise reflector to direct light downward and either a black multi-groove baffle or a white splay ring for brightness control. These luminaires usually provide too much glare for visual comfort and are inefficient at directing light down to horizontal surfaces. Although they are less expensive initially, they provide only short-term value: more watts are used to achieve an equivalent quantity of light.

Ellipsoidal downlights were early attempts at controlling the luminance of the source and providing a wide, soft distribution. They sometimes used silver-bowl lamps and were excellent at reducing the brightness of the aperture; they were, however, inefficient at directing light downward. These luminaires were large because the elliptical

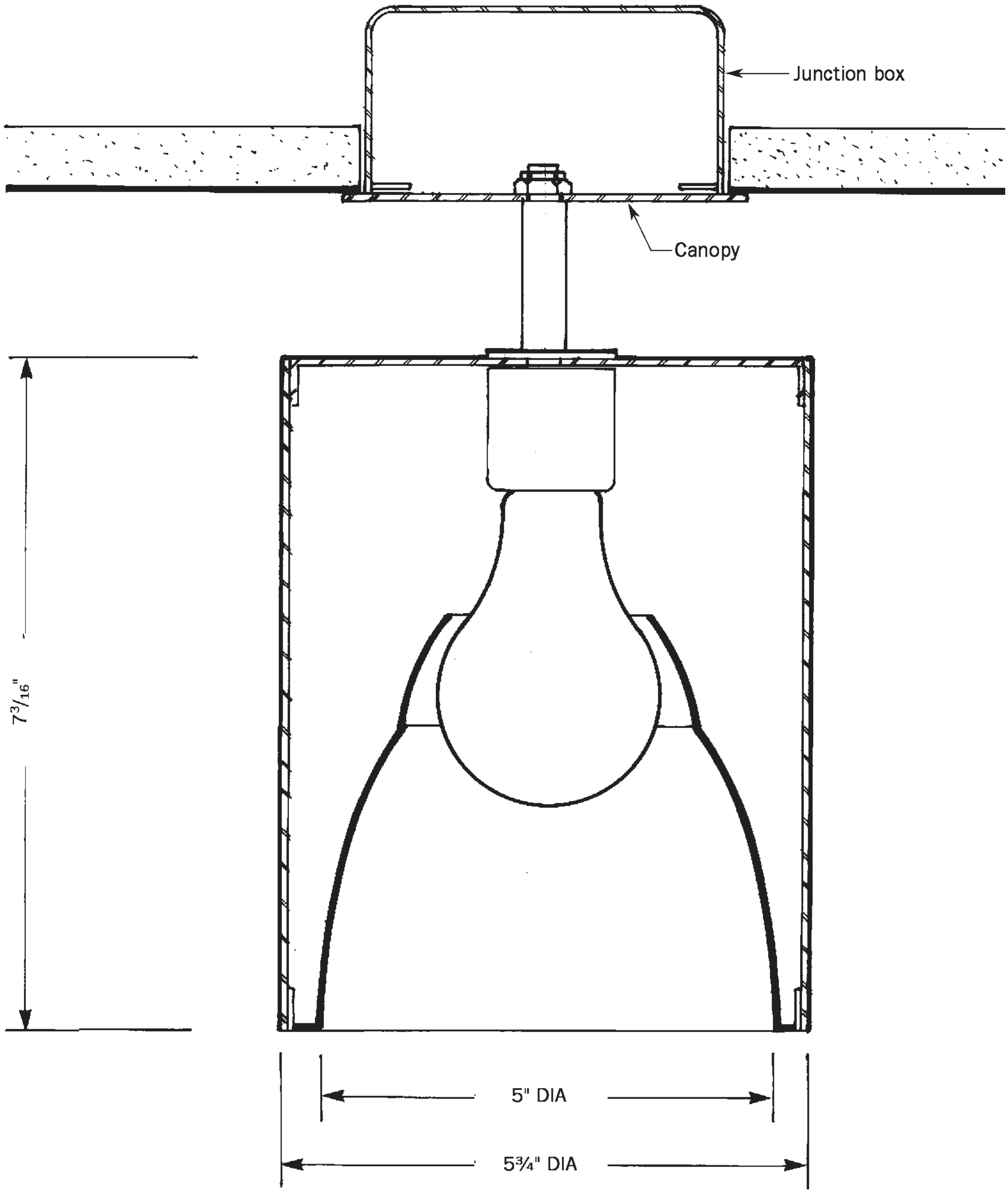

Figure 12.5 Pendant-mounted incandescent downlight with recessed junction box covered by a canopy.

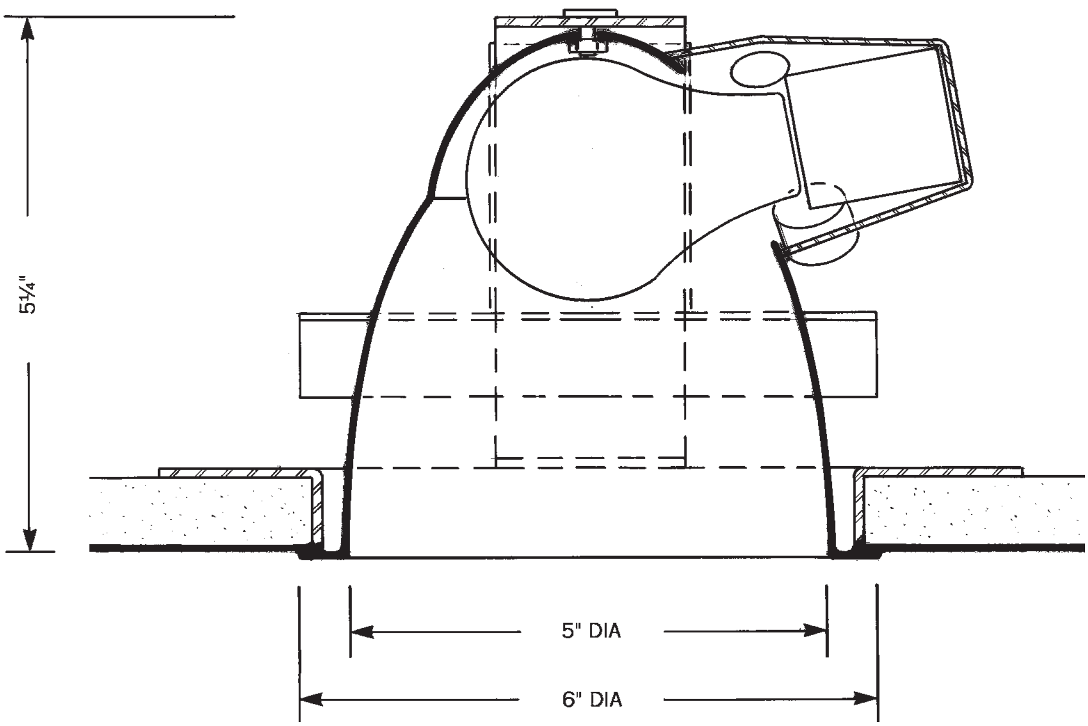

Figure 12.6 Side-mounted, A-lamp, shallow-depth downlight.

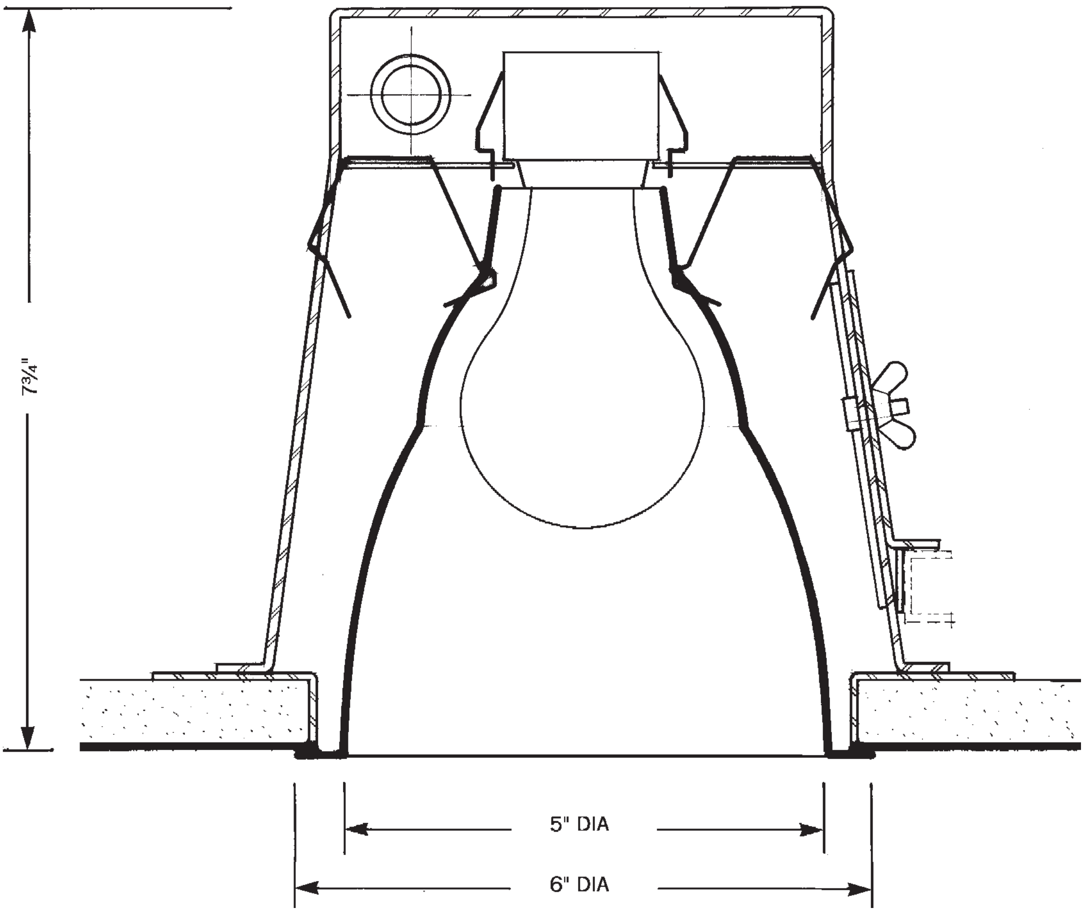

Figure 12.7 Incandescent, parabolic, open-reflector downlight with 5-in aperture.

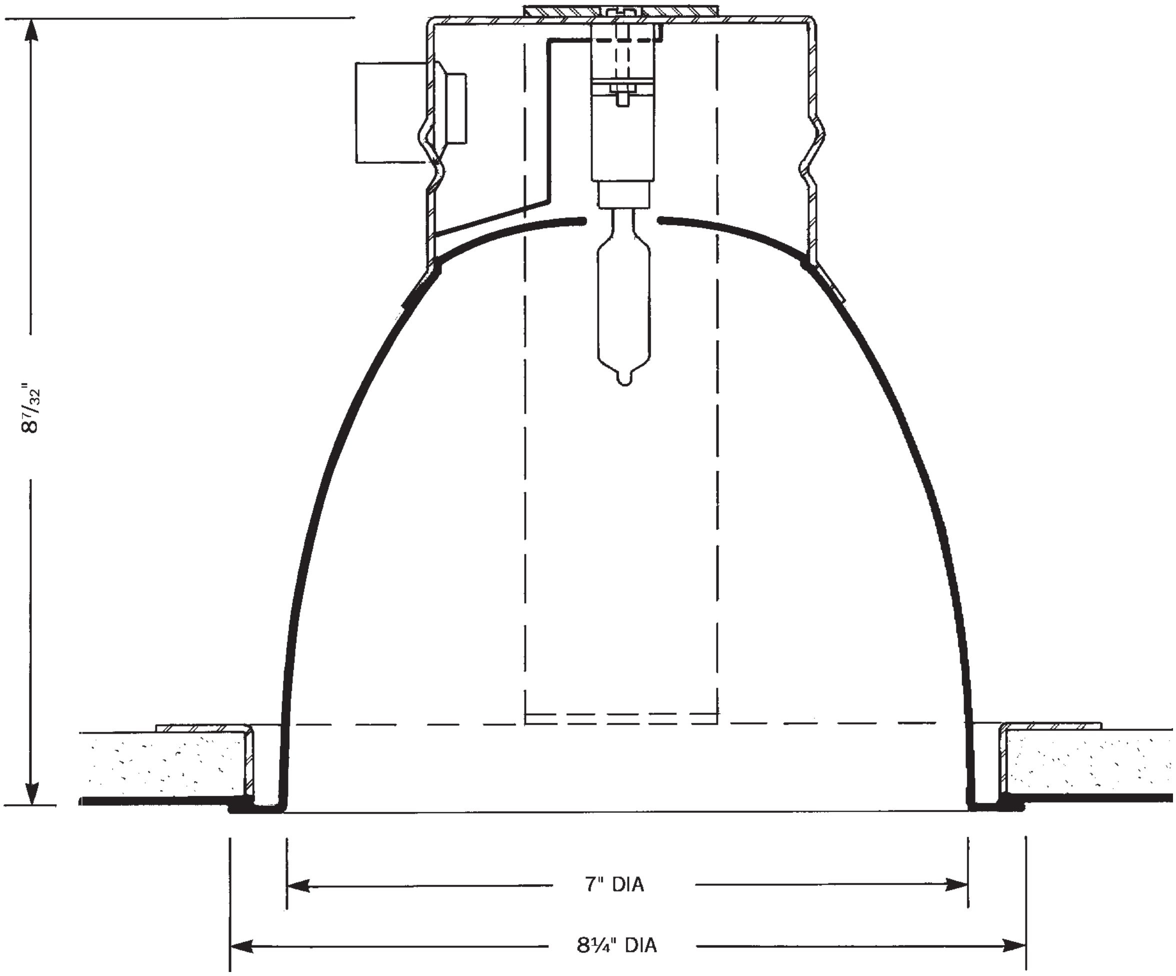

Figure 12.8 Tungsten-halogen, parabolic, open-reflector downlight with 7-inch aperture.

reflector is larger than the parabolic contour; they are used infrequently today (figure 12.11).

Shallow-contour, silver-bowl, open-reflector downlights are used for a general diffusion of light combined with sparkle at the ceiling plane, which is provided by the luminaire's "pebbled"-surface aluminum reflector. The reflecting bowl of the lamp throws light up into the luminaire reflector, which in turn redirects the light in a controlled downward beam (figure 12.12). The silver-bowl lamp provides built-in glare control.

Directional-source downlights do not require a light-controlling element because the AR, MR, PAR, or R lamp provides that

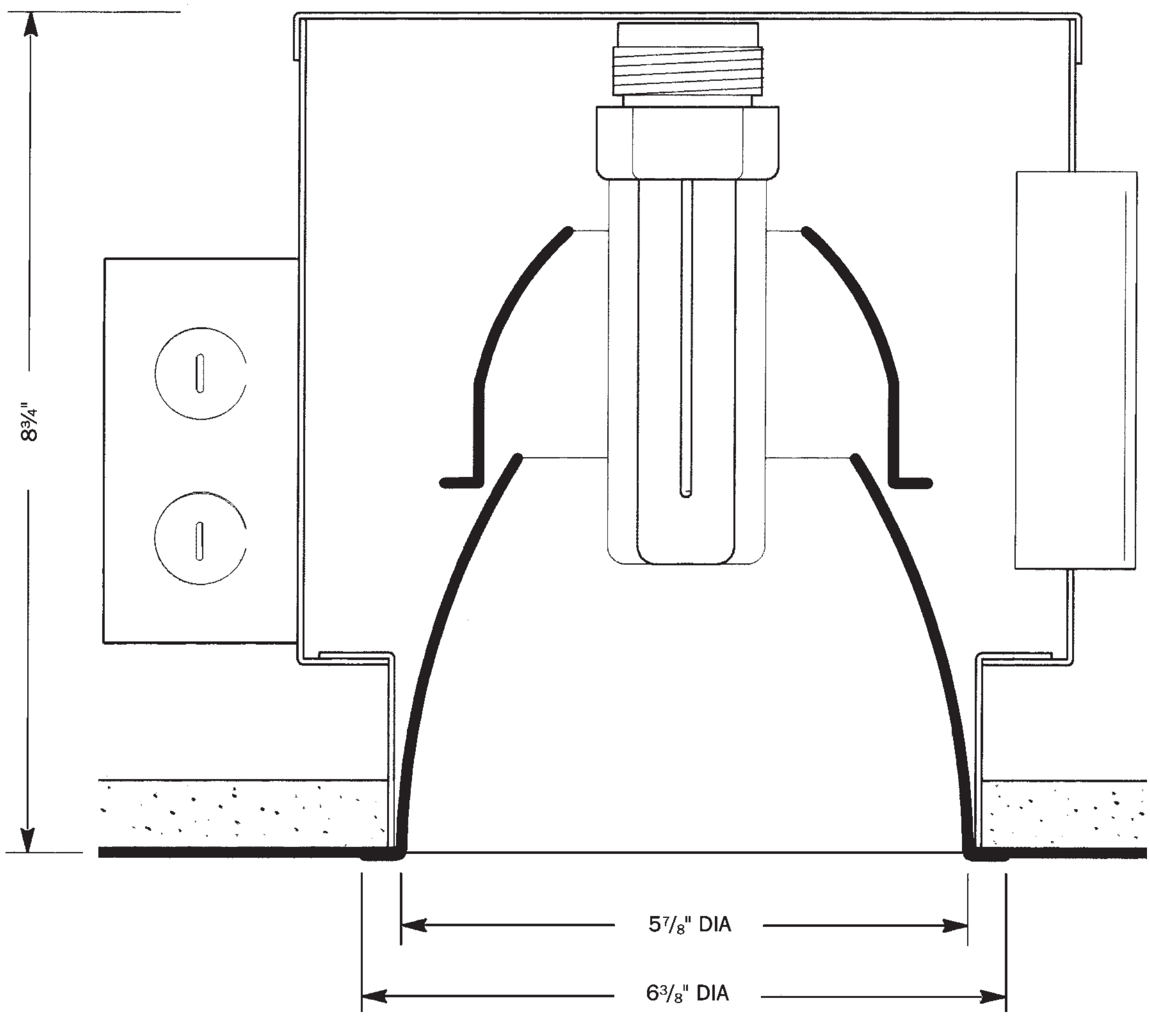

Figure 12.9 Compact fluorescent, parabolic, open-reflector downlight with 6-inch aperture.

function. Luminaires for these sources require only a brightness-controlling element; the most efficient is the open parabolic reflector. These luminaires are relatively easy to maintain: very little dirt collects on the underside of the lamp, and every time the lamp is changed, the entire optical system is replaced (figure 12.13).

R14 or R20 downlights are sometimes used with spot lamps when a narrow beam of light is desired from a small aperture (figure 12.14), but PAR16 and PAR20 lamps are more efficient. R30 and R40 downlights are infrequently used; the wide spread of the R flood lamp is available from an A-lamp downlight, which is more efficient

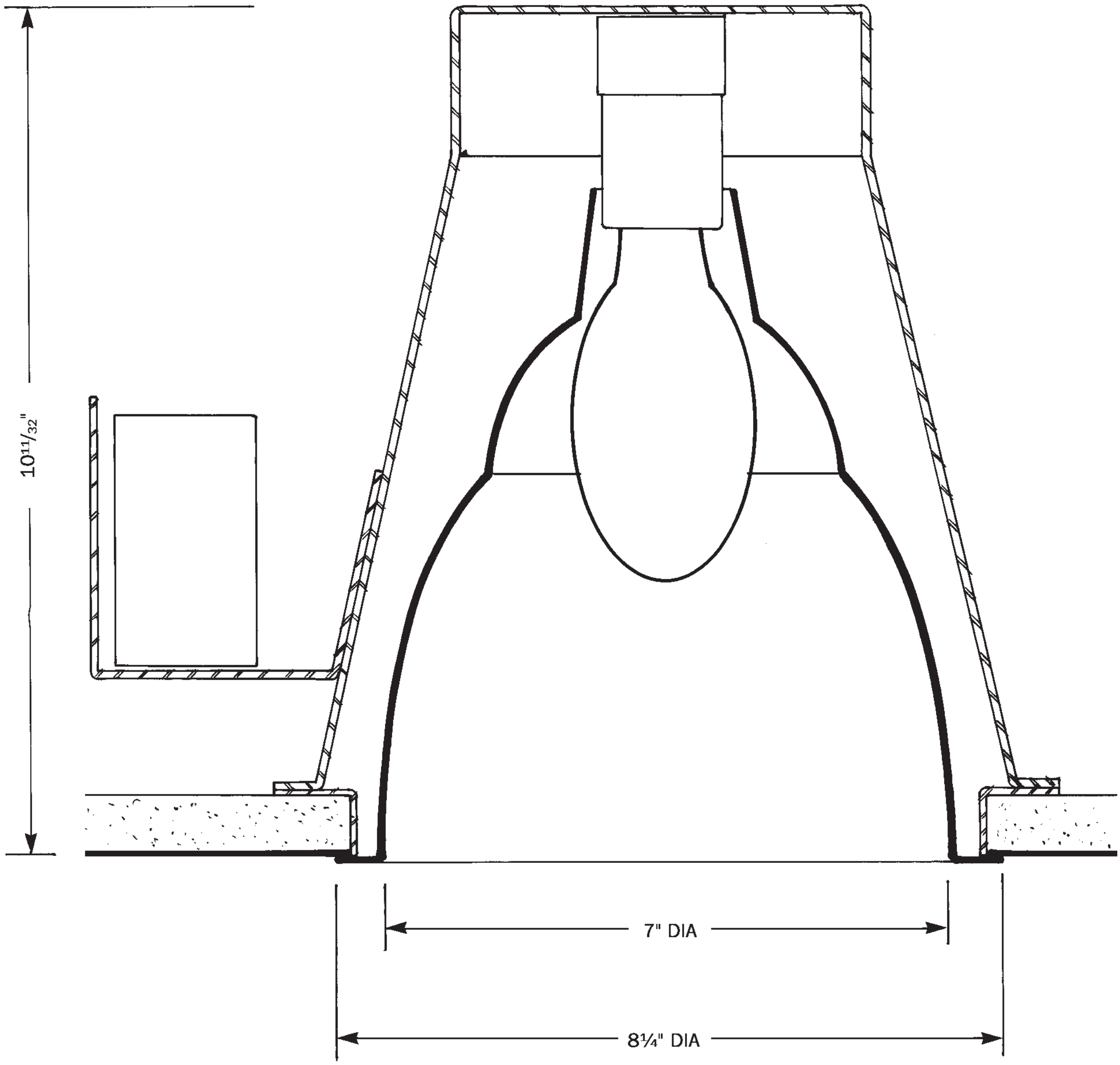

Figure 12.10 Low-wattage, metal halide, parabolic, open-reflector downlight with 7-in aperture.

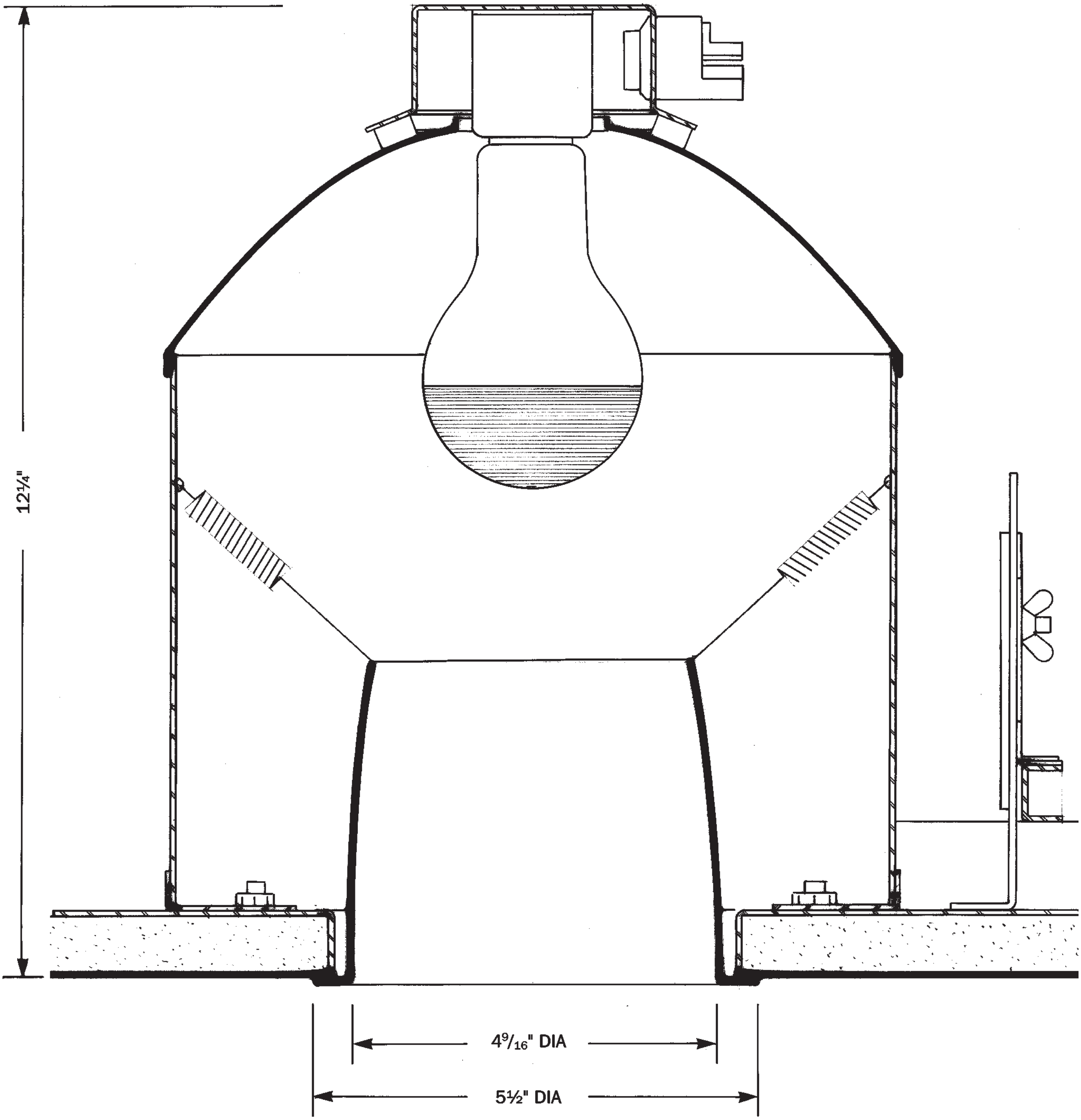

Figure 12.11 Incandescent, ellipsoidal, open-reflector downlight with 4½-in aperture.

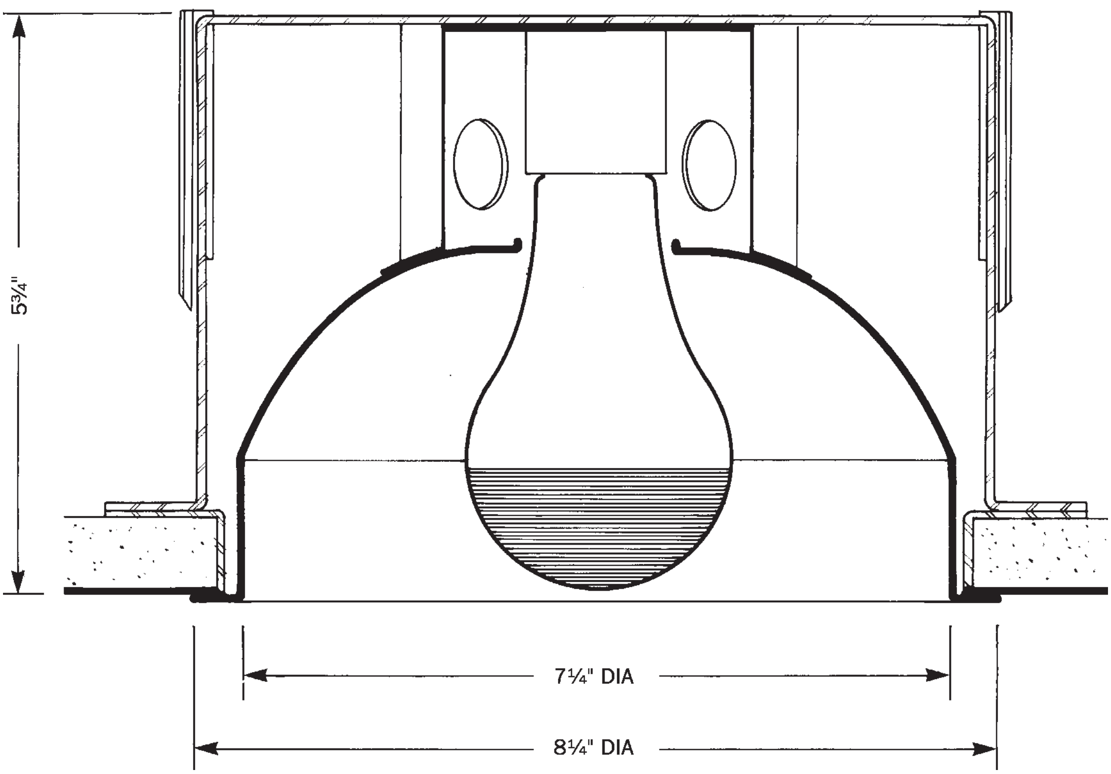

Figure 12.12 Incandescent, shallow-contour, silver-bowl, open-reflector downlight with 7¼-in aperture.

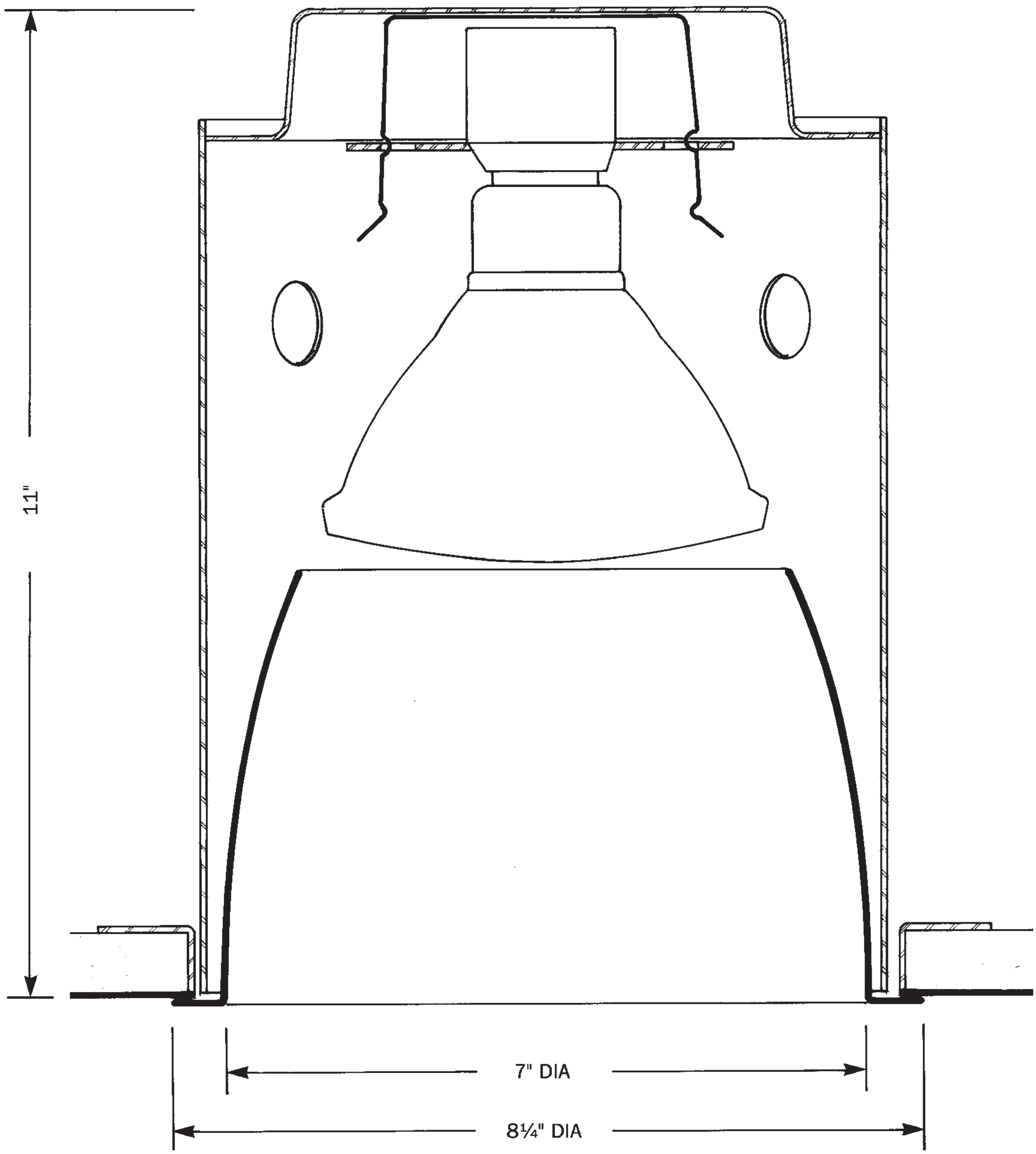

Figure 12.13 Parabolic, open-reflector PAR downlight with 7-in aperture.

and uses a source that costs approximately one-fifth as much (figure 12.15).

When a more concentrated beam is desired, PAR lamps are more efficient, delivering more light at a given wattage for the same cost. PAR lamp downlights are used for greater emphasis on the horizontal plane than is usually produced by other downlights (figure 12.13). This greater intensity of light is called “punch.”

Almost all open-reflector downlights have round apertures. Reflectors are available with either an overlap flange or a flush ceiling detail. The overlap flange is used in gypsum board and acoustical tile ceilings to conceal the uneven edge at the ceiling opening. Flush details are used in plaster ceilings to create a neat, finished appearance; the ceiling is plastered directly to the edge of a plaster ring or frame (figure 12.16).

Reflectors. Specular aluminum reflectors produce the most efficient beam control. Semi-specular reflectors are slightly less efficient, but they eliminate irregularities in the lamp beam or reflected images of the fila-

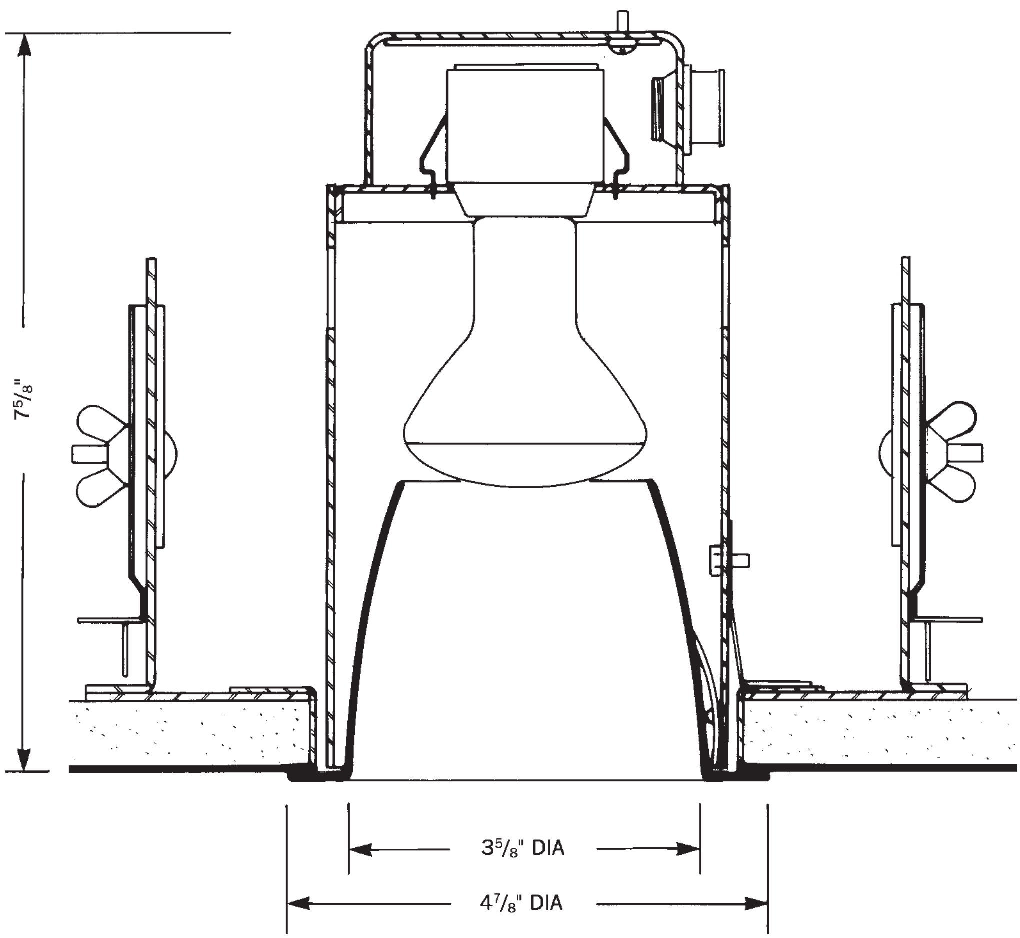

Figure 12.14 Parabolic, open-reflector R20 downlight with 3½-in aperture.

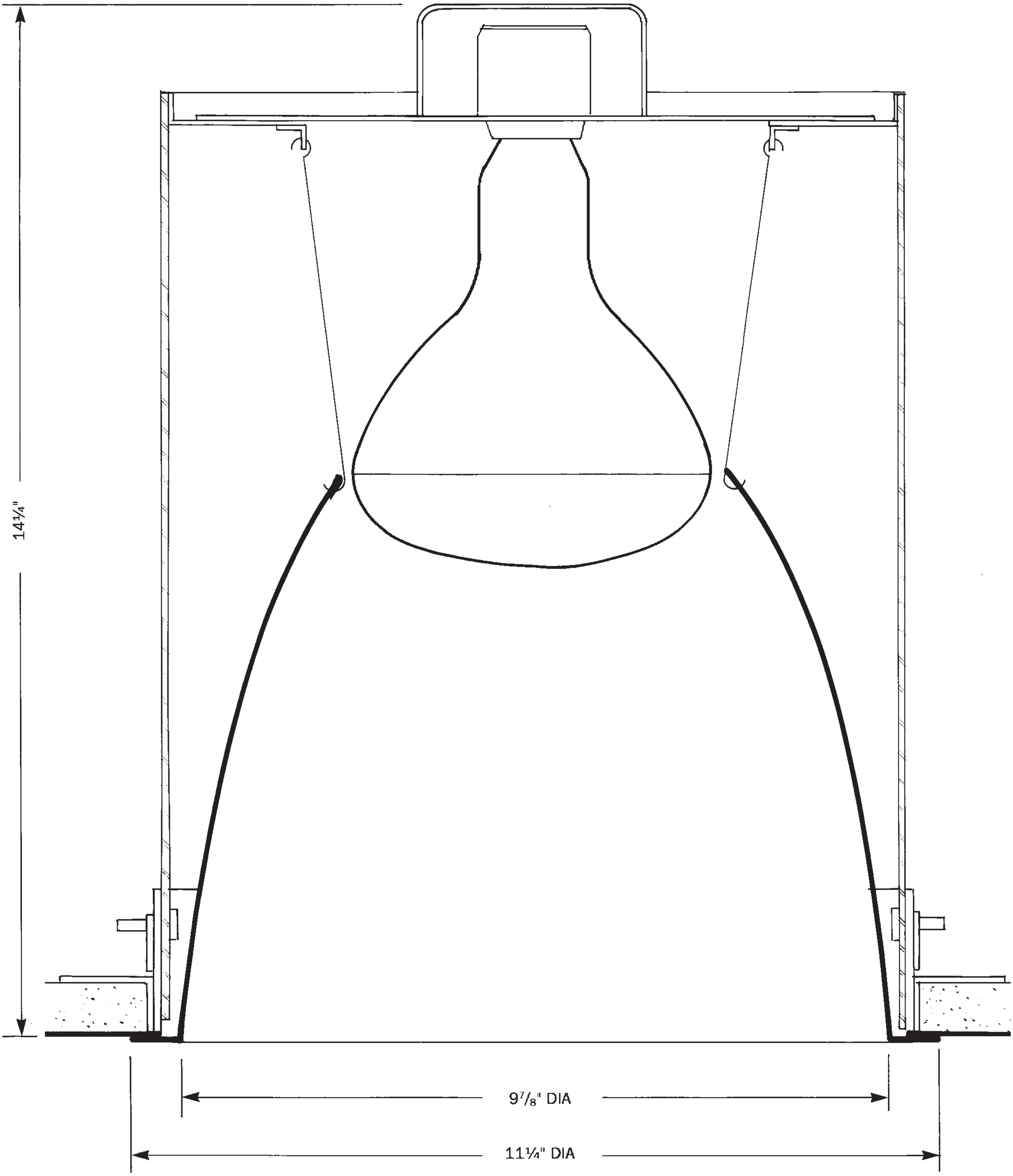

Figure 12.15 Parabolic, open-reflector R40 downlight with 10-in aperture.

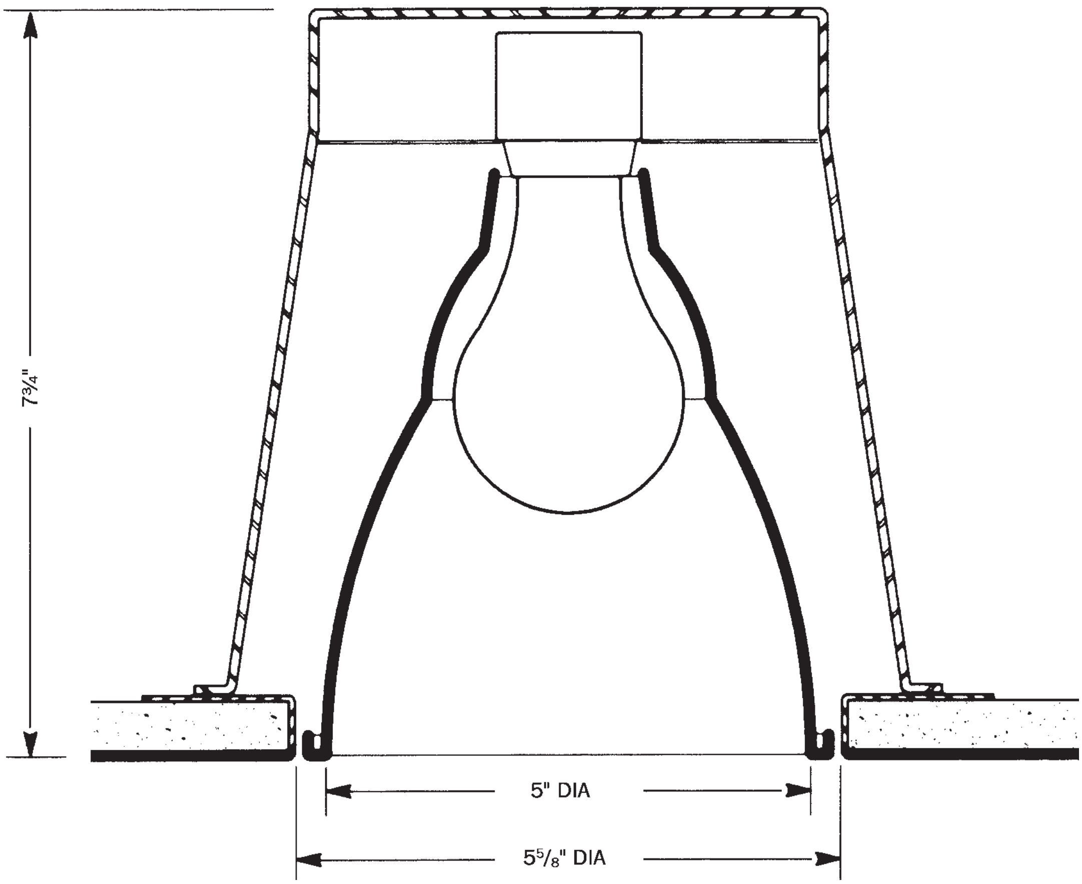

Figure 12.16 Parabolic, open-reflector downlight with flush-flange reflector.

ment coil or lamp phosphors. Although this slight diffusion of the reflector surface yields a reflector of greater luminance than a specular one, the semi-specular reflector still appears to be of low brightness when viewed in the ceiling plane.

Specular and semi-specular aluminum reflectors should be treated like fine glassware. Dirt, fingerprints, and scratches spoil the appearance and diminish the performance of reflectors. It is advisable to handle reflectors carefully during construction; once installed they may be cleaned with a soft cloth and glass cleaner or removed and cleaned in a dishwasher or industrial washing machine.

Rectilinear fluorescent downlights

Fluorescent downlights are based on the same principles as the incandescent downlight. They typically use either rapid-start T8, T12, or long compact fluorescent sources.

Common sizes for rapid-start fluorescent downlights, also called “troffers,” are 1

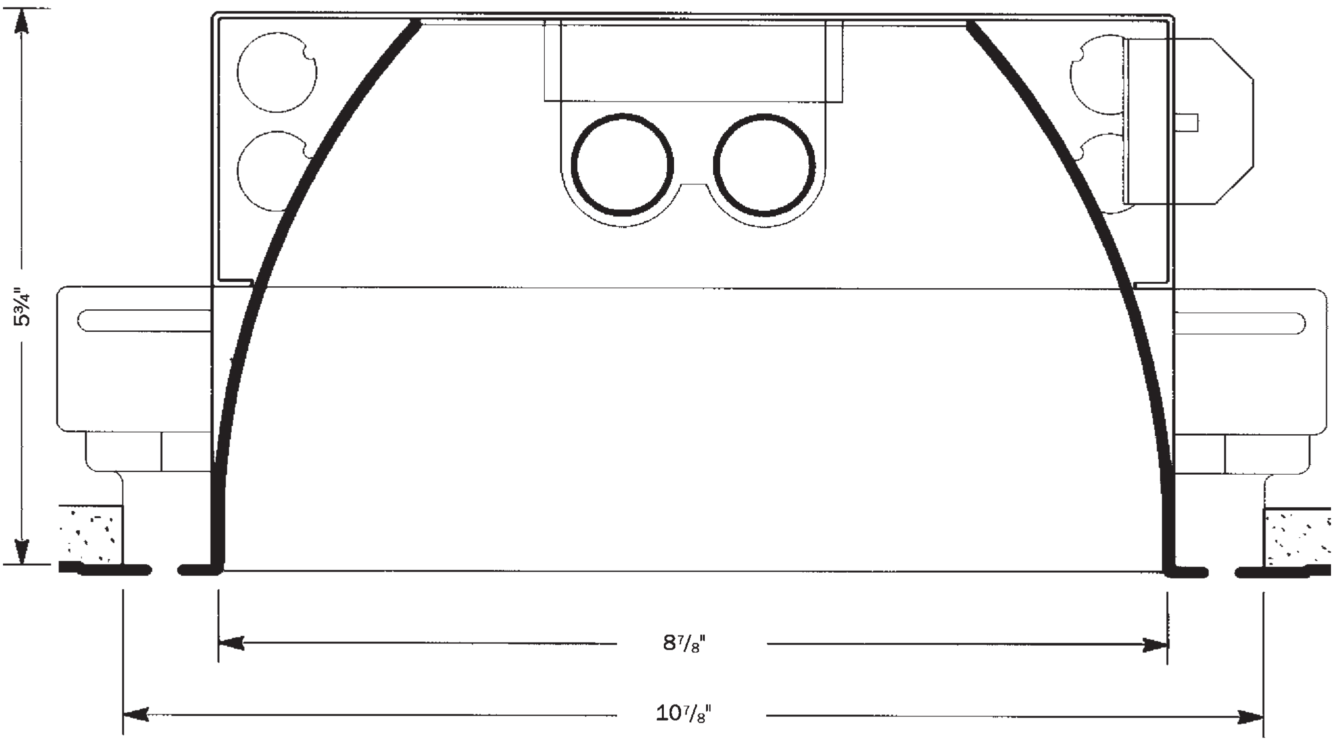

Figure 12.17 Fluorescent 1 ft ×4 ft eight-cell parabolic downlight.

ft × 4 ft, 2 ft × 4 ft, and 2 ft × 2 ft; the last of these is used when a nondirectional (square) ceiling element is desired. Because these luminaires take up such a large portion of the ceiling surface (as compared to a round-aperture downlight), they are significant factors in the design and appearance of the ceiling plane (figure 12.17).

Suspended ceiling systems frequently use 2 ft × 4 ft fluorescent downlights because they integrate easily. Square 1 ft × 1 ft and 1.5 ft × 1.5 ft luminaires with compact fluorescent sources take up a smaller portion of the ceiling surface, providing energy-effective luminaires in compact sizes.

Shielding. With all fluorescent downlights, the shielding material is the critical component, because this element is most prominent in the direct field of view. The purpose of diffusers, lenses, louvers, reflectors, and other shielding materials used in fluorescent downlight luminaires is to redirect light from the glare zone down toward work surfaces.

Prismatic lenses incorporate a pattern of small prisms or other refractive elements to reduce the brightness of the luminaire and inhibit direct glare. But almost all fluorescent luminaire lenses fail to reduce their luminance sufficiently to provide visual comfort and prevent bright images in VDT screens. The excessive contrast between the lens and the ceiling plane also creates distracting reflections.

Egg-crate louvers are made of intersecting straight-sided blades that reduce luminance by blocking light rays that otherwise would emerge at glare angles. They are made of translucent or opaque plastic or painted metal. Egg-crate louvers are inefficient in transmitting light, controlling glare, and preventing VDT screen reflections.

Parabolic louvers control luminance precisely; they consist of multiple cells with parabolic reflectors and a specular or semi-specular finish. The cells range in size from ½ in × ½ in to 1 ft × 1 ft.

Small-cell parabolic louvers reduce luminance, but are inefficient in light output. To maximize efficiency, they often have a highly specular finish, which may cause such a low luminance at the ceiling plane that the room seems dim and depressing.

Deep-cell open parabolic louvers offer the best combination of shielding and efficiency.

To avoid reflected glare in VDT screens, IESNA recommends that average luminaire luminance be less than

850 cd/m^2 at 55° from nadir

350 cd/m^2 at 65° from nadir

175 cd/m^2 at 75° from nadir

A manufacturer's luminaire photometric report should include a luminance summary that tabulates brightness values at angles above 45° from nadir. This summary may be used to evaluate the suitability of direct luminaires in offices with VDTs.

Although use of the footlambert (fL) is discouraged, some manufacturers still provide average luminance data in fL instead of cd/m^2. To check compliance with these limits, multiply the fL values by 3.42 to determine cd/m^2.

Spacing criterion

Manufacturers will sometimes publish the luminaire *spacing criterion* (SC) for their downlight equipment. This is an estimated maximum ratio of spacing to mounting-height above the workplane in order to produce uniform, horizontal illuminance. SC is a low-precision indicator; its purpose is to aid the designer in quickly assessing the potential of a downlight luminaire to provide uniform illumination of the horizontal plane.

SC values are sometimes assigned for uplights, but they are rarely assigned to wallwashers, object lights, task lights, or multidirectional lights because these luminaires are not intended to provide uniform, horizontal illuminance.

Luminous ceilings

A *luminous ceiling* also provides direct, downward distribution. It consists of a plane of translucent glass or plastic—often the size of the entire room—suspended below a regular grid of fluorescent lamps. The suspended element becomes the finished ceiling. This technique, popular in the 1950s and 1960s, provides uniform, diffuse, ambient light (figure 12.18).

The cavity above the luminous plane must be free of obstructions and all surfaces are to be finished with a high-reflectance (80 to 90 percent), matte-white paint. Luminous ceilings share the same drawback as indirect lighting—they light everything from all directions, with no shadows or modeling, giving the gloomy effect of an overcast sky.

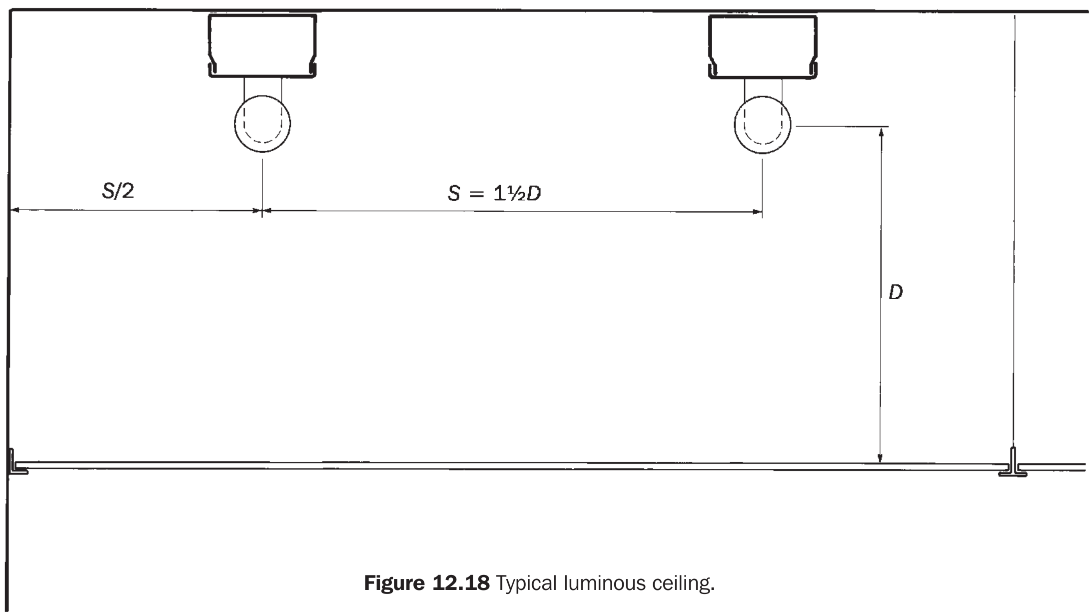

Figure 12.18 Typical luminous ceiling.

Wash Lights

Wash lights are luminaires that provide an even "wash" of relatively uniform brightness, usually on a wall but occasionally on a ceiling. In rooms of moderate size, walls are often the major element in the field of view; washing walls with light has properly become a major technique in the practice of creative illumination.

To minimize specular reflections near the top of lighted vertical surfaces, a matte (diffuse) finish is essential. Specular surfaces, such as mirrors and highly polished marble, cannot be lighted because the light received on the surface is reflected down to the floor and no impression of brightness is created.

Walls are lighted in two ways: (1) by using a row of individual, asymmetric-distribution luminaires placed parallel to the wall at a distance of about one-third the height of the wall, and with the individual units spaced about the same distance apart from each other as they are away from the wall; or (2) by using a system of linear sources or, ideally, closely spaced directional sources mounted in a continuous "slot" adjacent to the wall.

Asymmetric wall-washers

Asymmetric *wall-washers* are used for lighting walls, sometimes to light artwork, and occasionally to create ambient light in a space.

All asymmetric wall-washers use reflectors or directional lamps or both, frequently combined with lenses to spread the light sideways and smooth the beam. They fall into two categories: downlight/wall-washers and reflector wall-washers.

Downlight/wall-washers. The combination *downlight/wall-washer* is a special kind of wall-washer. It consists of a parabolic, open-reflector downlight with an added elliptical reflector, sometimes called a "kicker" reflector (figure 12.19). This additional reflector "kicks" light up toward the top of the wall,

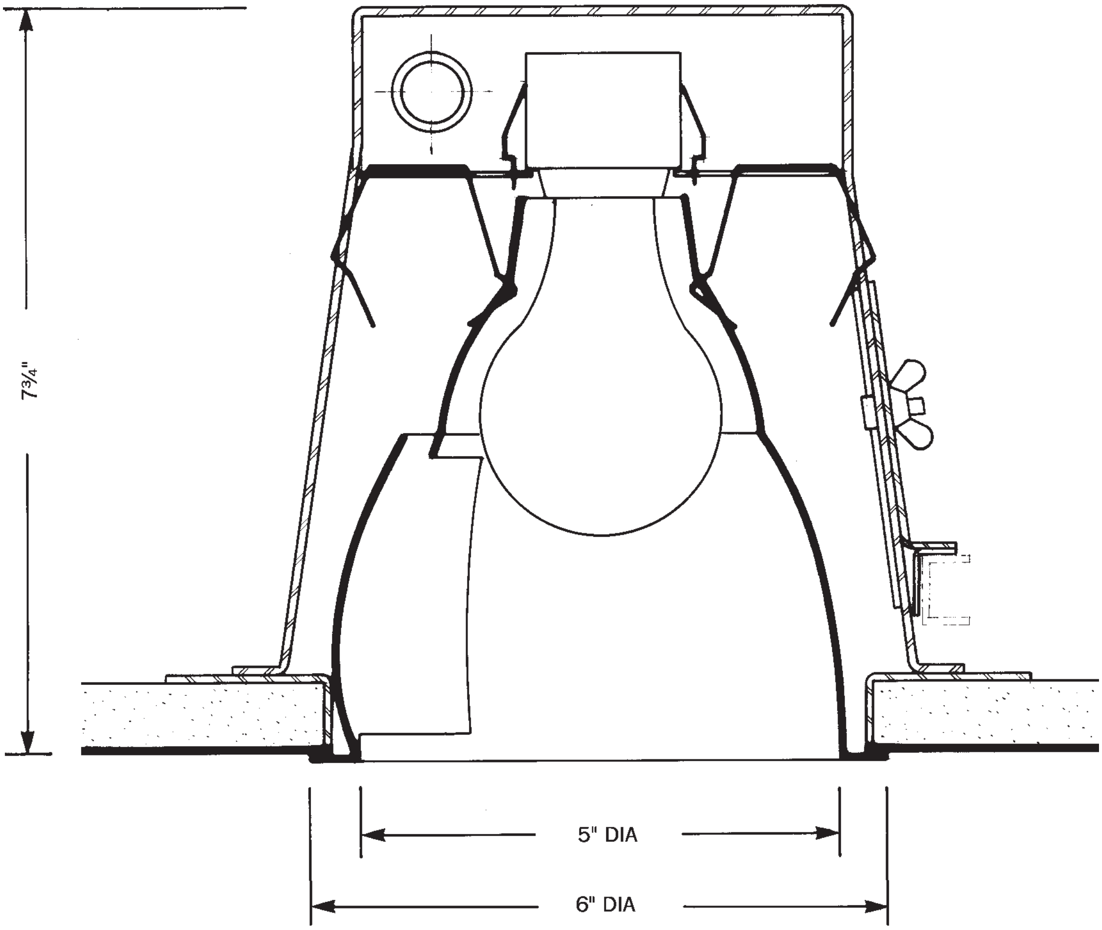

Figure 12.19 Parabolic, open-reflector downlight/wall-washer with 5-in aperture.

eliminating the parabolic scallop that is created by the normal, conical light pattern when it intersects a wall.

The downlight/wall-washer looks identical to the same-size aperture open-reflector downlight. This makes it possible to use downlights (without kickers) for general room illumination and to then add downlight/wall-washers adjacent to the walls, usually on closer centers for uniformity of illumination.

Downlight/wall-wash luminaires are available for incandescent A, tungsten-halogen, compact fluorescent, mercury vapor, metal halide, and HPS lamps. Variations of the downlight/wall-washer have been developed to light adjacent walls forming a corner (*downlight/corner wall-washer*), to light opposite sides of a corridor (*downlight/double wall-washer*), and to light the wall next to a door without spilling through the

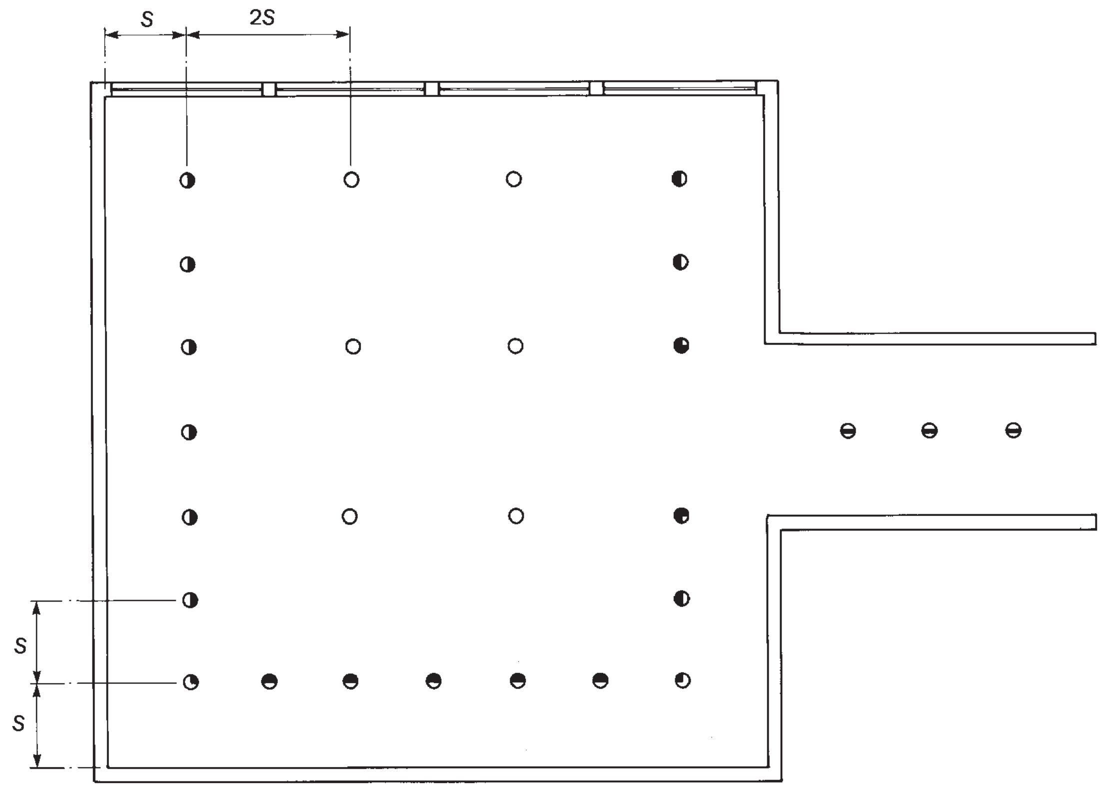

Figure 12.20 Typical room layout using matching-aperture, parabolic, open-reflector downlights and downlight/wall-washer variations.

doorway and causing glare (*downlight/half wall-washer*) (figure 12.20).

Downlight/wall-wash luminaires have downlight distributions in three directions virtually unchanged by the kicker reflector. They work well in small rooms, such as a 10-ft-wide office where opposite walls are lighted; the downlight component provides good modeling of faces throughout the room. The lighted vertical surface is moderately lighted; the horizontal and vertical planes appear to have relatively equal emphasis.

Reflector wall-washers. A greater emphasis on the vertical surface is provided by luminaires that light only the walls without any significant downward distribution. *Reflector wall-washers* make use of sophisticated optical systems to provide distribution and luminance control. There are two kinds of reflector wall-washers: lensed wall-washers and open-reflector wall-washers.

Lensed wall-washers contain a lamp, preferably a directional source; an internal kicker reflector; a spread lens; and a brightness-controlling reflector to shield glare (figures 12.21 through 12.24). Lensed wall-washers are available for tungsten-halogen MR and PAR, compact fluorescent, metal halide, and HPS lamps.

Reflectors that are not circular, parabolic, elliptical, or hyperbolic are called nonfocal reflectors. *Open-reflector wall-washers* have a compound-contour reflector shape

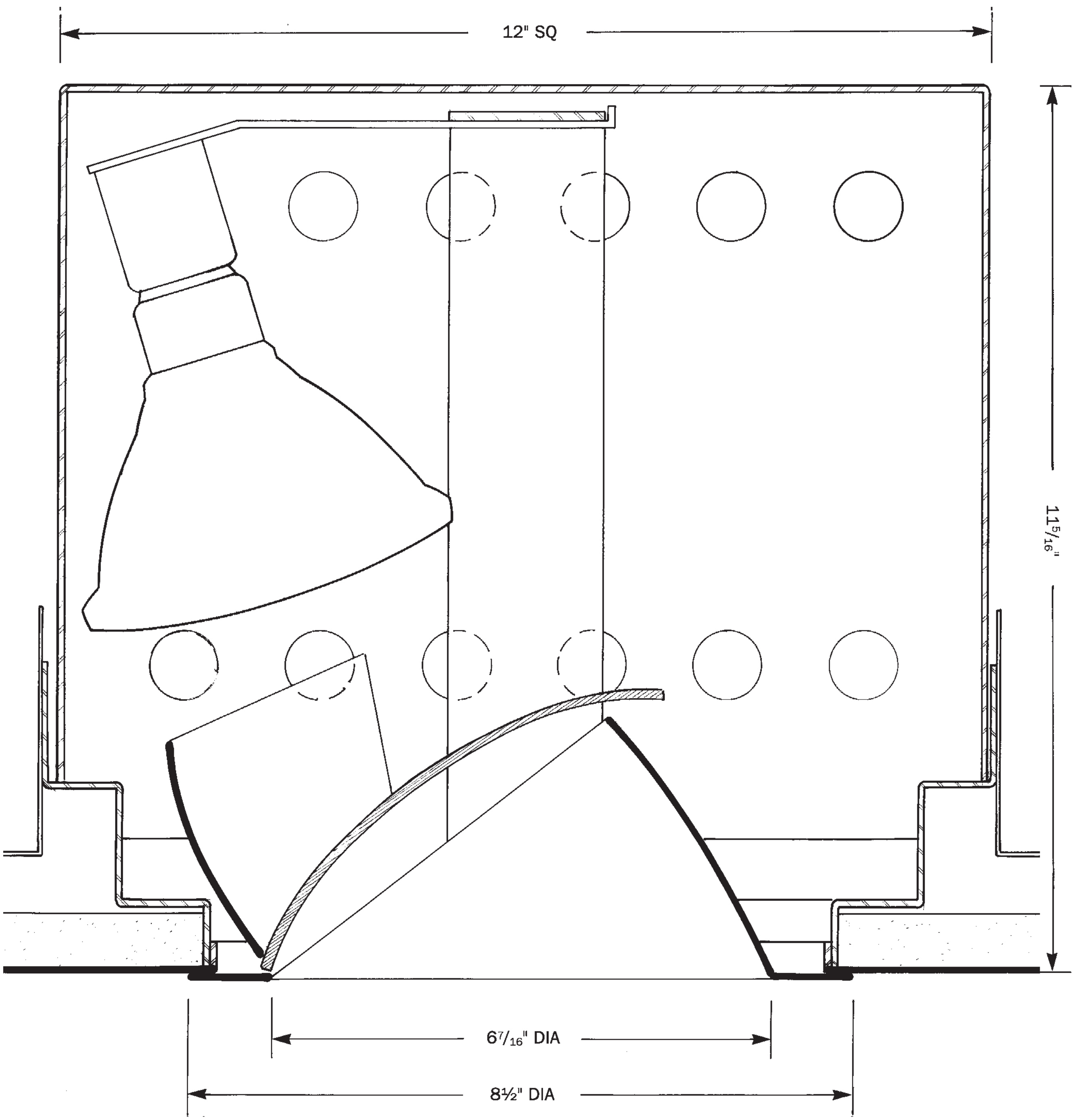

Figure 12.21 Recessed PAR38 lensed wall-washer.

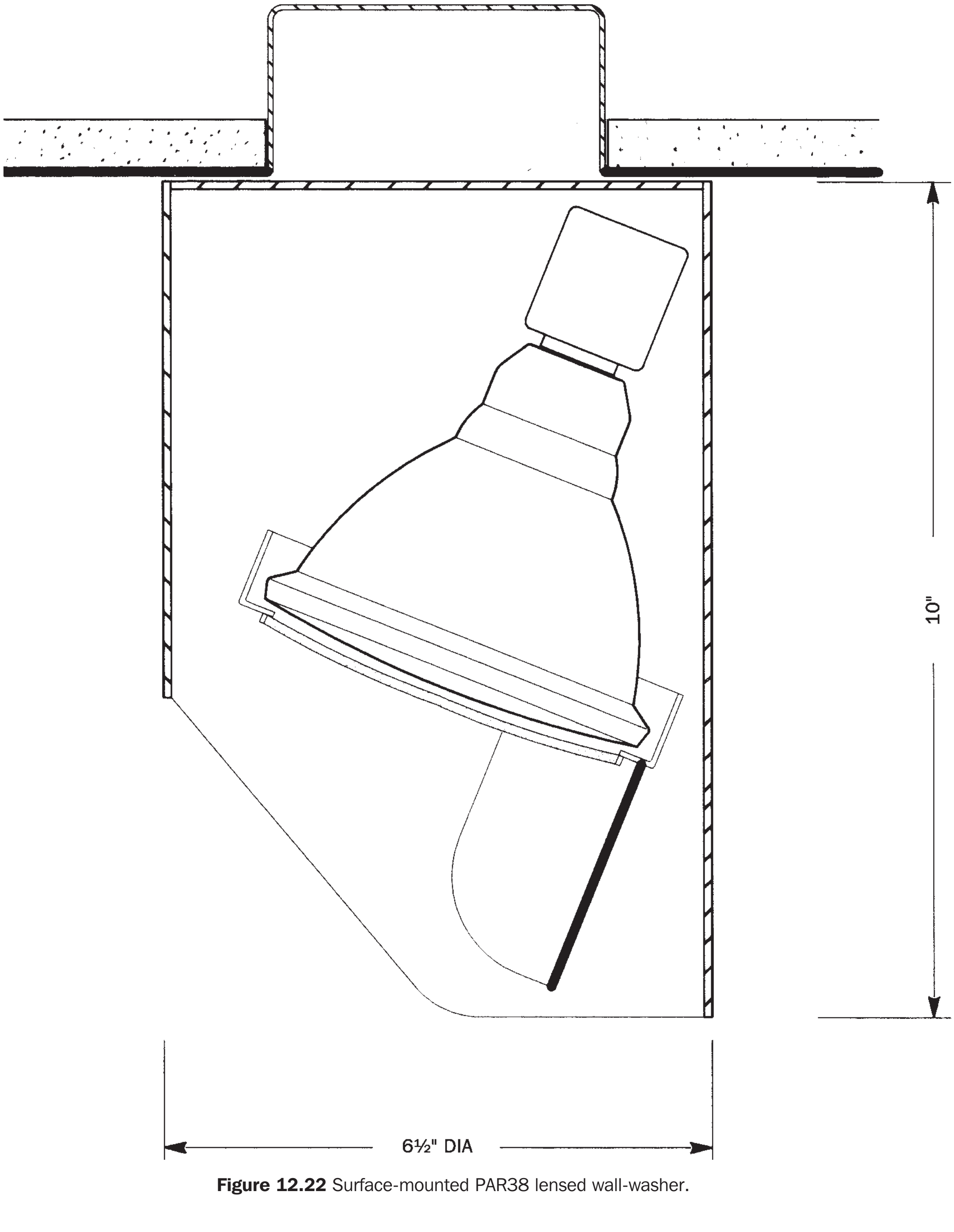

Figure 12.22 Surface-mounted PAR38 lensed wall-washer.

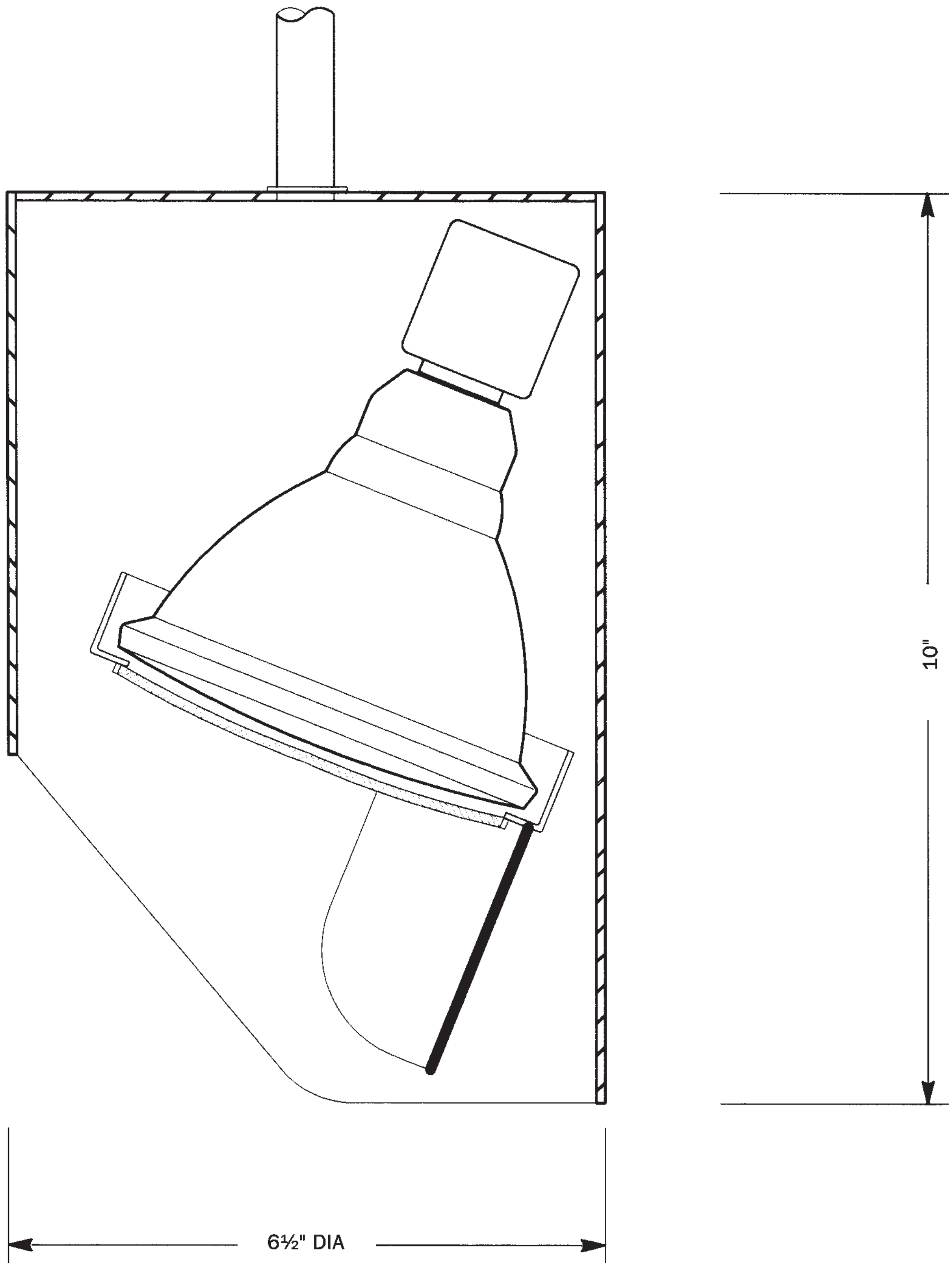

Figure 12.23 Pendant-mounted PAR38 lensed wall-washer.

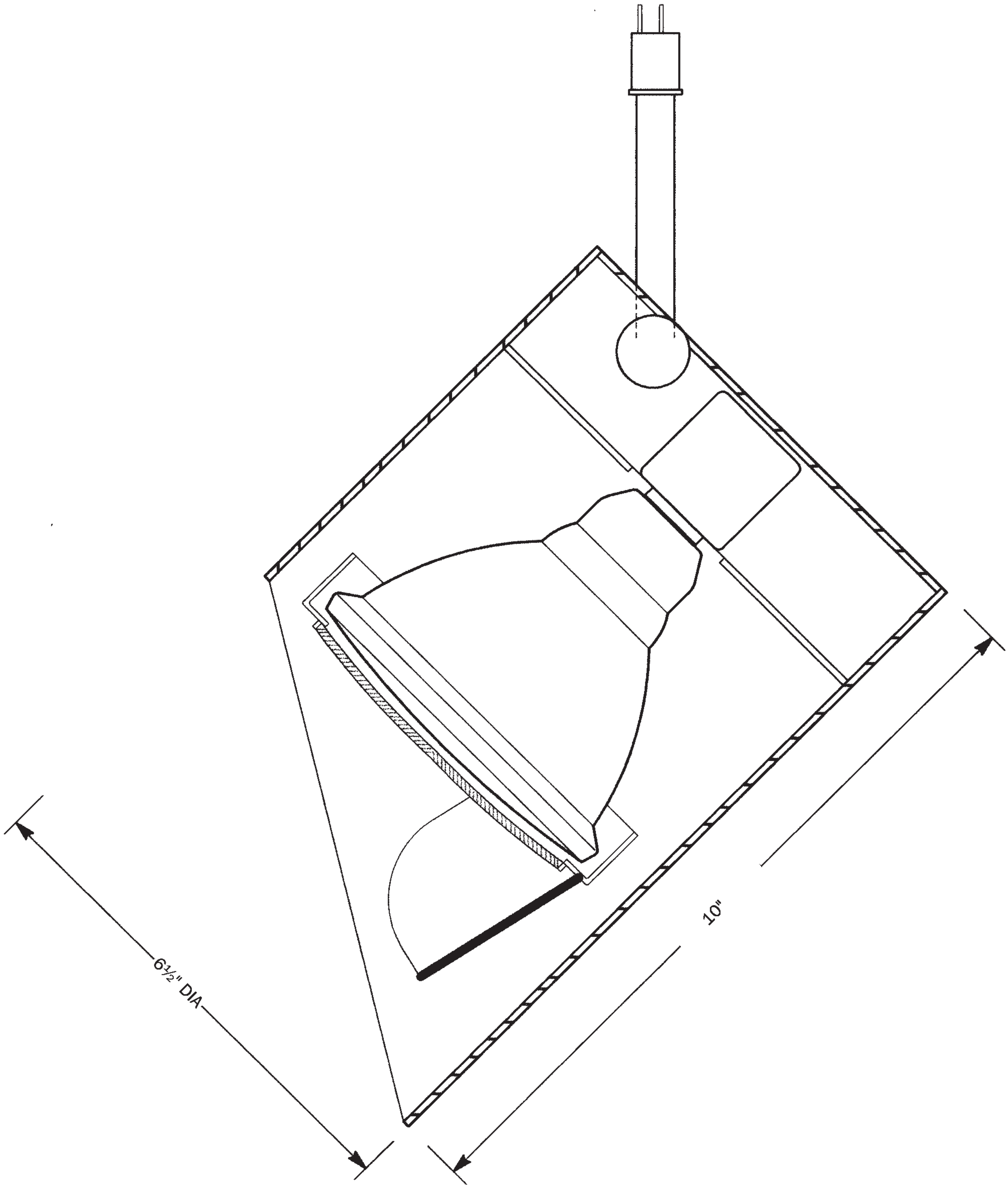

Figure 12.24 Track-mounted PAR38 lensed wall-washer.

that combines an ellipse with a parabola (figures 12.25 through 12.27) or they use nonfocal shapes. Open-reflector wall-washers require a point source with a compact filament; they are available for tungsten-halogen T3 and T4 and ceramic metal halide T6 lamps.

Lensed and open-reflector wall-washers used without downlights provide a shadowless, low-contrast setting. When people are distant from the lighted wall they are seen as flat-featured; people next to the lighted wall are seen as silhouettes. These problems are avoided by adding downlights.

Wall-washing is also produced by diffuse-source, fluorescent-lamp wall-wash systems. The inability of a diffuse source to project a high intensity toward the bottom of a wall usually results in a bright area at the top of the wall and a rapid falloff of luminance thereafter. Sophisticated reflector systems with a wide aperture help to solve this problem (figure 12.28). Fluorescent wall-wash systems, sometimes called "perimeter" wall-wash systems, are more energy-effective than their incandescent counterparts.

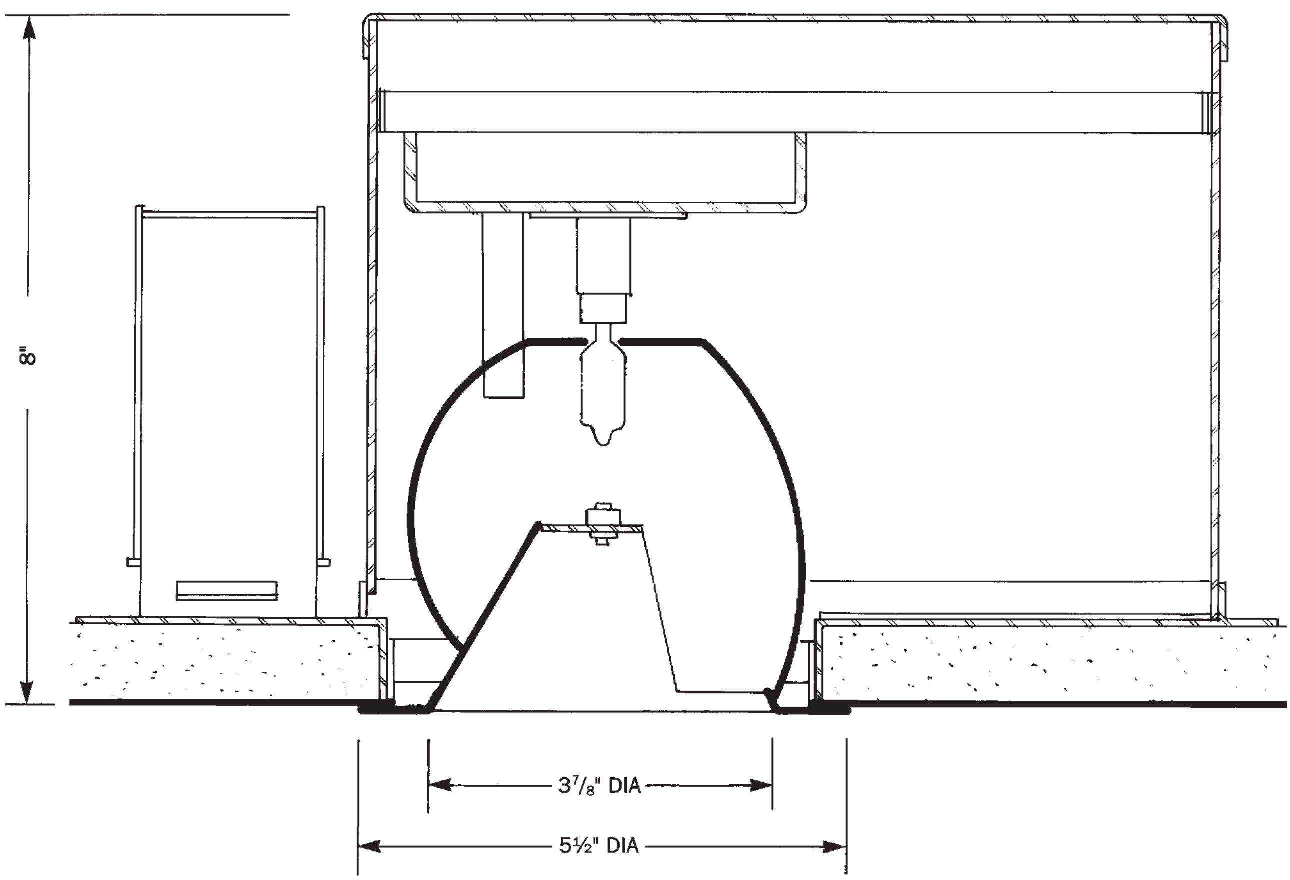

Figure 12.25 Recessed tungsten-halogen T4 wall-washer.

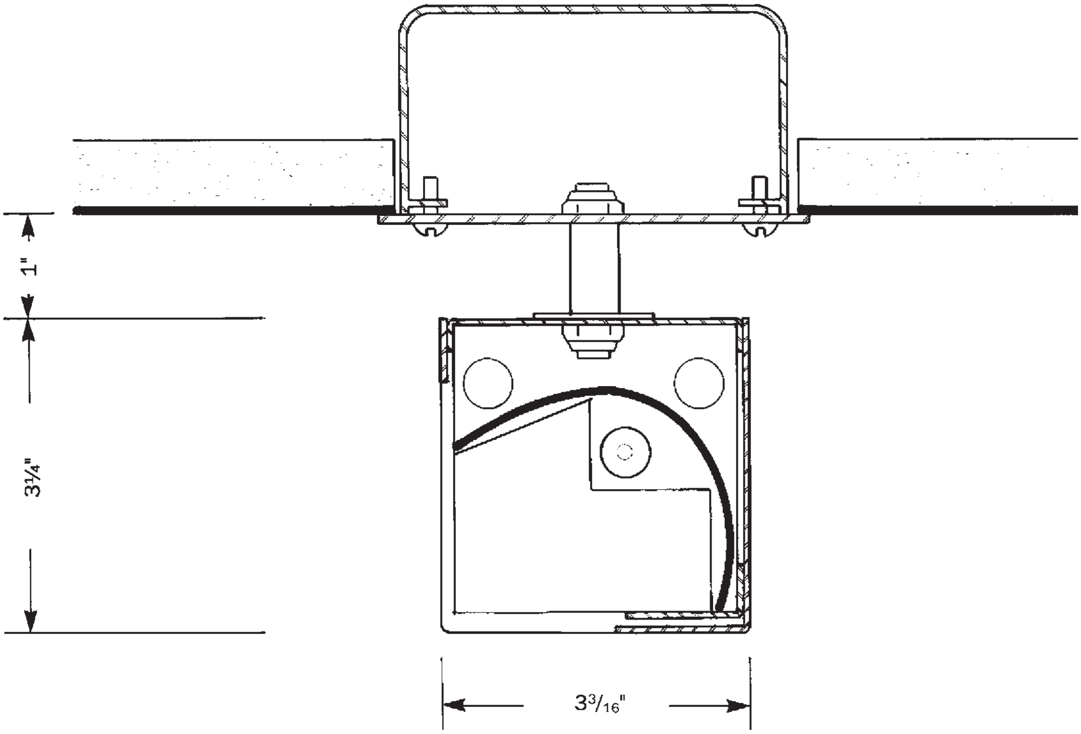

Figure 12.26 Surface-mounted tungsten-halogen T4 wall-washer.

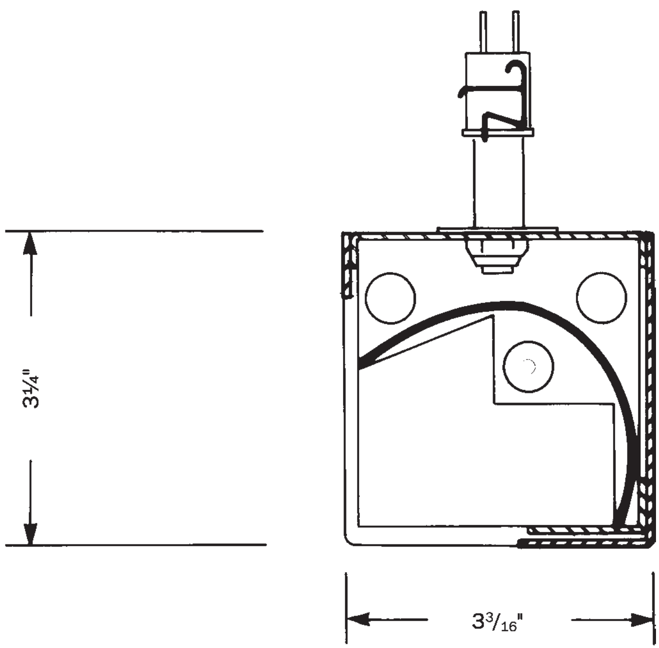

Figure 12.27 Track-mounted tungsten-halogen T4 wall-washer.

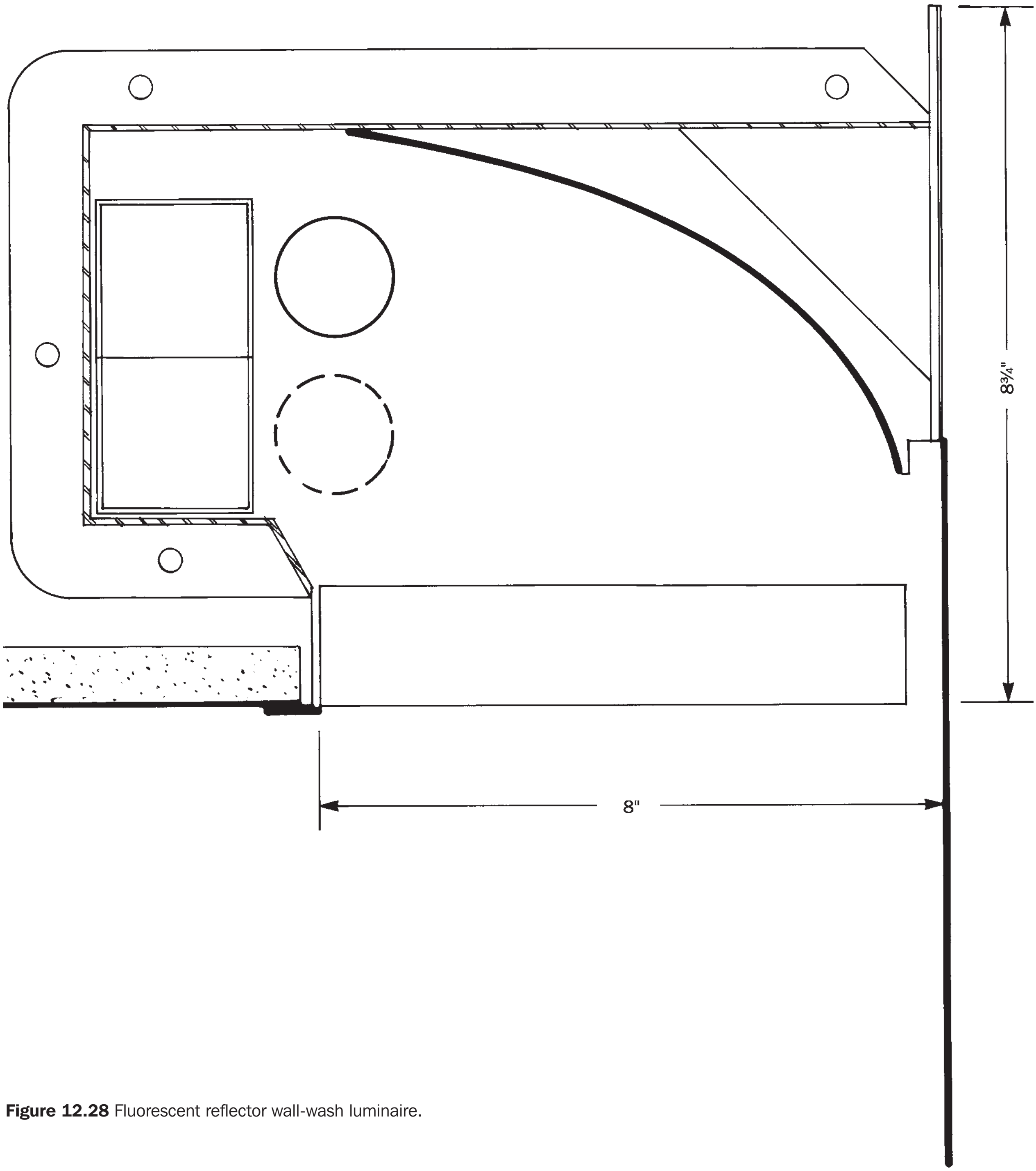

Figure 12.28 Fluorescent reflector wall-wash luminaire.

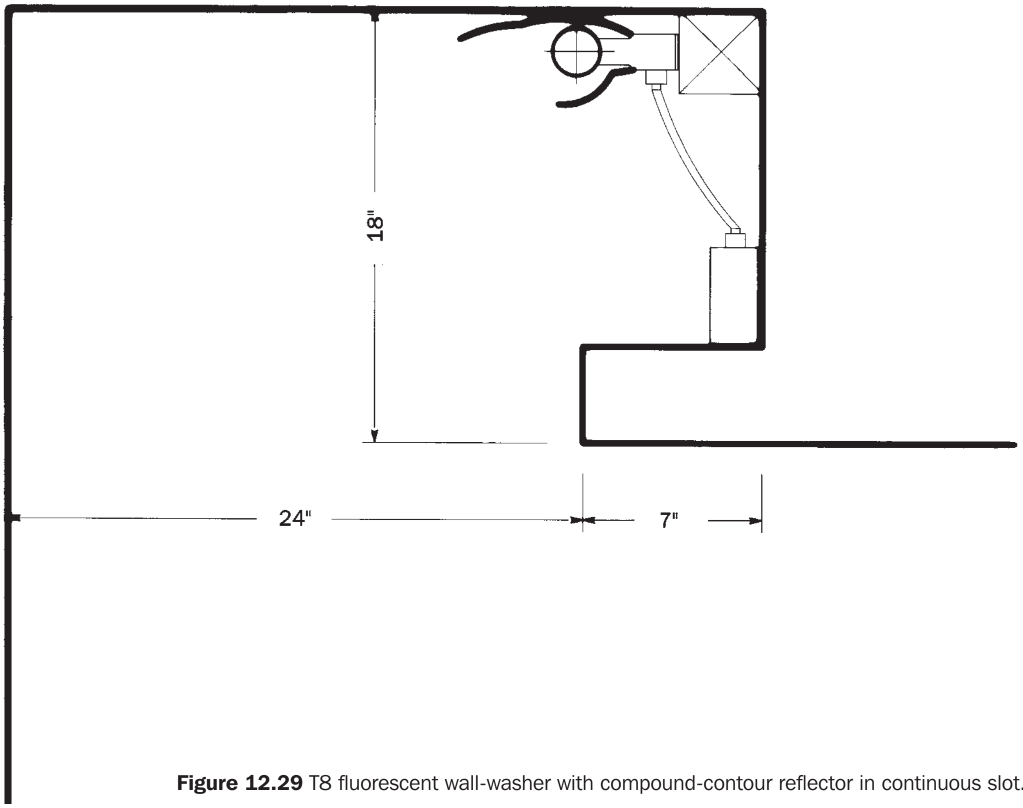

Figure 12.29 T8 fluorescent wall-washer with compound-contour reflector in continuous slot.

Linear wall-washers

Continuous slots are located in the ceiling next to the wall and can enclose other kinds of wall-wash luminaires (figure 12.29). The ceiling is de-emphasized, while vertical surfaces such as walls, murals, and draperies are given prominence.

Incandescent systems. Wall-washing may also be provided by individual directional lamps mounted on a repetitive spacing in a continuous, linear raceway. These systems require the use of a directional point source that is able to project its light over the height of the wall (figures 12.30 and 12.31). The multiple beams of the repetitive lamps overlap, producing uniform brightness along the breadth of the wall.

Lamps are typically mounted close to the surface being lighted. The distance from the lamps to the wall and the distance between the lamps are determined by a full-size mock-up. Excessive lamp spacing will cause scallops. To minimize scallops, the following maximum lamp spacing serves as a guide:

For PAR flood lamps:
maximum spacing is 0.8 × the distance to the wall

For R flood lamps:
maximum spacing is 1.0 × the distance to the wall

Fluorescent lamps. The minimum discernible variation in luminance is approximately 2:1. Even with the aid of precisely formed

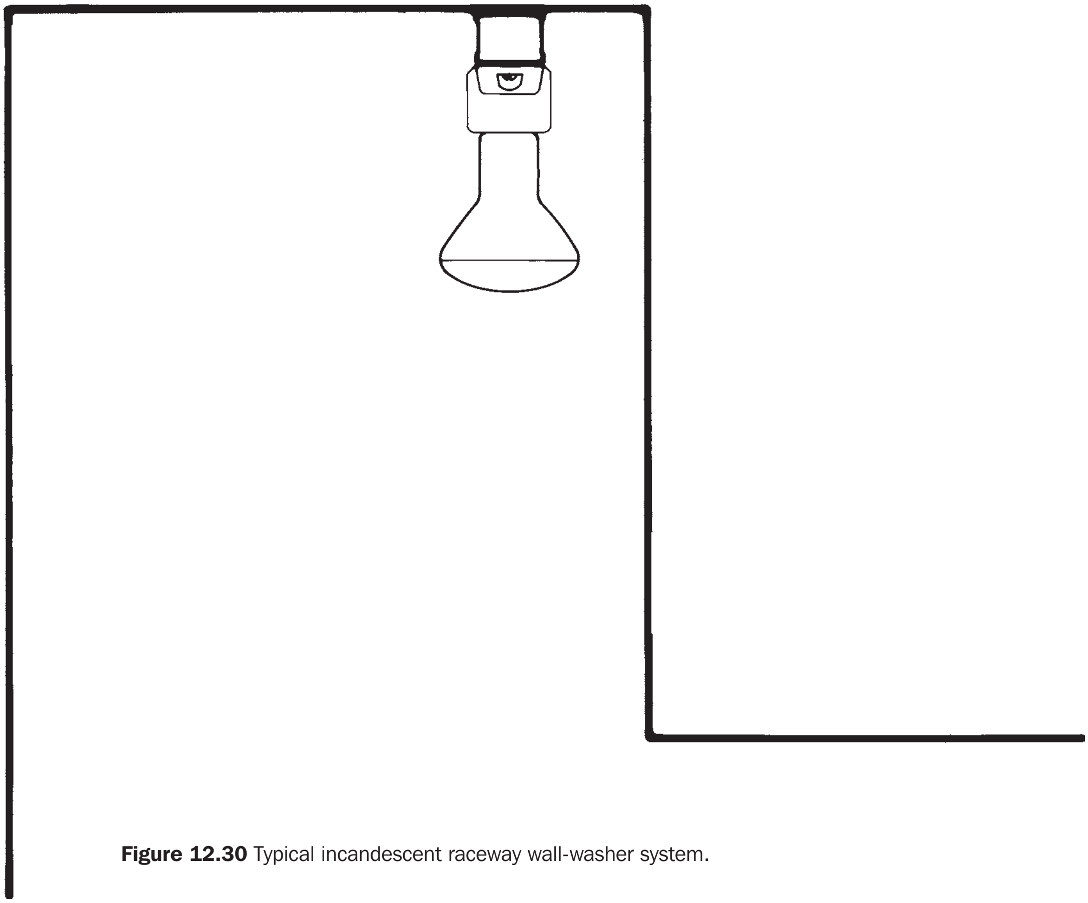

Figure 12.30 Typical incandescent raceway wall-washer system.

compound-contour reflectors, fluorescent lamps have difficulty projecting a high intensity toward the bottom of a wall. The following guide will be helpful in providing approximate visual uniformity with linear T5, T8, and T12 fluorescent lamps.

When using fluorescent lamps in standard reflector channels to light walls, display boards, or draperies, place the channels at a 1:4 ratio of distance away from the lighted surface to the height of the wall (figure 12.32). Luminance at the bottom will be about one-tenth of the luminance at the top. For many applications, the resulting perception of near uniformity is adequate.

Luminaires placed closer than the 1:4 ratio, called *grazing light*, emphasize surface texture and low sculptural relief. But this may also increase the awareness of irregularities and lack of flatness of the lighted surface. Additional frontal light, direct or indirect, reduces this problem by filling in the minute shadows cast by the irregularities.

When lighting from two opposite sides, or from four sides, place the channels at a 1:6 ratio of distance away from the lighted surface to the height of the wall. The 1:4 and 1:6 placement ratios are also applicable when fluorescent channels are mounted vertically (figure 12.33).

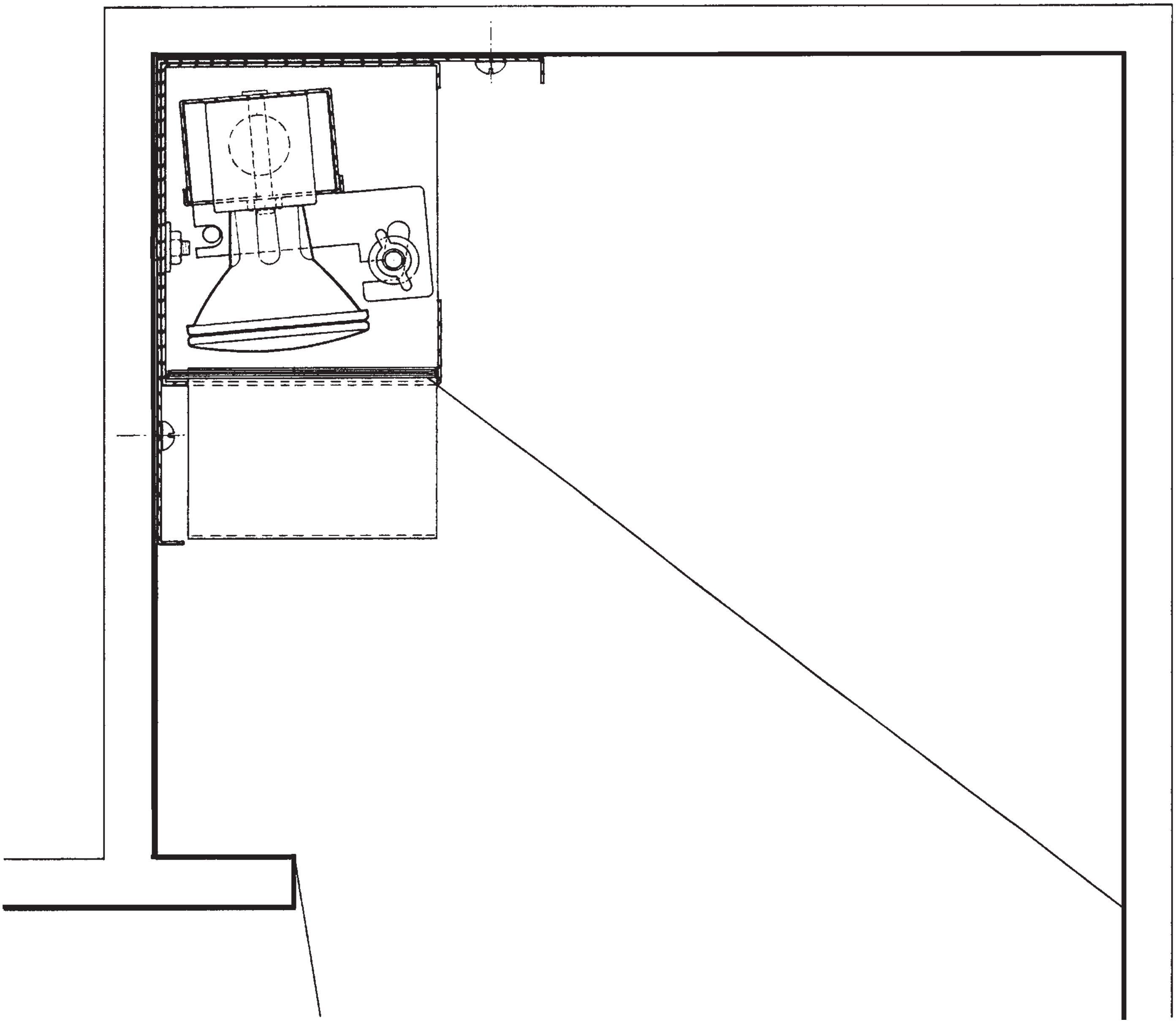

Figure 12.31 Manufactured linear wall-washer system includes linear spread lenses to distribute light evenly across the wall and baffles to shield the view of the lamps along the length of the slot.

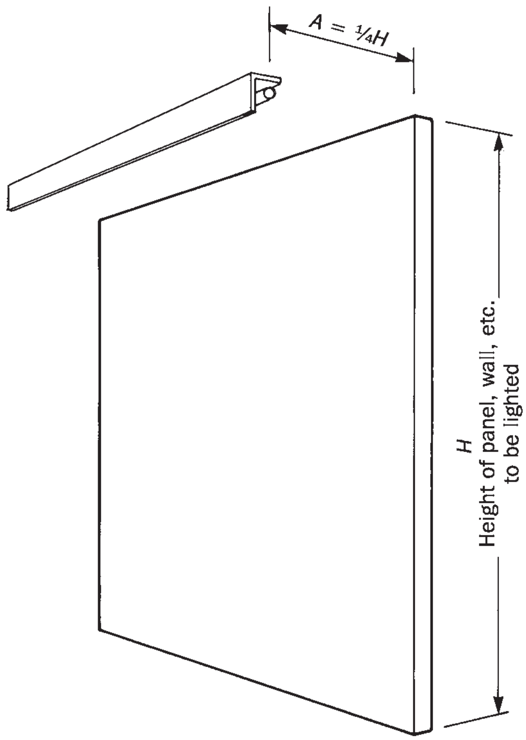

Figure 12.32 Uniformity is slightly improved when the floor has a high reflectance or has a high-reflectance border at the wall.

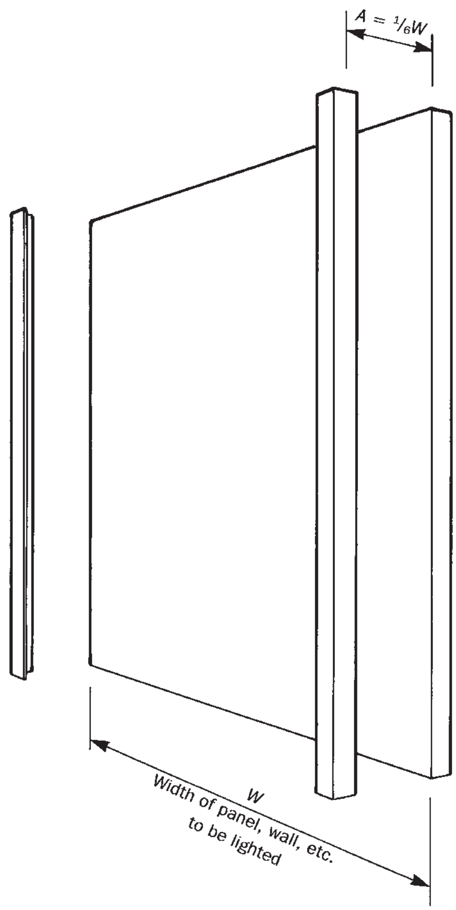

Figure 12.33 Illumination from two opposite sides with vertically mounted fluorescent channels. When fluorescent lamps are used, the cross-section dimension of the luminaire can be made smaller by locating the ballasts remotely.

Vertically mounted fluorescent channels are used for wash light when the ceiling height is low and the placement of overhead equipment is difficult (figure 12.33), but great care must be taken to avoid glare. The shielding angle for blocking the view of the vertical light source is even more critical than it is for horizontal slots and valances.

The close placement of the light source to the wall makes the luminance on the wall much higher near the source. Fluorescent continuous slots and vertically mounted channels are useful techniques when this nonuniformity of luminance is acceptable.

Lighting the ceiling plane

"Washing" with light has come to mean the use of a continuous row of lighting devices located at the edge of the "washed" surface. Ceilings are usually not "washed"; they are lighted by devices known as *uplights* or *indirect luminaires* (figure 12.34). These are

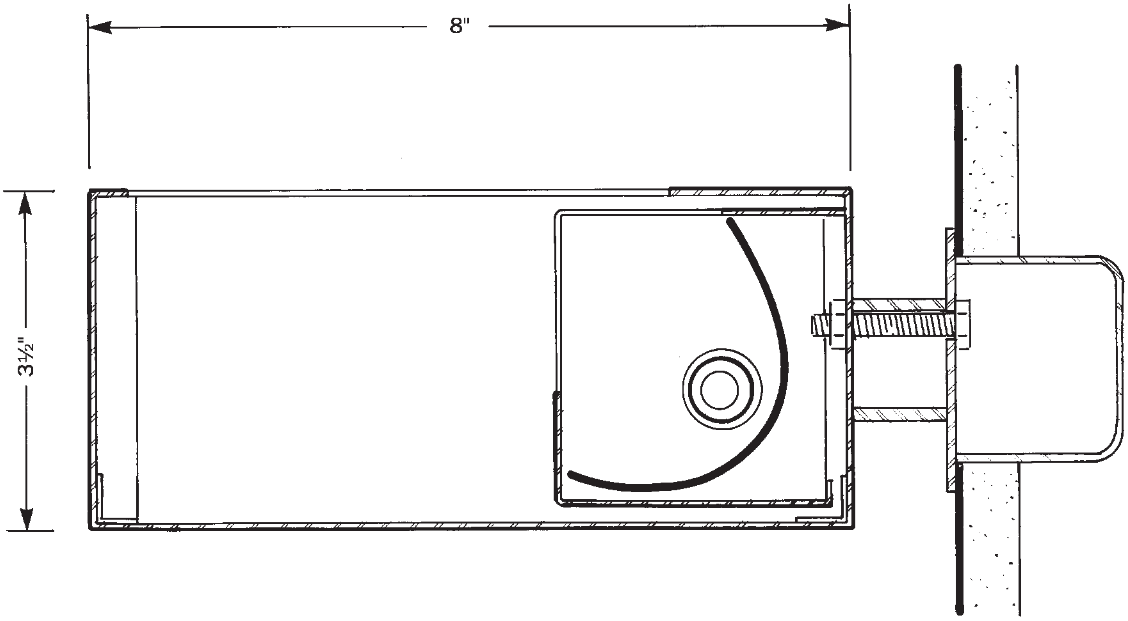

Figure 12.34 Typical tungsten-halogen uplight.

suspended from the ceiling by stems or cables; mounted on top of furniture above eye level; or attached to walls, columns, or the tops of floor stands. Some provide indirect light only; others, usually stem-mounted, also have a downlight component.

Uplights. Point-source indirect luminaires often use linear sources, such as T2½, T3, and T4 tungsten-halogen lamps; ED18, T6, T7, and T15 metal halide lamps; and ED18 and T15 HPS lamps. Diffuse-source indirect luminaires use compact, T5, T8, and T12 fluorescent lamps.

Fluorescent uplights (figure 12.35) were developed primarily to provide an evenly illuminated ceiling similar to the recessed luminous ceiling (figure 12.18). The intent is the same: to create an evenly illuminated ceiling plane without variations in luminance on the ceiling surface.

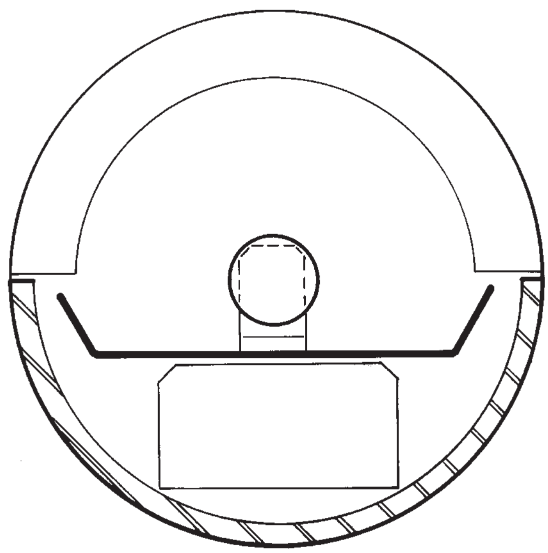

Figure 12.35 Typical fluorescent uplight ("indirect") luminaire.

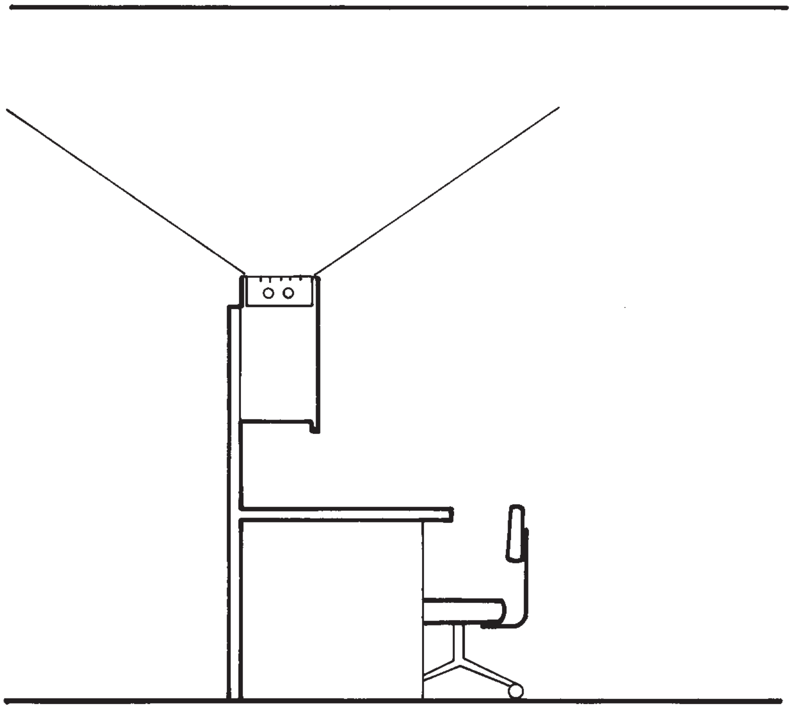

Figure 12.36 Furniture-mounted indirect luminaire.

Uplights are especially suitable for high-ceilinged rooms, which permit the luminaires to be positioned far enough below the ceiling to avoid "hot spots." If they are mounted too close to the ceiling surface, the variations in light and dark will often be unpleasant and disturbing; the ceiling surface will become a series of hot spots and dark shadows instead of an evenly illuminated plane.

Researchers have demonstrated that people perceive a greater quantity of light in a given area when they can see the source of illumination. Pendant-mounted fluorescent uprights that provide a source of brightness from below give an impression of increased illuminance. Uplights that are completely opaque (dark) from below yield an impression of lower illuminance.

Furniture-mounted uplight luminaires incorporate an indirect lighting element onto the top of furniture or freestanding partitions (figure 12.36). They are usually mounted with their apertures slightly above average eye height at 5 ft 6 in AFF in order to avoid glare. Furniture and partition layouts must accommodate the luminaire's spacing criterion to achieve uniform ceiling luminance.

Wall- or ceiling-mounted uplight luminaires are mounted to walls and columns (figure 12.37). Like wall-washers, they have an asymmetric light distribution that produces a sweep of light across the ceiling and avoids hot spots and "spill light" on adjacent surfaces.

Architectural coves. *Coves* are another method of providing general ambient light in high-ceilinged rooms (figure 12.38). Their luminaires direct light toward the ceiling plane, which—like a washed wall—becomes

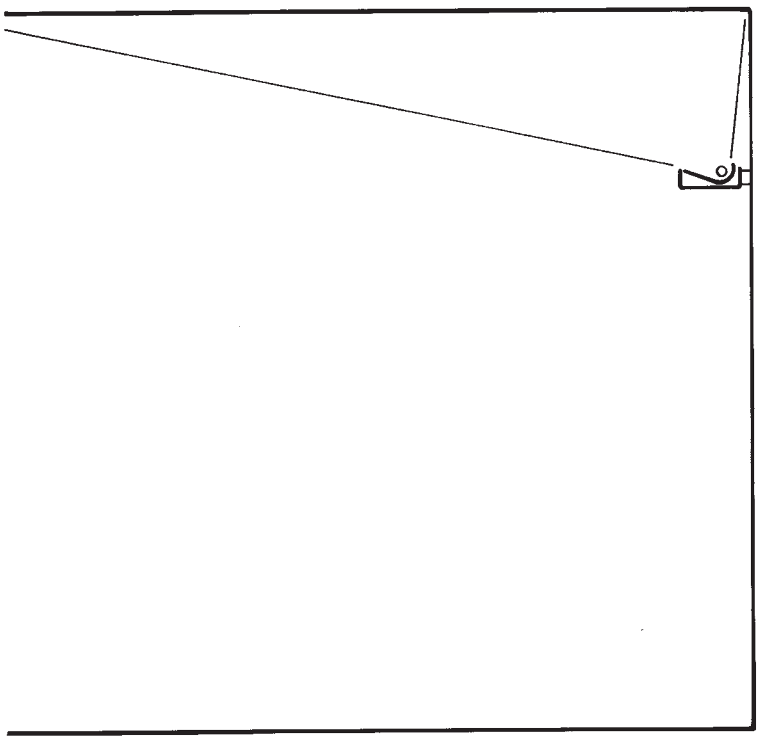

Figure 12.37 Column-mounted indirect luminaire.

a large-area diffusing source. Coves are useful to supplement more energy-effective lighting methods, such as recessed down-lighting systems.

The placement ratios in figure 12.38 are intended to produce approximate visual uniformity. Specular reflections are minimized if the ceiling surface is a high-reflectance matte or satin finish. Typical cove dimensions are shown in figure 12.39.

Custom-built coves are constructed of wood, plastic, or metal. A glass or plastic bottom is sometimes used to introduce a downward component of light for sparkle.

Fluorescent lamps or cold-cathode tubes are commonly used in coves because they are energy-efficient, linear sources. All lamps must be of the same color, and it is best that they are of the same tube diameter and have the same manufacturer to prevent color variations on the lighted surfaces. Lamps of similar light output per foot of length are also desirable to avoid noticeable variations in luminance on the illuminated surfaces.

When the lamp mounting channels are placed end-to-end, a noticeable gap in light occurs because the lampholders take up space and the lamps emit less light near their ends. The shadows caused by this gap may be avoided by staggering the mounting channels so that they overlap by at least three inches. Prefabricated single-lamp and two-lamp staggered channels with overlap-

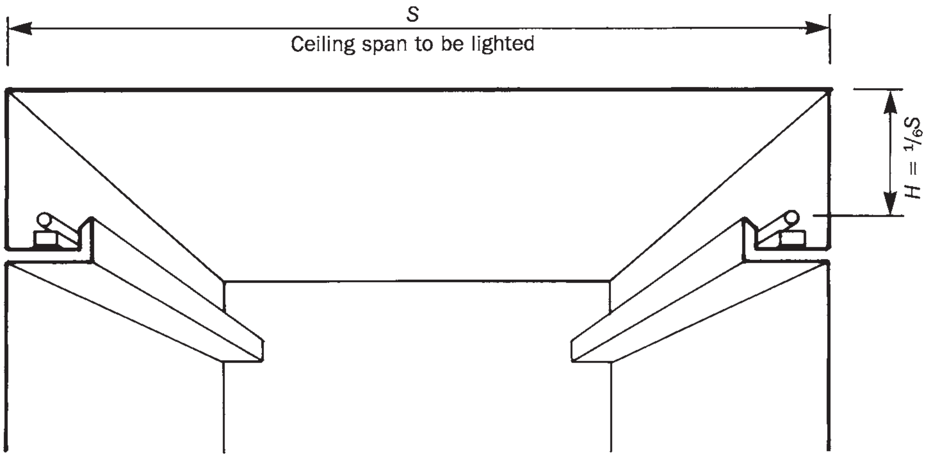

Figure 12.38 A 1:4 placement ratio is applicable when light is emitted from one side only. A 1:6 ratio is applicable when light is emitted from two or four sides.

ping lamps achieve the same result (figure 12.40).

When space constraints limit the cove design so that the source is located too close to the adjacent wall and ceiling, these surfaces will appear excessively bright. Shields can be incorporated into the cove design to intercept some of the light and prevent it from reaching the upper wall. The upper wall will be lighted by reflection from the cove lip and ceiling, reducing the light gradients (figure 12.41).

To ensure uniformity on the ceiling plane, the distance from the center line of the lamp to the ceiling must be a minimum of 12 in for rapid-start lamps and 18 in for HO and VHO lamps. Curved transitions between adjacent surfaces will produce more gradual, softer gradients (figure 12.42).

The height of the vertical shield or "lip" of the cove is determined by a *sight line* analysis. On a section drawing through the cove, draw a line between a viewer's eye, located at the farthest viewing point, and the edge of the cove lip (figure 12.43). The lip of the cove is designed to shield the lamp at normal viewing angles but must not interfere with the distribution of light across the ceiling (figures 12.44).

When incandescent directional sources are used in a linear array, the beam axis is aimed at a point two-thirds of the way across the lighted surface. This provides relative uniformity of illumination (figure 12.45).

Object Lights

Adjustable *object lights*, sometimes imprecisely called "accent lights," provide a symmetric distribution of light aimed at one or several objects. They use a directional source such as an AR, MR, PAR, or R lamp. Also called "spot lights," they are used to provide focal glow and add contrast to a setting.

Recessed, adjustable, object lights may have a horizontal rotation stop to prevent wires from tangling as the lamp is rotated. Vertical adjustment is from 0° to between 35° and 45° (figure 12.46). Surface-, pendant-, and track-mounted luminaires have a greater range of vertical adjustment than recessed equipment (figures 12.47 and 12.48). The best track-mounted adjustable object lights are designed to rotate slightly more than 360°; inferior luminaires have a

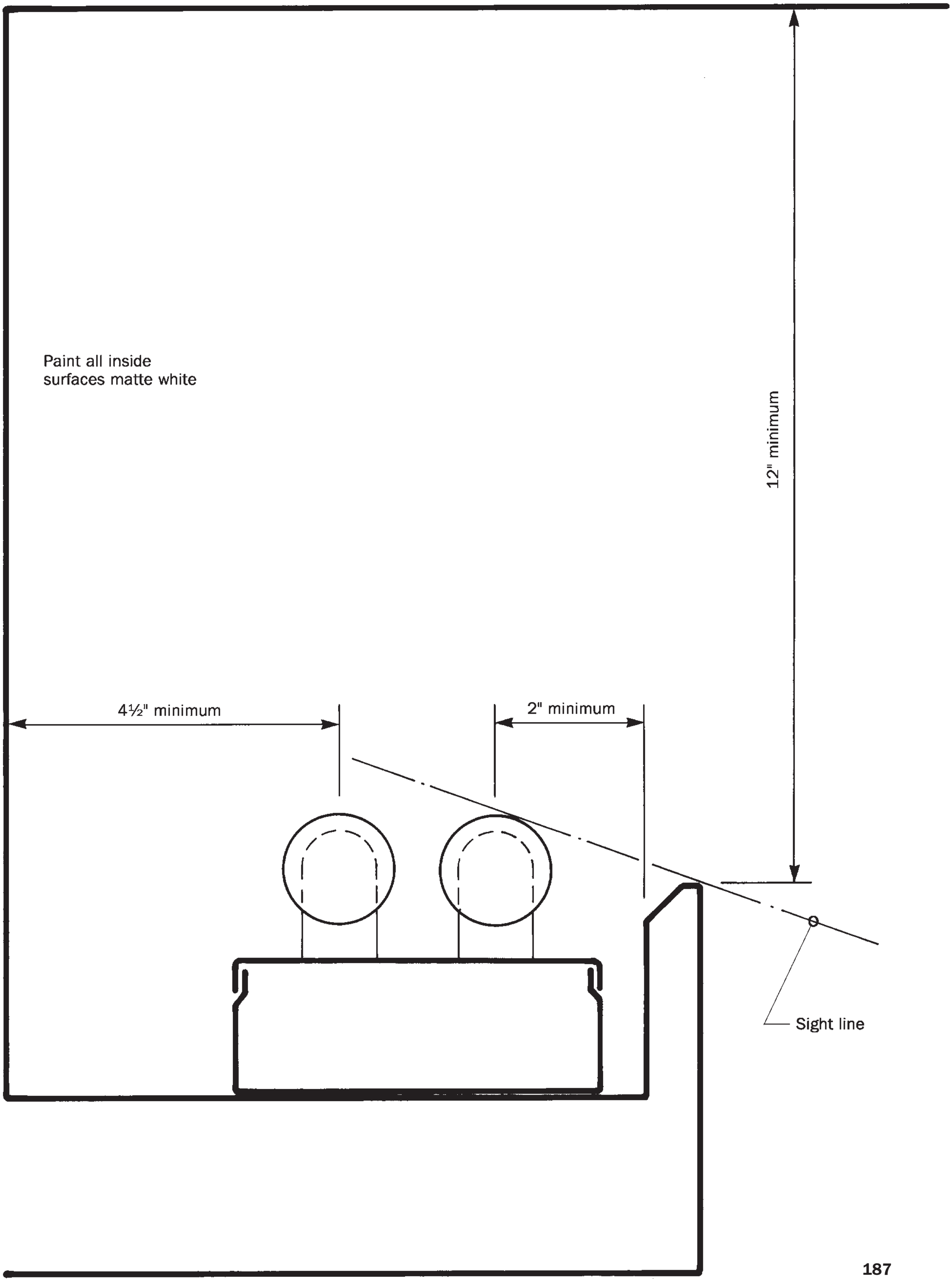

Figure 12.39 Typical cove dimensions for two-lamp fluorescent cove.

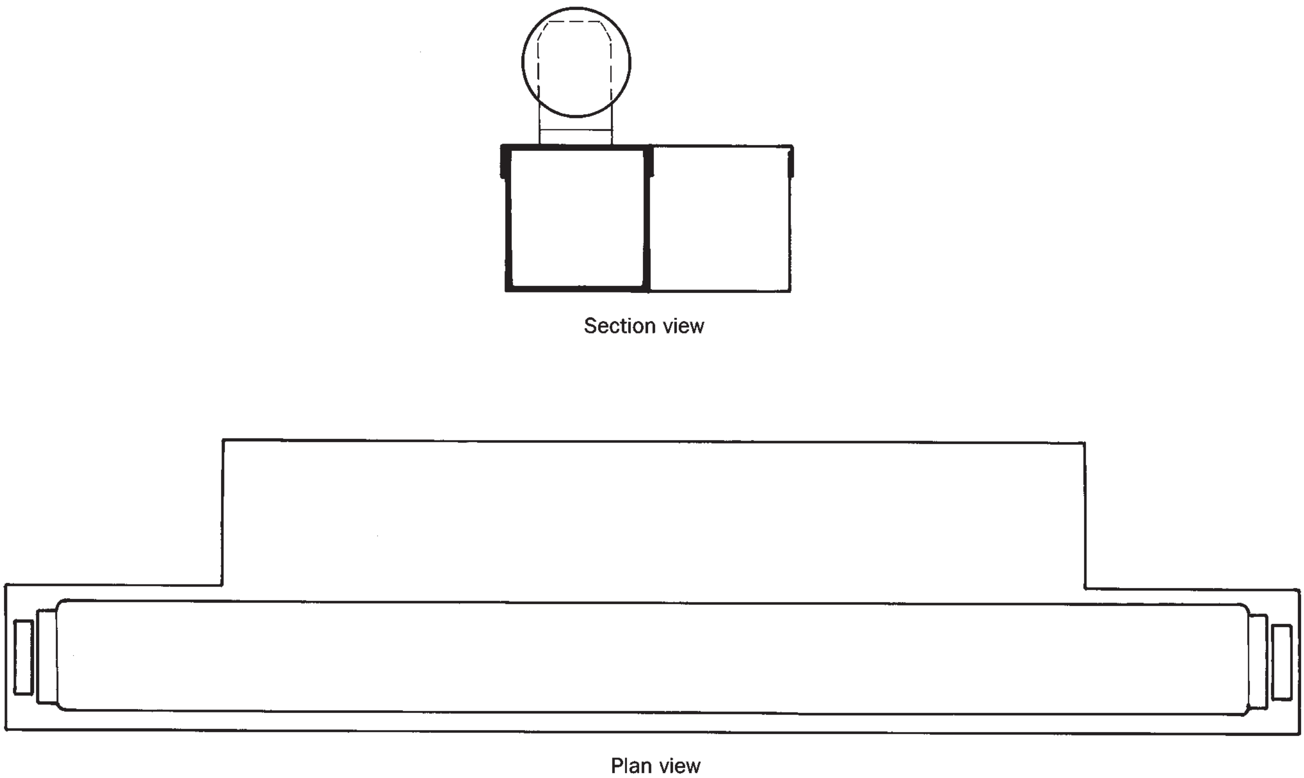

Figure 12.40 Single-lamp fluorescent staggered channel.

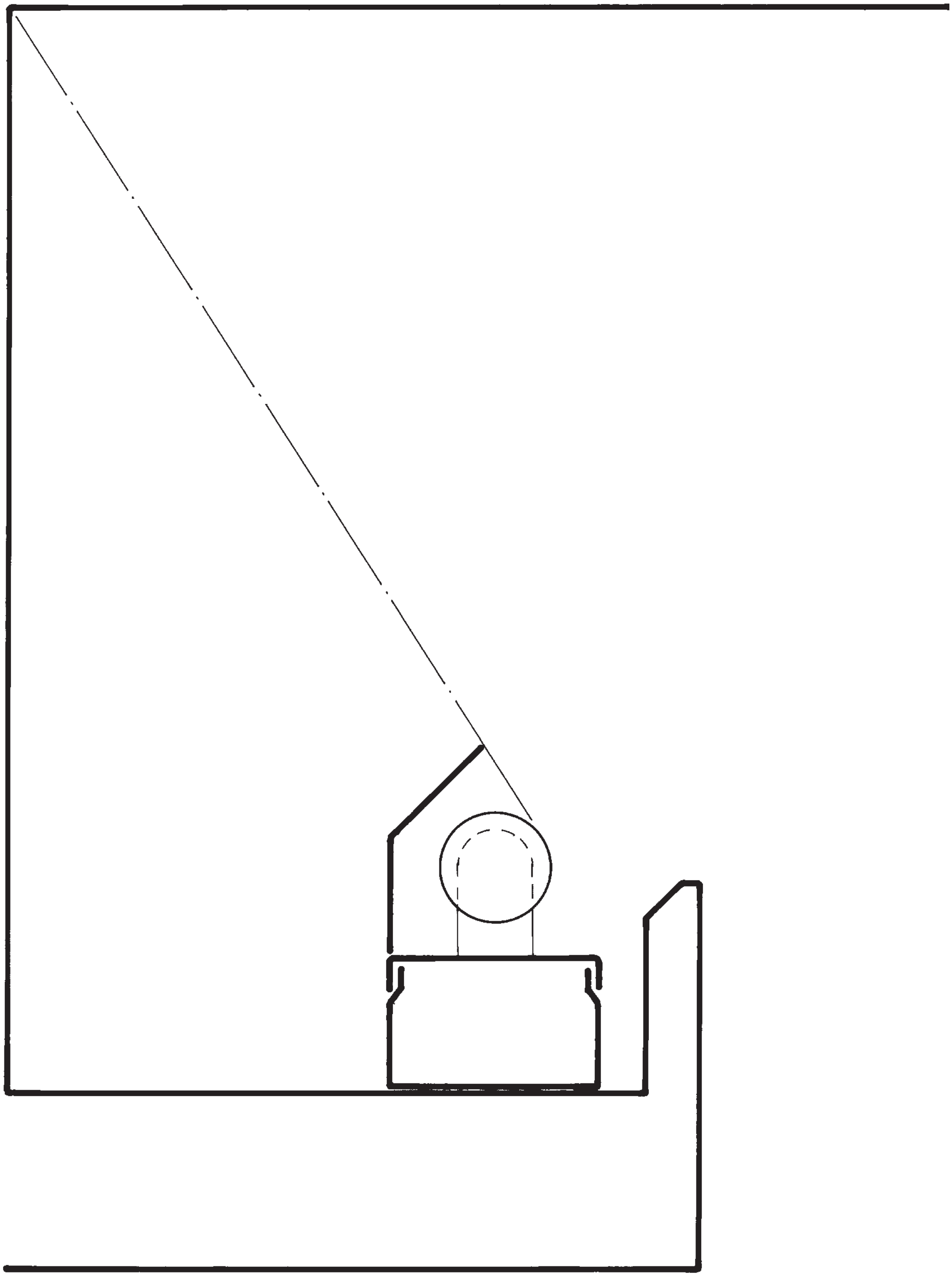

Figure 12.41 External shield to prevent light from reaching the upper wall.

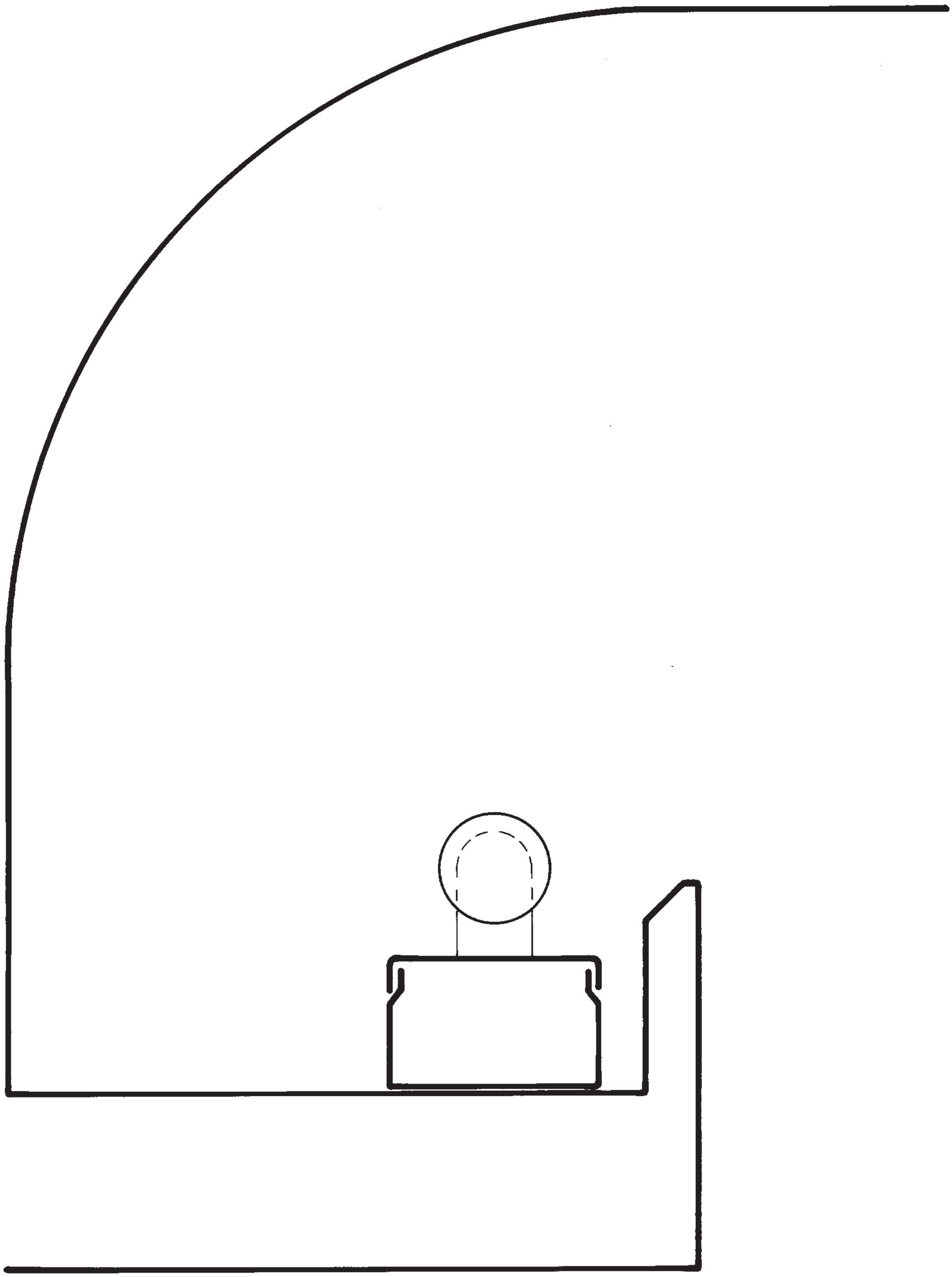

Figure 12.42 Curved contour for architectural cove.

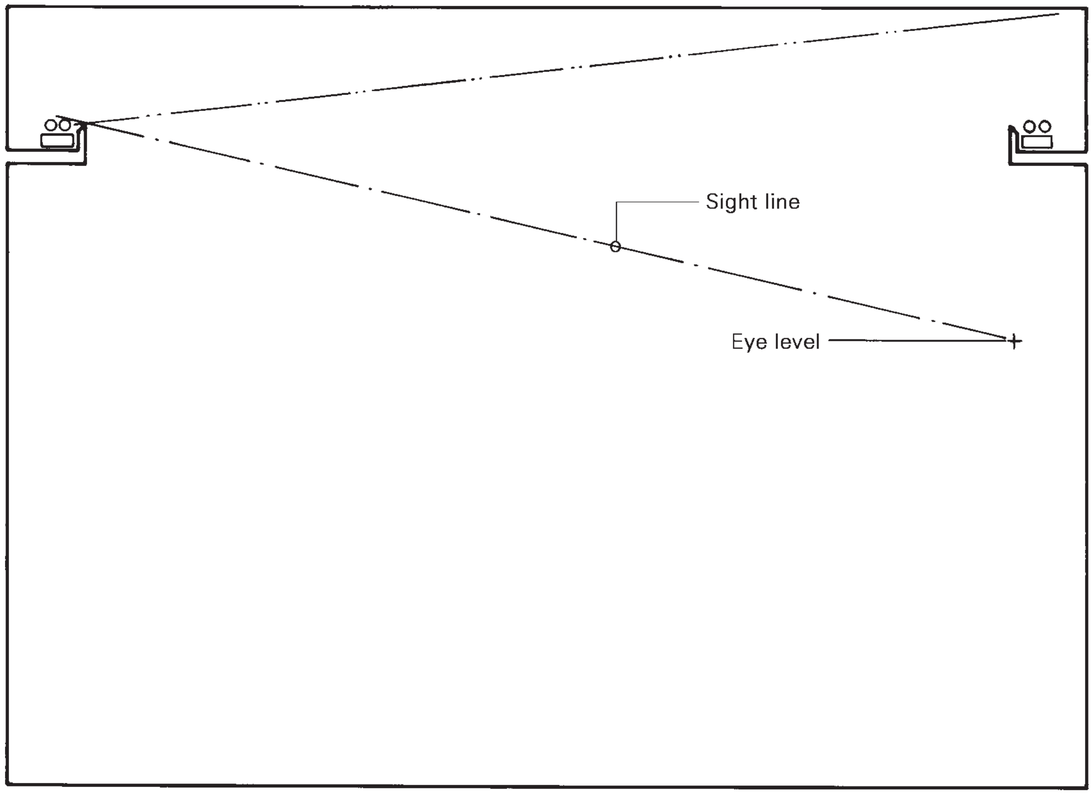

Figure 12.43 Shielding angle for coves.

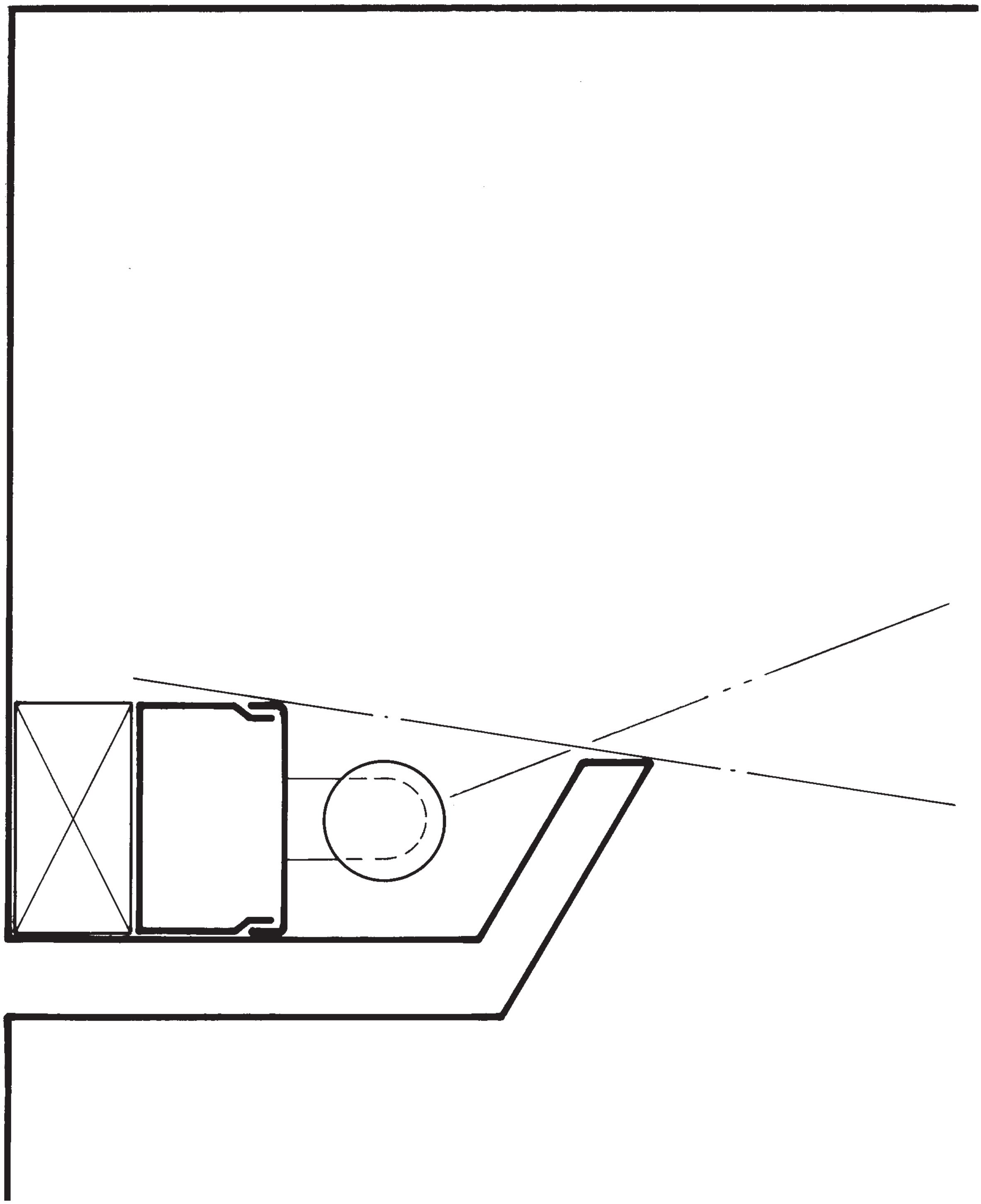

Figure 12.44 Typical cove “lip.”

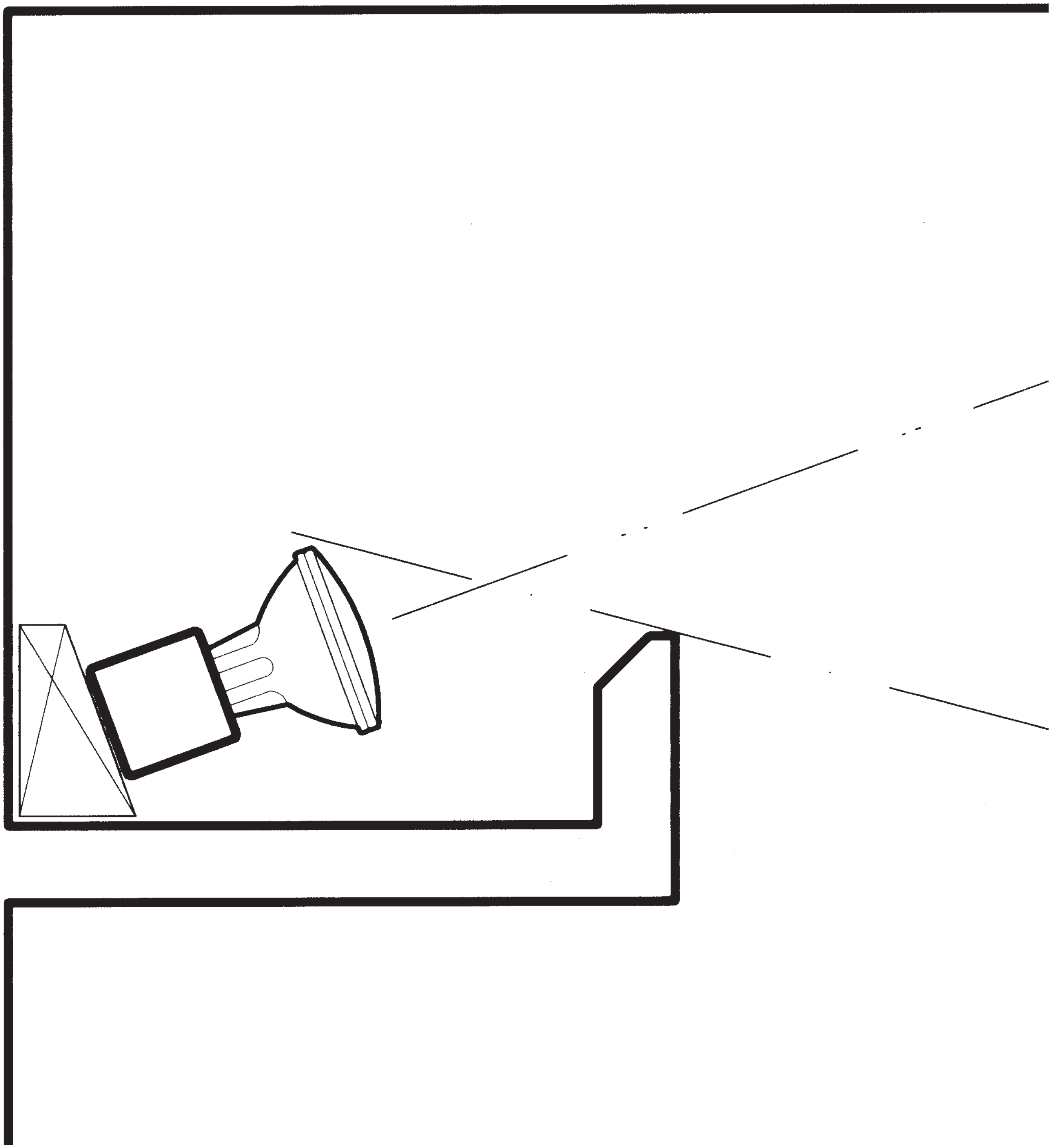

Figure 12.45 Typical incandescent lamp raceway in an architectural cove.

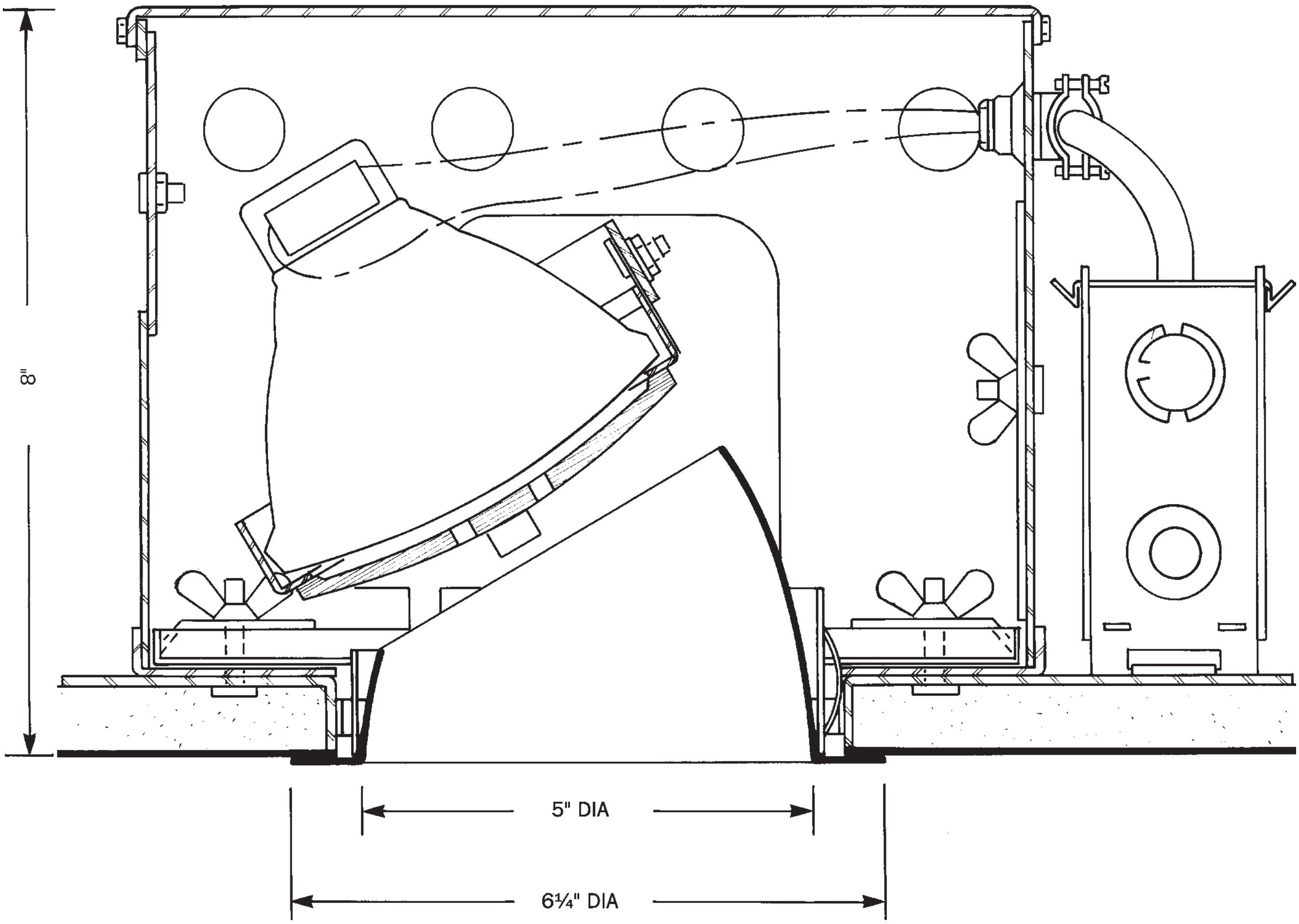

Figure 12.46 Recessed, incandescent, adjustable-angle object light.

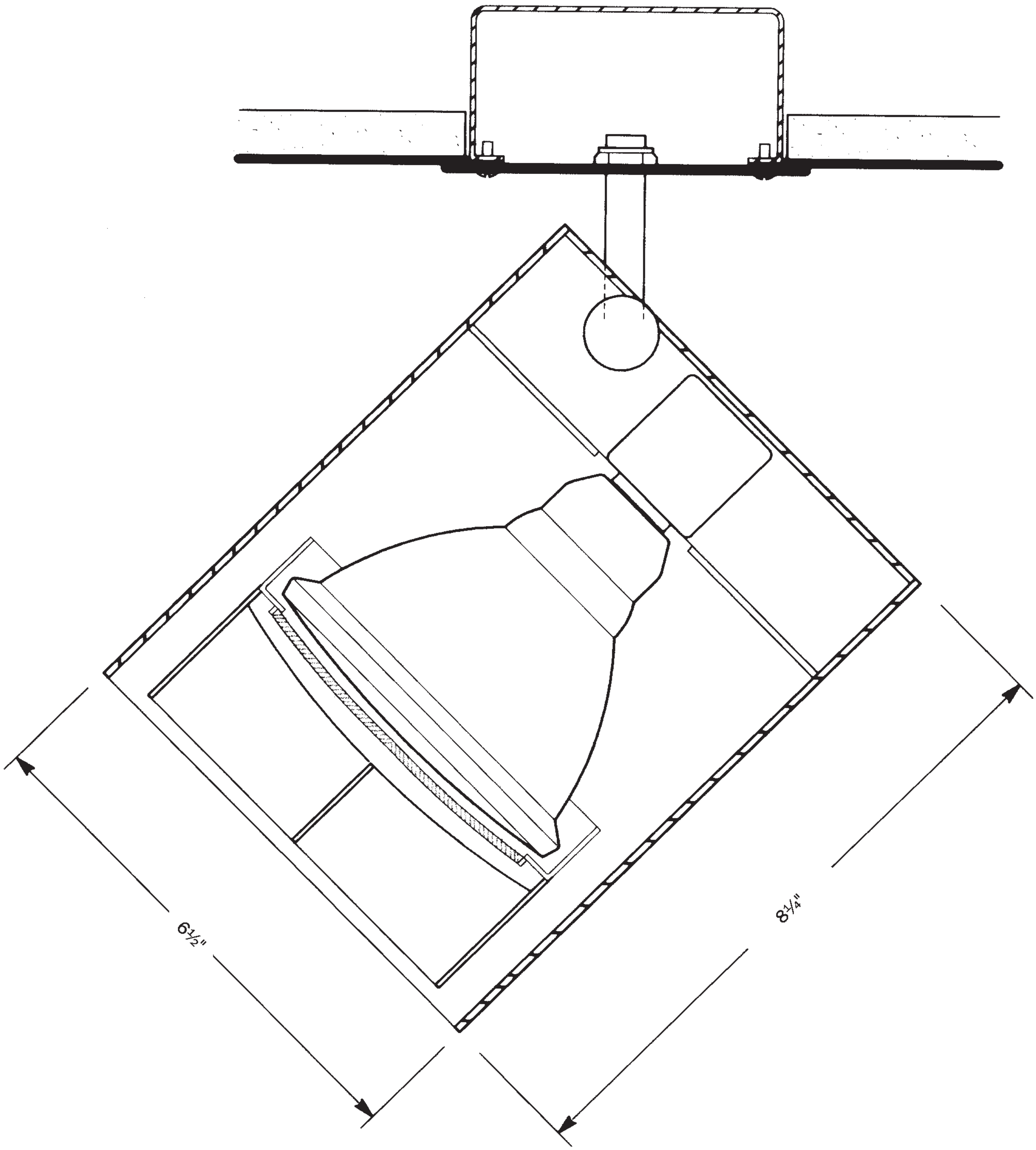

Figure 12.47 Surface-mounted, incandescent, adjustable-angle object light.

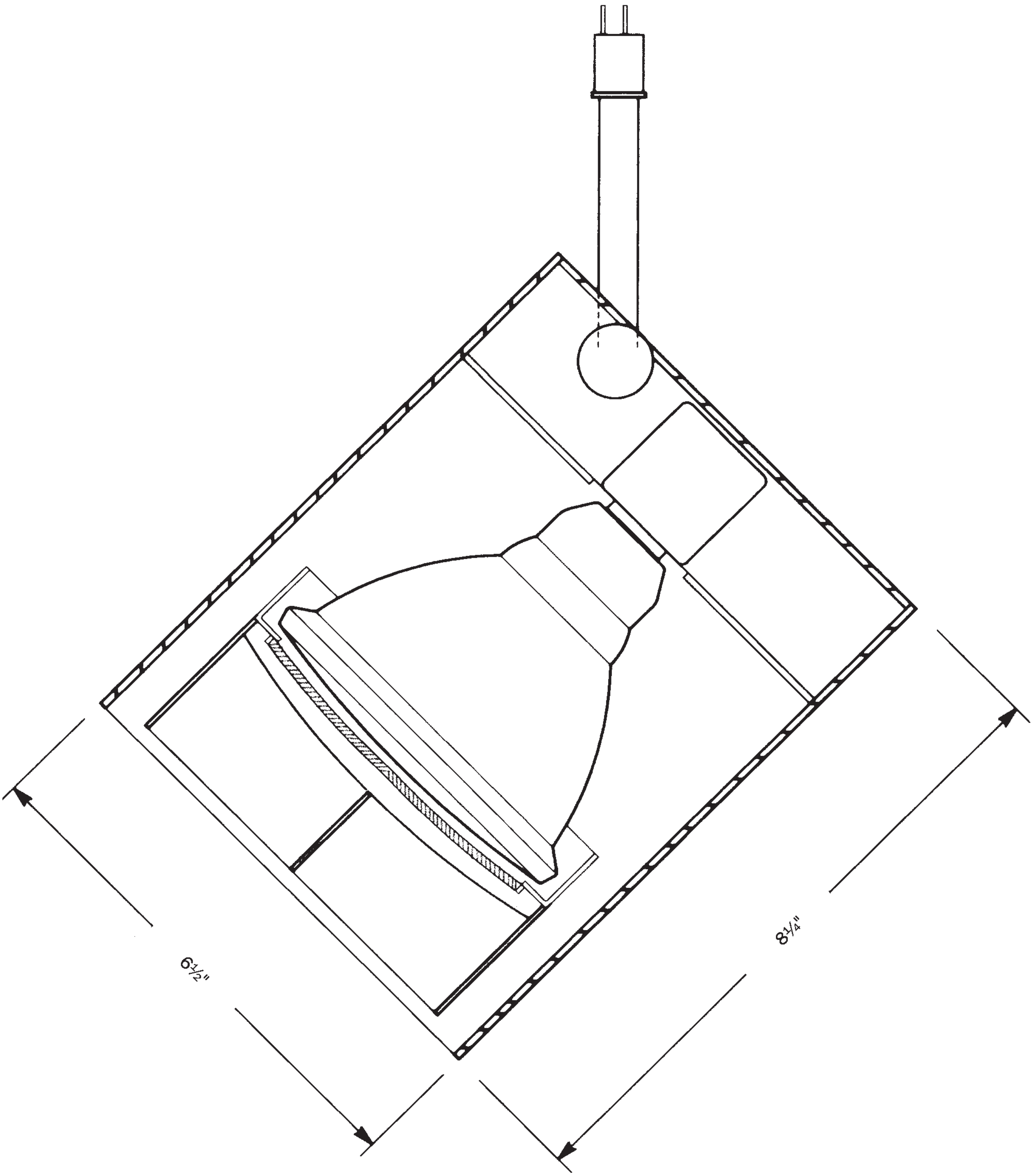

Figure 12.48 Track-mounted, incandescent, adjustable-angle object light.

"blind spot" with horizontal rotation limited to between 300° and 350°.

Whether surface-, pendant-, track-mounted, or recessed, adjustable object light housings are usually designed to shield direct view of the lamp while avoiding undue interference with the beam pattern of directional lamp sources.

The least expensive luminaires may lack any brightness control, and the source glare can be uncomfortable. Better-quality lighting fixtures provide greater degrees of brightness control, typically using an open reflector in recessed equipment and cube-cell louvers or baffles in surface-, pendant-, and track-mounted luminaires.

Louvers intercept some of the light in the beam. *Cube-cell louvers* reduce light output as much as 50 percent. *Cross-baffles* are a more efficient method of shielding lamps from the eyes because the light loss is minimized.

When used to illuminate artwork and larger objects, object lights are also supplied with a linear *spread lens* to modify the distribution and soften the edge of the beam. Linear spread lenses are typically made of borosilicate glass with a fluted pattern; they are usually designed to spread the beam in one direction only and are rotated as required during luminaire focusing. Without the spread lens, the same object light source provides a symmetrical, concentrated beam-spread suited to smaller objects and those that require a greater intensity of illumination or "punch."

Object lights contribute to a moderate- to high-contrast setting because they introduce nonuniform illumination. Medium- to wide-beam lamps give moderate contrast; narrow-beam lamps give high contrast.

Task Lights

Task luminaires bring the light source close to the surface being lighted. They are useful for work surfaces of systems furniture, which may receive insufficient light from an overhead lighting system because of shadows from vertical partitions and furniture-mounted high shelves and cabinets.

Local task luminaires are often energy-effective and useful for reducing reflections in VDTs. Task lighting uses less power because the source is closer to the surface being lighted. Task luminaires can provide the illuminance required for paper-based visual tasks while allowing the ambient light to be of a lower illuminance and decreasing the chances of distracting VDT screen reflections.

Task luminaires are often mounted under a cabinet or shelf that is directly over the work station (figure 12.49). This location is in the reflected glare zone, however; the luminaire may produce *veiling reflections* on the work surface. This is eliminated by using optical lenses for the luminaire that block the perpendicular light rays and convert them to rays that fall on the task from the side and thus do not cause veiling reflections.

Adjustable task luminaires are usually mounted at one side of the task. An adjustable arm permits positioning the luminaire to suit the task, maximizing task visibility. An asymmetric light distribution is sometimes incorporated to direct light more uniformly over the task area.

Soffits

A lighting *soffit* is used for task light (focal glow) rather than ambient light. It is located adjacent to a wall or similar vertical surface and is sometimes used to light niches. The top is often closed and all light is directed downward (figure 12.50).

Over work areas, reflectors increase the useful light (figure 12.51); open louvers or lightly etched plastic or glass perform best. Matte finishes for work surfaces minimize specular reflections (figure 12.52).

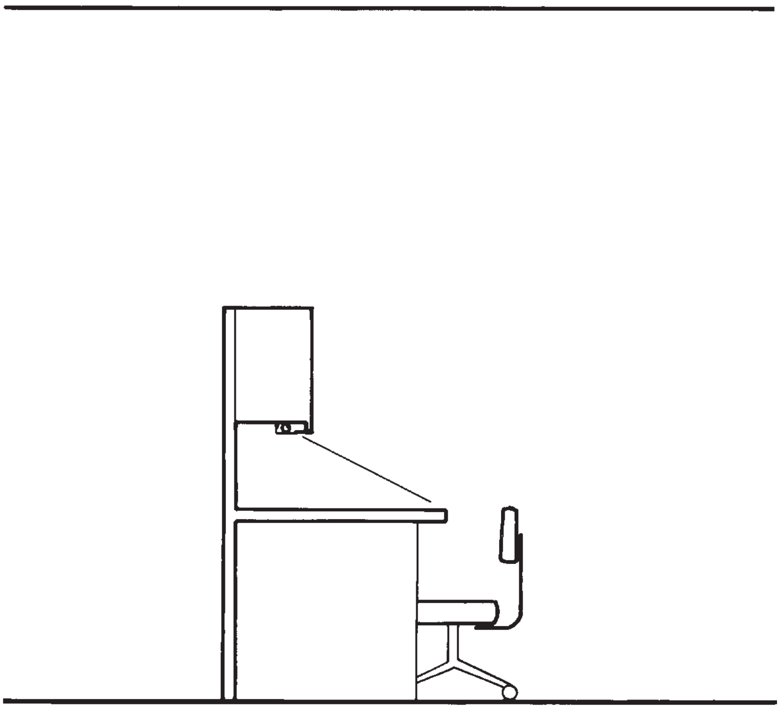

Figure 12.49 Sometimes under-cabinet or under-shelf task luminaires cause veiling reflections. This is eliminated by using a luminaire equipped with a lateral lens.

For make-up and grooming areas, a translucent diffusing panel lights faces from many directions, minimizing harsh shadows. A light-colored countertop is of further help, as it reflects light back toward the face (figure 12.53).

Low brackets. *Low brackets* are used for lighting special task areas such as countertops and writing or reading surfaces (figure 12.54).

Multidirectional Luminaires

Direct-indirect luminaires

Direct-indirect luminaires provide a combination of downlight (direct lighting) and uplight (indirect lighting), with all of the attributes of both systems. The sharper shadows created by direct systems are softened by the diffuse, indirect light. The increased ceiling luminance creates a greater diffusion of light in the space. Interreflections reduce ceiling plane luminance variations and the resulting VDT screen reflections.

Valances. A lighting *valance* is used over windows, usually combined with draperies, or special features, such as artwork. It provides both indirect uplight that reflects back from the ceiling for ambient illumination and downward wash-light for the drapery or artwork (figure 12.55).

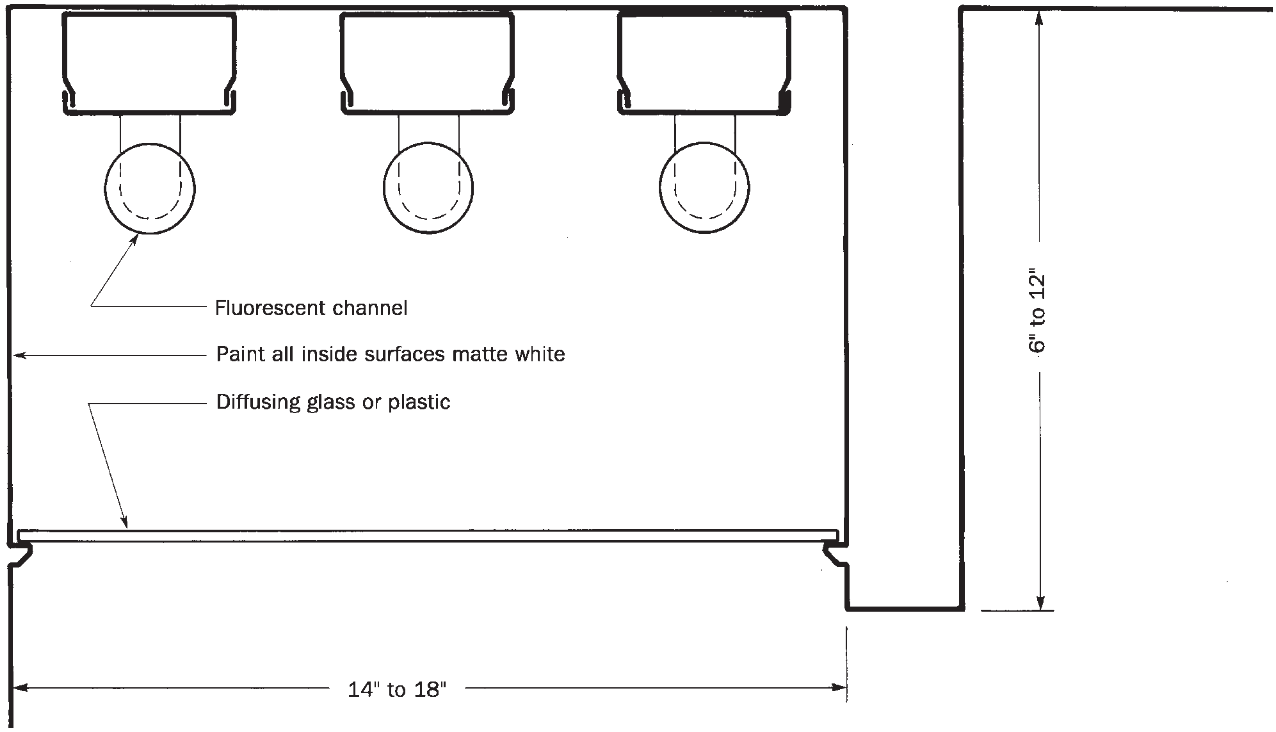

Figure 12.50 Typical lighting soffit. Electronic ballasts will eliminate noise.

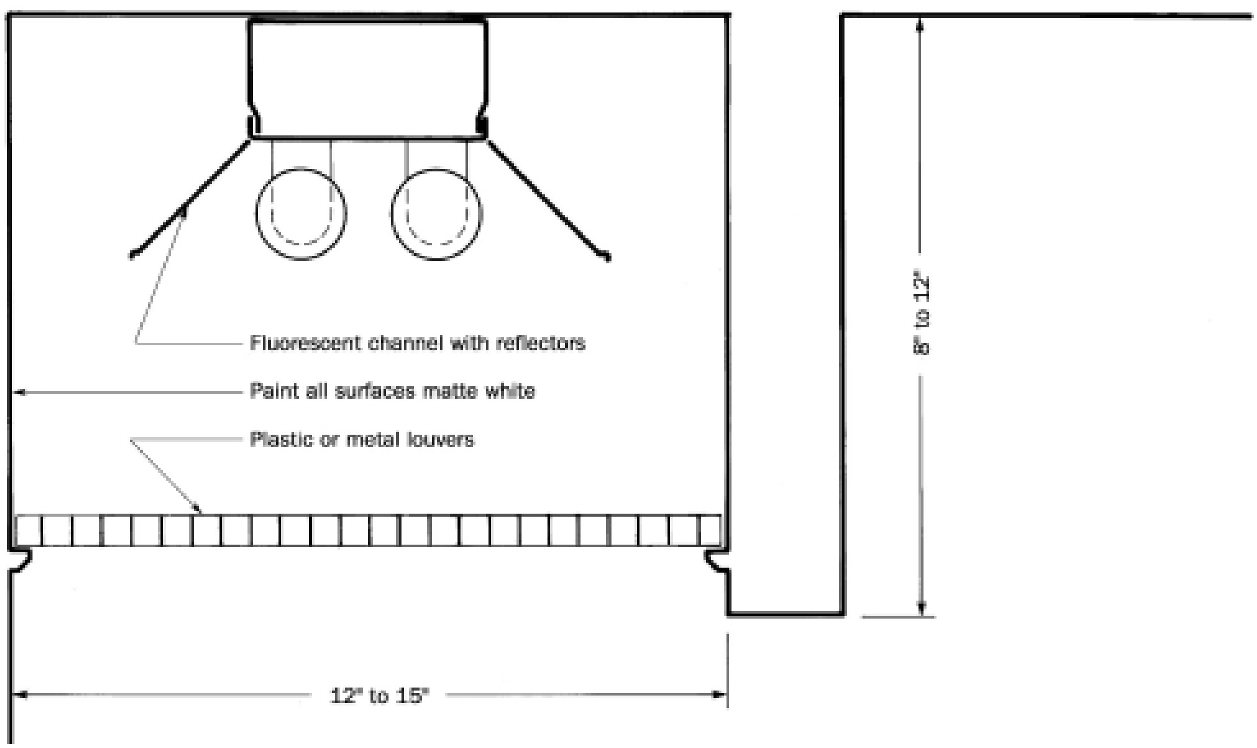

Figure 12.51 Typical lighting soffit over work area with fluorescent reflector channel.

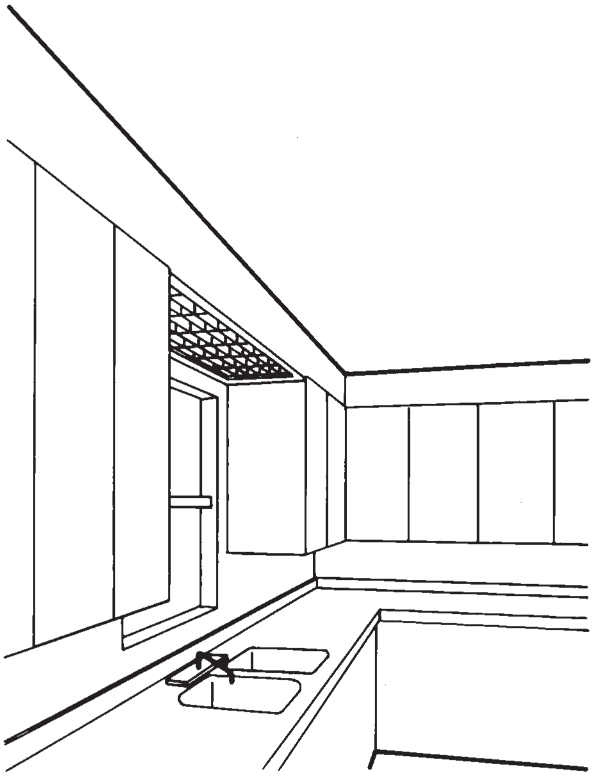

Figure 12.52 Typical lighting soffit over work area with open louver.

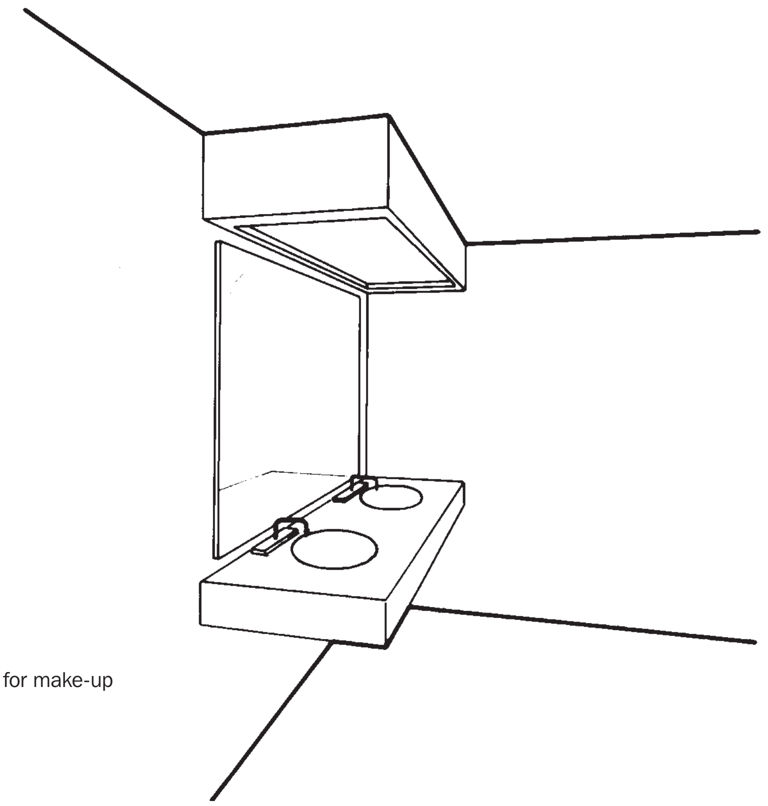

Figure 12.53 Typical lighting soffit for make-up and grooming areas.

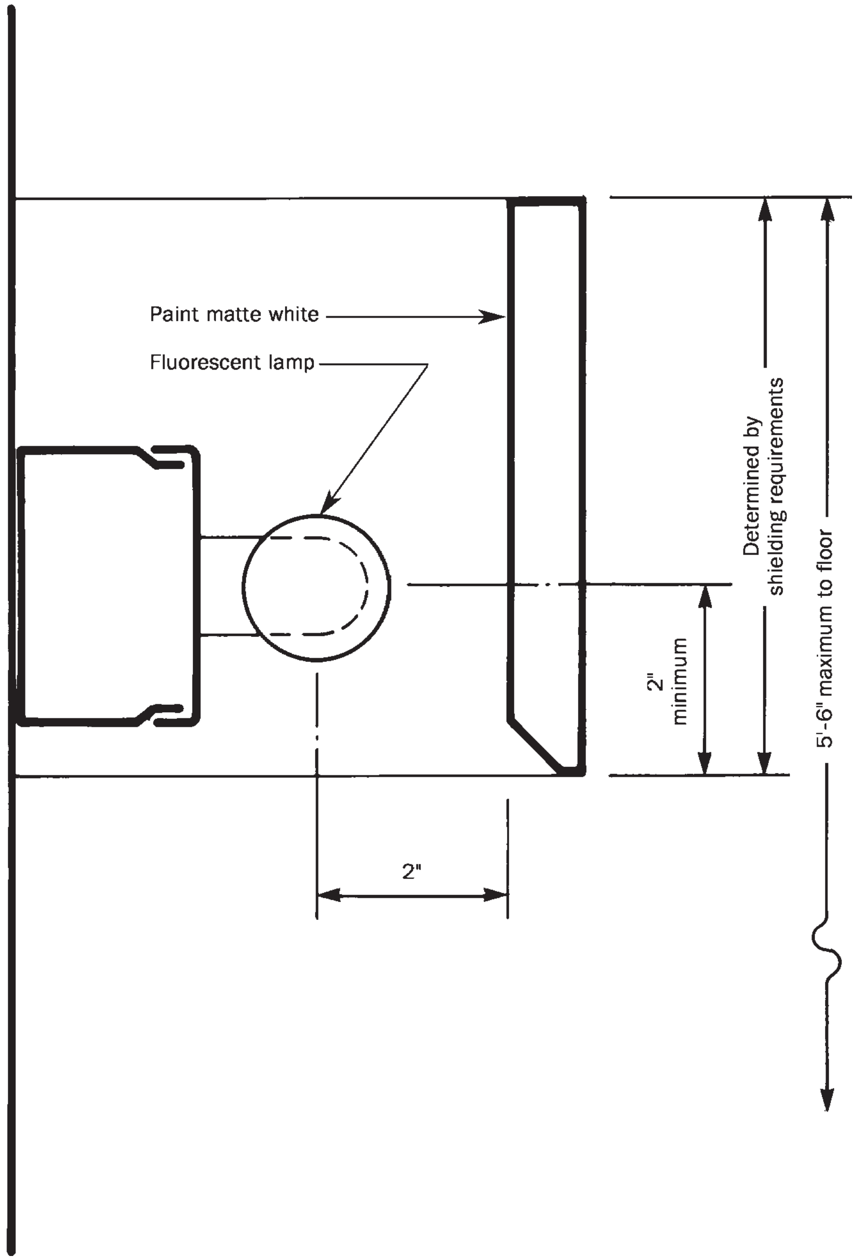

Figure 12.54 Lighted low bracket.

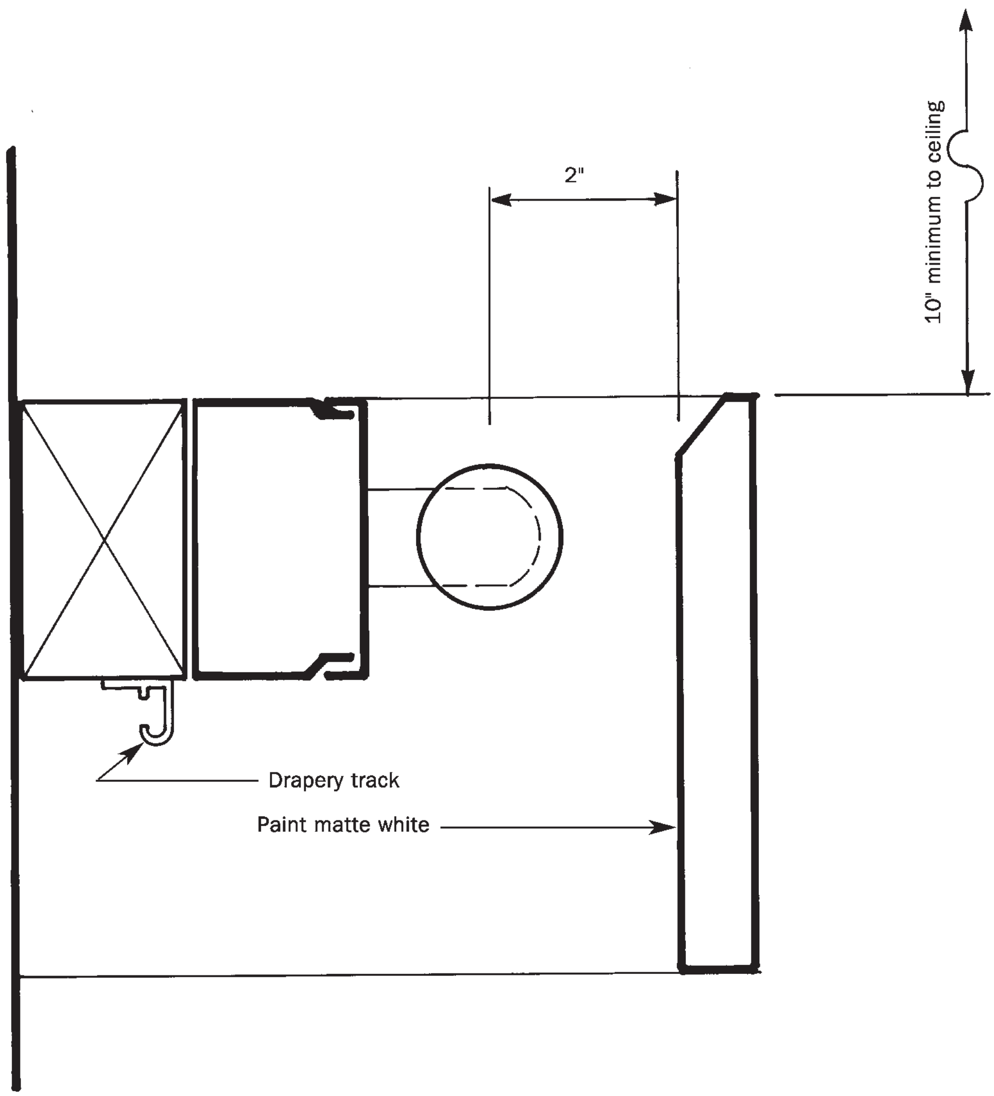

Figure 12.55 Lighted valance.

High brackets. *High brackets* are used on interior windowless walls. They provide both uplight and downlight for ambient illuminance or specific emphasis on surfaces and artwork (figure 12.56).

Decorative Luminaires

Decorative luminaires are used to provide ambient lighting in areas where their appearance contributes to the design harmony of the space (figure 12.57). They are available

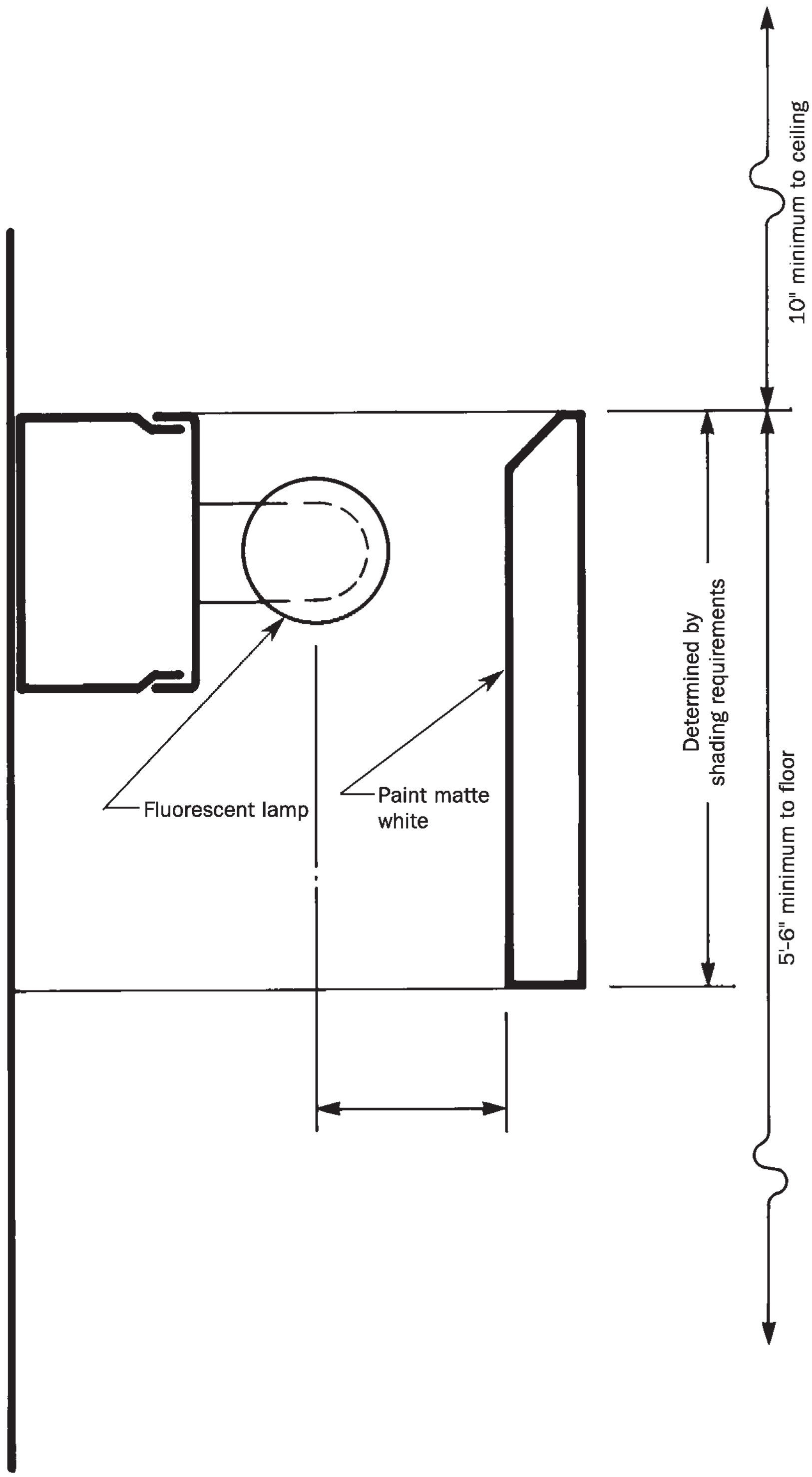

Figure 12.56 Lighted high bracket.

Figure 12.57 Decorative luminaires provide ambient light while contributing to the design harmony of the space.

as ceiling-mounted globes and diffusers (figure 12.58), pendant-mounted and suspended *chandeliers* (figure 12.59), wall-mounted lanterns and *sconces* (figure 12.60), floor- and ceiling-mounted corner lights, and floor-mounted *torchères* (figure 12.61).

Almost all decorative luminaires produce multidirectional distribution. Some have optical control hidden inside their decorative exteriors to provide a specific distribution of light.

Figure 12.58 Ceiling-mounted diffuser luminaires.

Figure 12.59 Pendant-mounted luminaires

Figure 12.60 Wall-mounted sconces.

Figure 12.61 Floor-mounted torchère.

13 Design

Lighting design is a process. Specifically, it is the process of integrating light into the fabric of architecture.

Successful lighting is integrated into both the architectural concept and the physical structure.

The lighting concept is integrated into the architectural concept in three ways: (1) by enhancing the original designer's conception of the space, (2) by reinforcing the activity in the space, and (3) by highlighting areas to be prominent, while de-emphasizing areas to be subdued.

Lighting equipment is integrated into the physical structure of the building in three ways: (1) by selecting visible elements that harmonize with the design motif, (2) by incorporating hidden elements within the architectural forms and surfaces, and (3) by coördinating electrical systems with the other mechanical systems of the building.

VISUAL CLARITY

People search for simplification of their visual fields when faced with demanding tasks and activities. In an environment that is used for complex activities, too many visual stimuli or too many patterns will result in an overload condition. We become tense and frustrated and have a diminished ability to perform a complex task.

When we are reading with music playing nearby, the sound competes with the written material yet allows comprehension of simpler passages. At a complex portion of the material, where the reading task becomes more absorbing, we instinctively turn the volume down or off. In doing so, the amount of information that is competing for attention is reduced.

Meaningless or confusing luminances in a space are similarly distracting. The brain becomes overstimulated, spending additional time and energy sorting out conflicting information. This is called *visual clutter*; it is analogous to noise or static in acoustical design.

As the activity or task becomes more complex (more loaded), visual clutter becomes more distracting. It affects worker performance, particularly when the worker is faced with demanding (more stimulating) tasks. Visual clutter undermines long-term performance of all complex tasks.

Visual clarity reduces the number of stimuli in the field of view. It allows us to move through space and complete tasks without any attention being drawn to the lighting system. This leaves our concentration available for the task at hand (figure 13.1).

Figure 13.1 Low-brightness louvers minimize clutter on the ceiling and establish the primary focus in the activity portions of the visual field.

It is the designer's role to simplify the visual process and the environmental background so that distortions and irrelevant clutter are minimized. The goal is to reduce distractions so that the environment assists concentration and conserves our energy for the demands of more productive tasks and activities.

Luminaire Patterns

An irregular luminaire pattern on the ceiling confuses orientation and spatial understanding. We react negatively not because tasks are poorly illuminated or because glare produces discomfort, but because of the distractions produced by the luminaire placement. When the irregular luminaire pattern directs attention to the ceiling, we must overcome the distraction and consciously focus attention on the activities and more meaningful visual stimuli in the room.

An organized pattern on the ceiling minimizes the effort required to discover or impose regularity on the environment (figure 13.2). Carefully organized brightness patterns and repetitive luminaire layouts are useful techniques for simplifying the processes of orientation and activity comprehension. In addition to establishing organized luminaire patterns, matching luminaire apertures of the same dimension and finish further reduce confusion (figure 13.3). Because greater cer-

Figure 13.2 An organized ceiling pattern simplifies orientation and activity comprehension.

Figure 13.3 Matching luminaire apertures of the same dimension and finish.

tainty is felt in an organized environment, less attention is paid to it.

Lighting designers are ceiling designers. Lighting layout drawings include locations of luminaires, sprinkler heads, air diffusers, return grilles, smoke detectors, loudspeakers, and so forth. To prevent visual clutter, these ceiling elements are organized in an invisible grid (figure 13.4).

Whether providing uniform or nonuniform lighting, organize luminaires in a pattern based upon an invisible grid that is related to the architecture. For example, figure 13.5 shows a 78-ft-long room and luminaires with a maximum spacing of 10 ft. The solution presented is eight equal spaces measured to the *center line* of each luminaire. A half-space at either end ensures adequate illuminance near the walls. In the other direction, which is 36 ft, four equal spaces to the center line of each luminaire are shown.

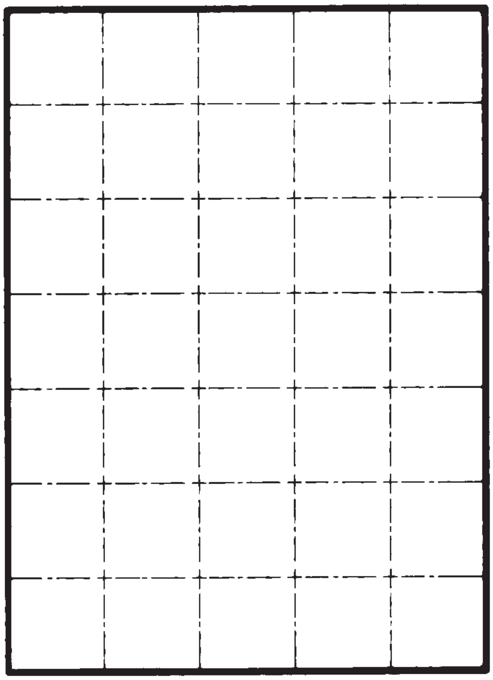

Figure 13.4 Invisible grid for luminaire placement.

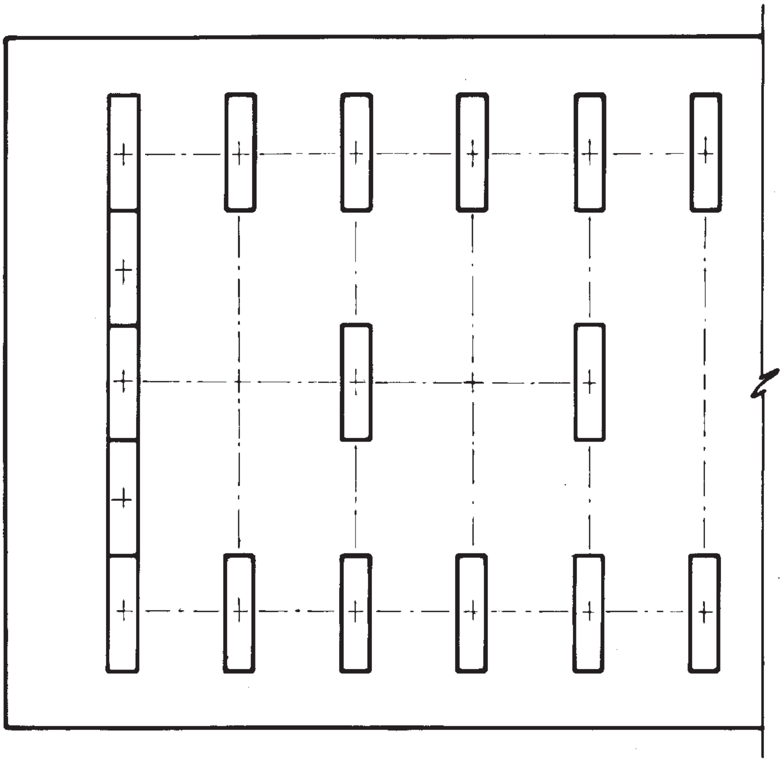

Figure 13.5 1 ft × 4 ft luminaire pattern.

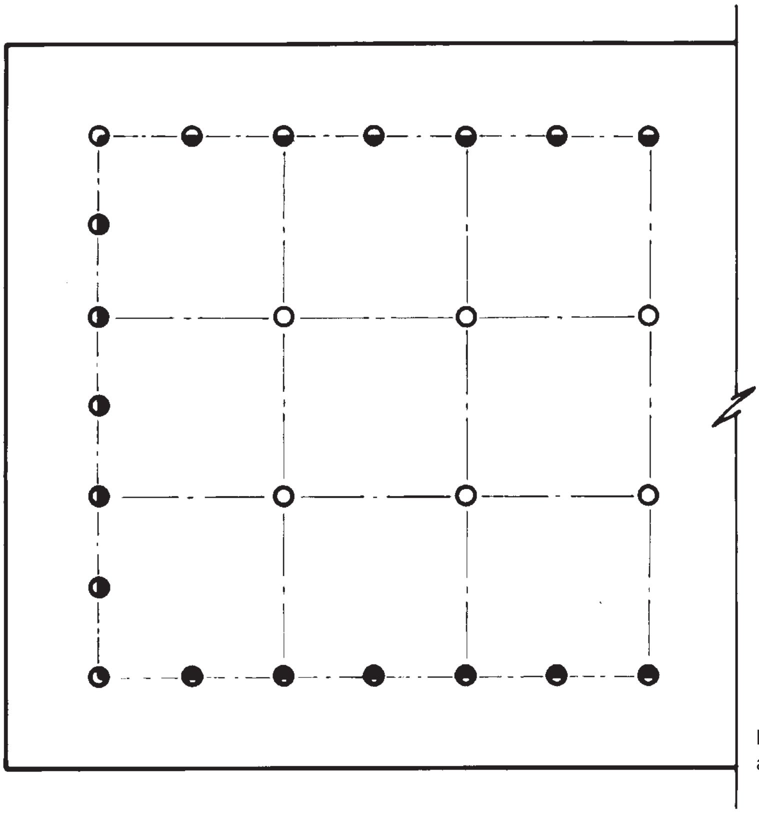

Figure 13.6 6-inch-diameter round-aperture luminaire pattern.

It is unnecessary to fill each cross-point of the invisible grid to maintain the order supplied by that pattern. With the round-aperture luminaires in figure 13.6, spacing at the perimeter is half the spacing of the room to provide uniform wall lighting with open-reflector downlight/wall-wash luminaires.

ARCHITECTURAL SURFACES

When the primary emphasis of lighted space is within the visual field, the resulting patterns of brightness reinforce our priorities for defining space (orientation) and defining activities (participation).

People define their environment through a process of additive perception. Information is gathered by scanning the boundaries of a space, thereby forming a concept of direction and limits. When the lighting system is designed to establish the physical boundaries of a space, it helps people to maintain a sense of direction and an understanding of spatial form with minimal distraction from the environment.

Lighting helps to define and separate the major surfaces of a space if the shape of the light distribution relates to the form of the surface. For example, a wall or ceiling lighted with a uniform wash of light will approximate the form and dimension of that surface.

A linear wash of light facilitates clear visual separation between the vertical and horizontal planes (the wall and ceiling sur-

Figure 13.7 A linear wash of light facilitates spatial clarity.

faces and the wall and floor), the borders of interior space (figure 13.7). The evenly lighted wall is perceived as an integrated visual form (figure 13.8). The same is true of the evenly lighted ceiling plane.

Lighting Vertical Surfaces

Vertical surfaces require special attention: they are the first surfaces that we see upon entering a space. Vertical surfaces define the boundaries of the space; they are used for displaying works of art and communicating a message. Clear perception of vertical surfaces significantly impacts our perception of the overall design.

Reliance upon formulas to provide a specific illuminance value on the horizontal plane disregards the importance of vertical surfaces. Consequently, luminaires used for ambient illumination often cast unanticipated or undesired light patterns on the vertical surfaces, or leave them in relative darkness. If not distracting, the resulting environment is unintentionally dull and monotonous.

It is critical to anticipate where downlight distributions will intersect vertical surfaces. *Scallop* patterns and similar irregularities are to be minimized. Except for special situations, a lighted surface is not intended to be perceived as a form or surface that is intersected by arbitrary patterns of light; it is intended to be perceived as a unified form.

Scallops of light are incompatible with the plane form of the wall. Because the eye is involuntarily attracted to areas that contrast with the ambient brightness, scallops result in a disorienting pattern of superimposed light that confuses perception of the visual form of the wall (figure 13.9).

Figure 13.8 An evenly lighted wall is perceived as an integrated visual form.

Figure 13.9 Scallops distort the plane form of the wall.

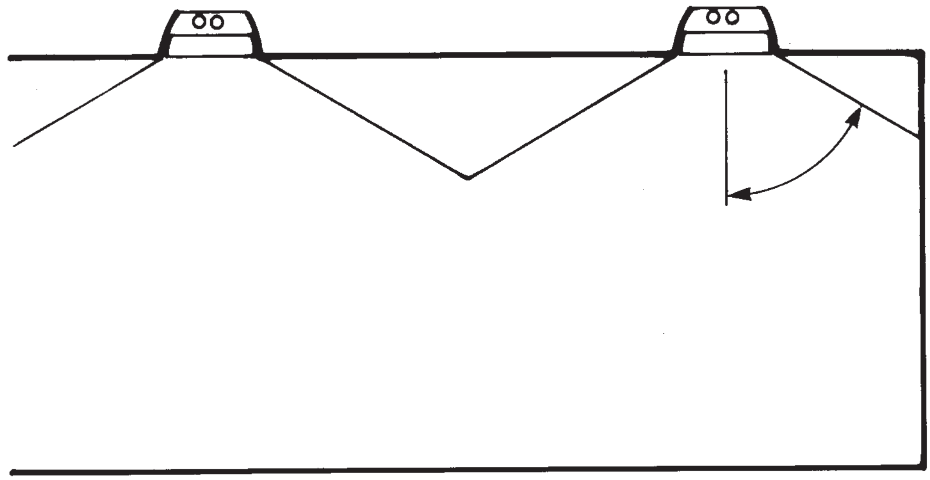

Figure 13.10 Sharp-cutoff luminaires produce shadows along the top of an adjacent wall.

To alleviate scallops when using open-reflector point-source downlights, use downlight/wall-wash reflectors at the perimeter, as indicated in figure 12.20, if the wall surface is matte. If the wall surface is specular, no adjustment is necessary; the intersecting light pattern is unnoticeable on a mirror-like surface.

Rectilinear fluorescent downlights with sharp luminance *cutoff* show an abrupt falloff of light at the upper part of adjacent walls. This results in a shadow line along the top of the wall, which often causes a space to be perceived as dimly lighted (figure 13.10). Wall-washers or a continuous perimeter system will fill in this shadow. A similar result is achieved by using a specular wall finish in the shadow area with a matte finish below it.

Irregular patterns of light are sometimes desirable. A shaft of sunlight has intrinsic value, as do some electric light patterns that avoid a relationship to the physical form of a space. The value of these irregular patterns of light is that they serve as a temporary visual stimulant.

Irregular light patterns are also successful when they relate to an appealing attribute of the physical space, such as a painting, sculpture, plant, or architectural detail. Unless specifically intended, however, avoid irregular light patterns.

Matte vertical surfaces

Three kinds of lighting systems are available for *uniform* vertical surface illumination of matte surfaces: (1) individual unit, point-source wall-wash; (2) continuous, linear, point-source wall-wash; and (3) continuous, linear, diffuse-source wall-wash.

Individual unit, point-source wall-wash. To provide uniform illumination from top to bottom, luminaires are placed parallel to the wall at a distance of about one-third the height of the wall. For uniform lighting from side to side, the "square rule" applies: luminaires are located on centers closer than or equal to their distance from the wall. The center-to-center spacing varies with the ceiling height and the light intensity desired on the surface.

Continuous, linear, point-source wall-wash. Uniform lighting is also provided by a grazing light from luminaires located close to the surface being illuminated (figure 13.11). The same square rule applies: the lamps are spaced on centers closer than or equal to their distance from the wall. Again, the center-to-center spacing varies with the ceiling height and the light intensity desired on the wall surface. The goal is also the same: to provide the perception of uniform brightness both horizontally across the wall and vertically from top to bottom.

A full-scale mock-up tests for the following:

1. Beam-spread overlap (spot beam-spreads usually require a spread lens).

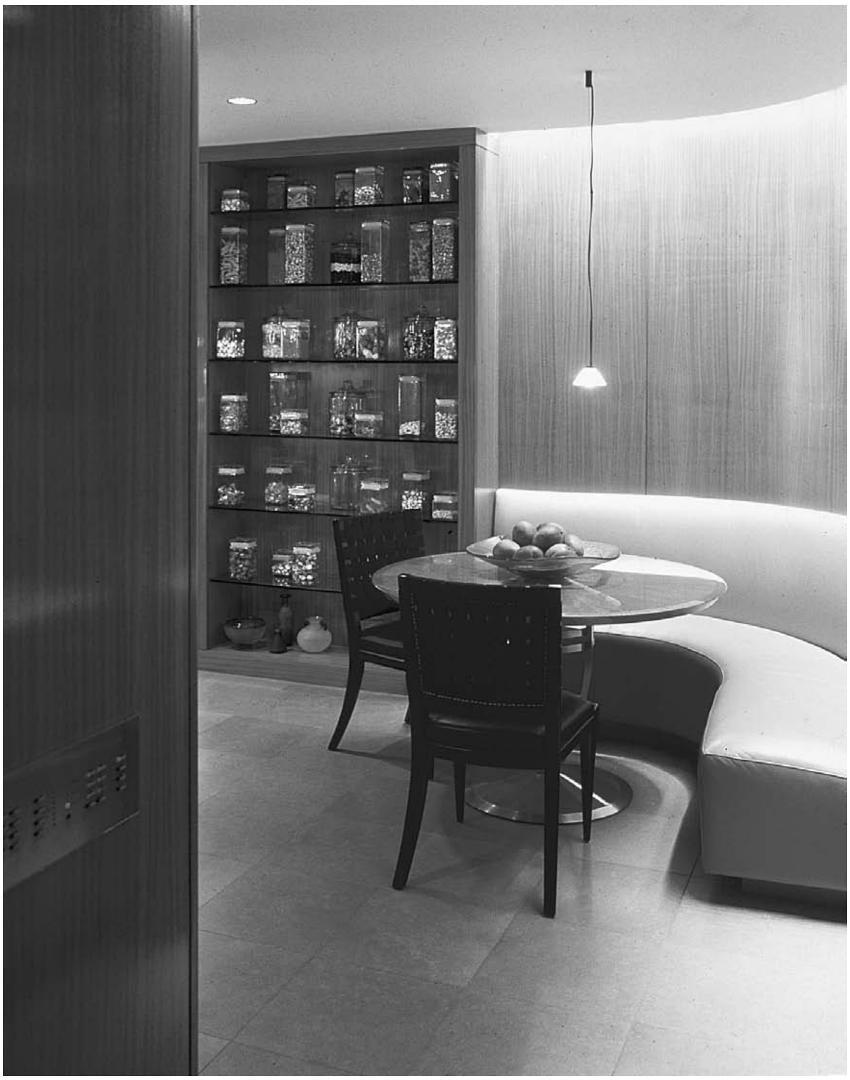

Figure 13.11 Continuous, linear, point-source wall wash.

2. The optimum distance away from the wall and on-center spacing.
3. The mounting cavity height, depth, and finishes required.
4. The necessity of baffles to shield the lamps from view along the length of the cavity.

A full-size mock-up is the only way to ensure that the finished installation will achieve the desired illuminance value and avoid scallops and striations at the top of the wall. No miniature light sources exist to test the performance of architectural lamps in a scale model.

Continuous, linear, diffuse-source wall-wash. The diffuse fluorescent source is good at providing even lighting across the wall in the horizontal direction but is inadequate at providing even illuminance vertically from top to bottom. Reflectors help to mitigate the problem but fail to solve it for walls exceeding 10 ft in height. The use of a fluorescent wall-wash system is reserved for low ceiling areas with wall heights from 8 to 10 ft.

Specular vertical surfaces

When providing light for glossy surfaces, such as glass, marble, high-gloss enamels, and varnishes, specular reflections complicate the placement of lighting equipment. Careful location and shielding of the source prevents distracting reflections and veiling images.

Think of the glossy surface as a mirror; eliminate glare by minimizing high luminance in the reflected field of view. To reduce reflected images, remove bright elements in the reflected field of view or shield them with properly located baffles or screens.

People, objects, and other surfaces in the room become secondary light sources. If they are located in the reflected field of view, they will cause distracting or veiling reflections in glossy surfaces. In some cases, the perception of varnished or glass-covered paintings, or of marble and other specular materials, is partially or completely obscured by such reflected images.

TASK LIGHTING

Lighting systems in the workplace provide for accurate perception at a specific task area (a desk, counter, machine, or workbench). This is achieved by using one of two lighting methods: a general-ambient approach or a task-ambient approach.

General-ambient systems provide a uniform quantity of light throughout a space. This approach is often used when the task location is apt to vary widely or when the space will be reconfigured frequently.

Task-ambient systems are more energy-effective. Higher values of task illuminance are provided for the workplane while lower values of ambient illuminance are provided for surrounding areas.

Task-ambient systems are appropriate in rooms where task areas are permanently located, such as private offices, factories, laboratories, and stores. Task lighting is provided for task areas, with the remaining space lighted for more casual activities (figure 13.12).

When designing a task-ambient system, first light the task (focal glow), then supplement the task lighting with ambient room lighting. In typical task-ambient systems, task-oriented luminaires are mounted on or near the furniture and supplemented by an ambient (uniform) lighting system that provides lower illuminance.

Ambient lighting provides overall illumination for circulation, provides balance between the VDT task luminance and its surround, and provides part of the illuminance for paper-based tasks. Areas surrounding visual tasks need less illuminance than the

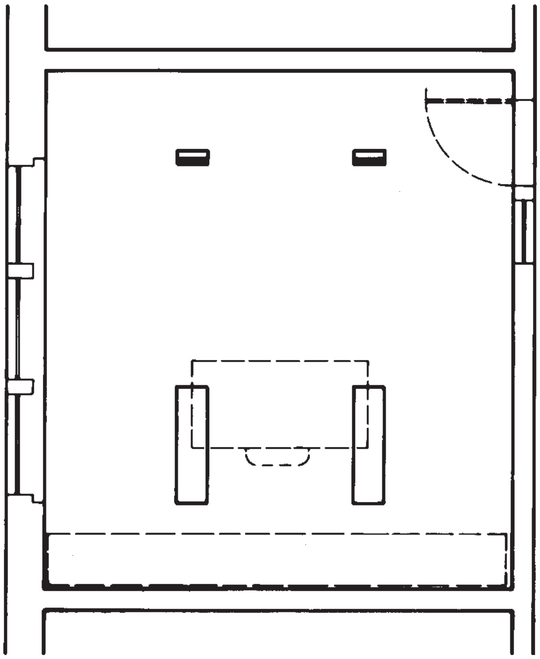

Figure 13.12 Task-ambient (nonuniform) office lighting layout.

visual tasks. For comfort and ease of adaptation, make the ambient illuminance at least 33 percent of the task illuminance.

VDTs

VDT screens present a particular challenge for designers. Almost all VDT screens have a dark, glossy, or satin surface that reflects images of the surrounding space; the operator will see luminaires, ceilings, walls, or windows as elements of excessive brightness reflected in the screen (figure 13.13). The designer must carefully select and locate luminaires to minimize reflected images.

VDT tasks often require an almost horizontal line of sight when viewing the screen. Because of this, a large area of the ceiling will be in the field of view in large open offices. It is critical to minimize variation in luminance on the ceiling plane in order to prevent discomfort glare (figure 13.14).

With well-designed direct luminaires, the luminance of the aperture will be equivalent to the luminance of the ceiling. This results in minimal brightness contrast

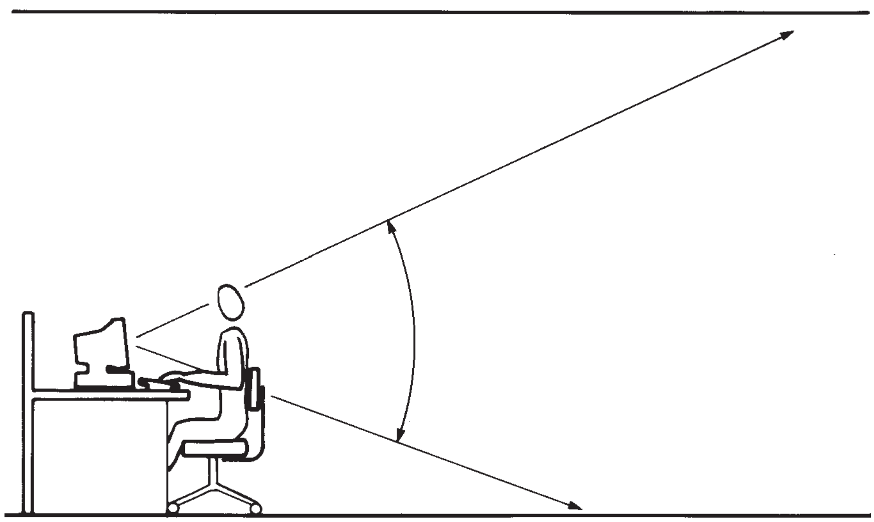

Figure 13.13 Normal range for reflected line-of-sight angles in a VDT (65° to 110° from vertical).

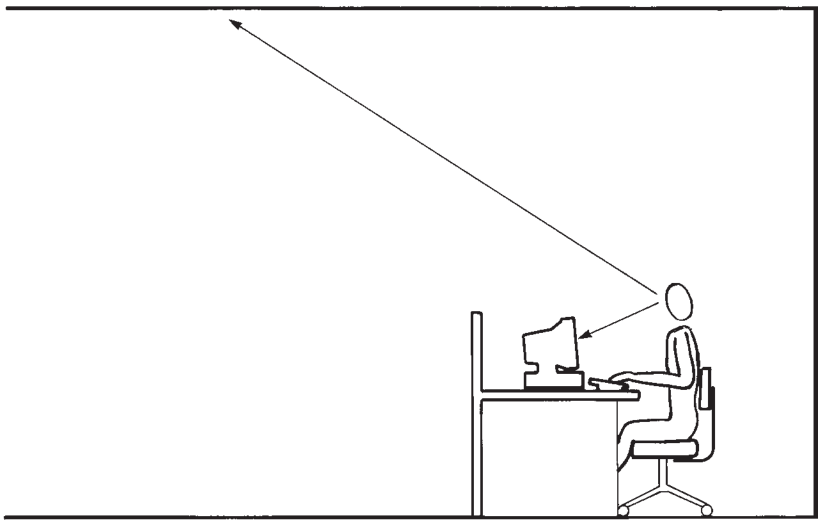

Figure 13.14 A large area of the ceiling is within the field of view when viewing a VDT.

between the reflected screen images of the luminaire and ceiling.

With a well-designed indirect system, the light received on the ceiling plane exhibits an even luminance, yielding minimal brightness contrast in the VDT screen. The underside of the indirect luminaires must be approximately the same luminance as the ceiling plane. When the luminance seen across the VDT screen is uniform, minimal interference occurs.

Paper-based tasks

Almost all office work involves paper-based tasks. Paper documents are referenced for word processing, order entry, information retrieval, and computer-aided design. In addition to the lighting requirements for VDT tasks, lighting for paper-based visual tasks must also be considered.

AMBIENT LIGHTING

Ambient lighting is provided by two basic methods: (1) downlighting (direct), where overhead luminaires provide a downward light distribution, and (2) uplighting (indirect), where pendant luminaires provide upward light that is then reflected from the ceiling.

Downlighting (Direct)

With downlighting (direct lighting), luminaires are arranged according to the ambient lighting requirements for either uniform or nonuniform distribution over the horizontal workplane.

For direct ambient lighting, the spacing criterion (*SC*), or spacing-to-*m*ounting-*h*eight (*S/MH*) ratio, provided by the luminaire manufacturer, gives the maximum recommended spacing between luminaires to achieve uniform, ambient lighting.

To quickly assess the potential of a downlight luminaire to provide uniform illumination of the horizontal plane, *SC* is the center-to-center distance between luminaires (spacing) based on their mounting height above the workplane.

$$S = MH \times SC$$

For example, if the $SC = 1.5$, then for an 8-ft ceiling height,

$$MH = 8 \text{ ft } 0 \text{ in} - 2 \text{ ft } 6 \text{ in to the workplane}$$
$$= 5 \text{ ft } 6 \text{ in AFF}$$

$$S = 5.5 \text{ ft} \times 1.5 = 8.25 \text{ ft}$$

The center-to-center maximum spacing from the center of one luminaire to the center of the next is thus 8.25 ft (figure 13.15).

For rectilinear luminaires, *SC* is expressed as parallel or perpendicular, indicating the spacing-to-mounting-height ratio in either the direction parallel to or perpendicular to the orientation of the lamps within the luminaire.

To maintain uniformity of light intensity over a large work area, avoid exceeding the manufacturer's recommended maximum SC. Because of wall surface absorption, maximum distance from the last row of luminaires to the wall is usually one-half to one-third the spacing in the room to prevent a falloff in illuminance near the walls (figures 13.16 to 13.18).

Even with this reduced spacing, work surface illuminance near the walls is often only half that measured in the center of the room. In critical seeing areas, supplementary luminaires are added near the wall (figure 13.19).

Office partitions block some overhead light from a direct system, preventing it from reaching work surfaces. Depending on the location of the downlights, some areas will be left in shadow (figure 13.20). Well-designed uplighting, because it produces even illuminance overhead, softens and reduces this shadowing.

Uplighting (Indirect)

The primary use of uplighting (indirect lighting) is to create evenly luminous ceilings that reduce VDT screen reflections. For uplighting to be successful, luminance differences on the ceiling plane must be minimal. If bright patches of higher luminance occur, they are reflected in the VDT screen, causing a distracting background.

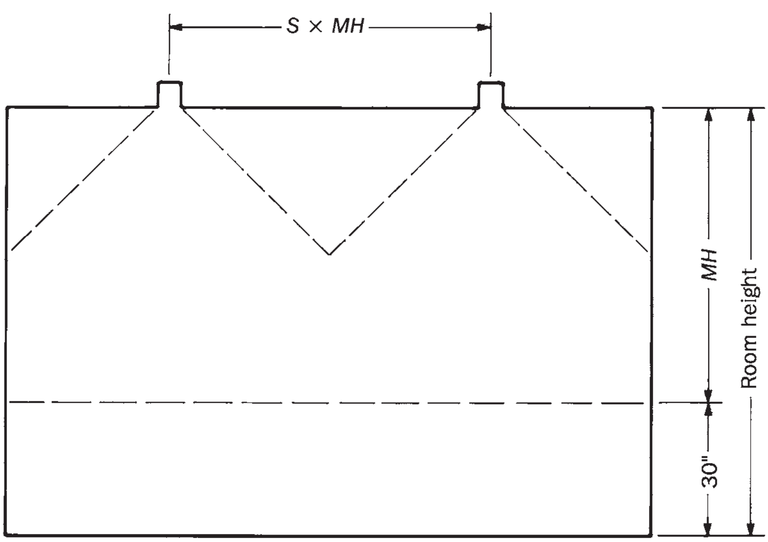

Figure 13.15 Spacing-to-mounting-height ratio.

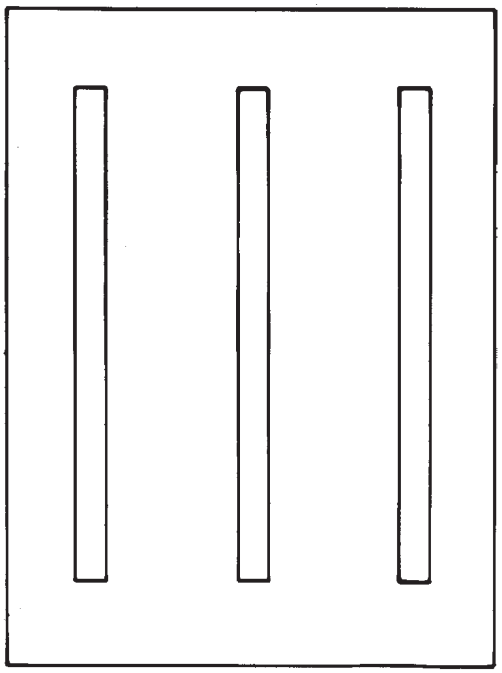

Figure 13.16 Linear pattern, continuous 1 ft × 4 ft rectilinear luminaires.

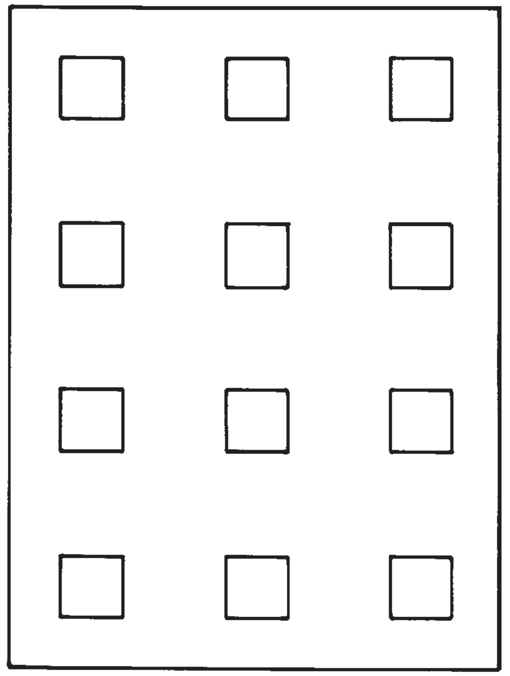

Figure 13.17 Regular pattern, 2 ft × 2 ft square luminaires.

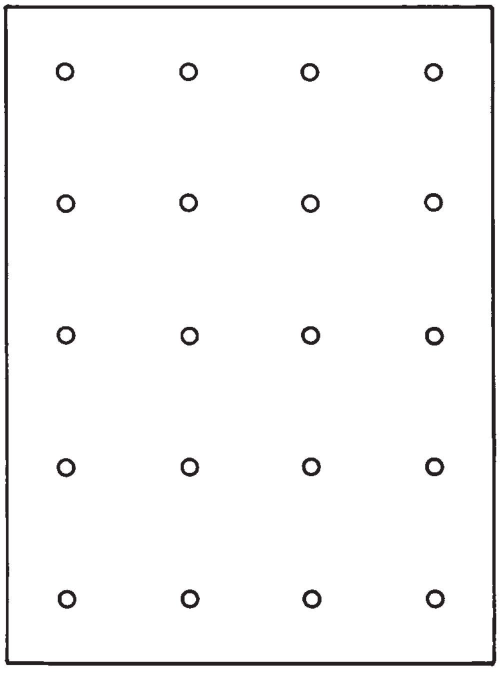

Figure 13.18 Regular pattern, 6-inch-diameter round-aperture luminaires.

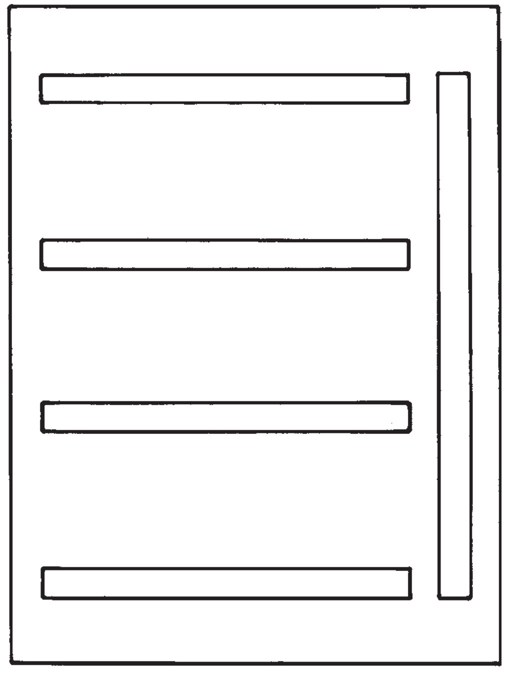

Figure 13.19 Supplementary illumination near the wall.

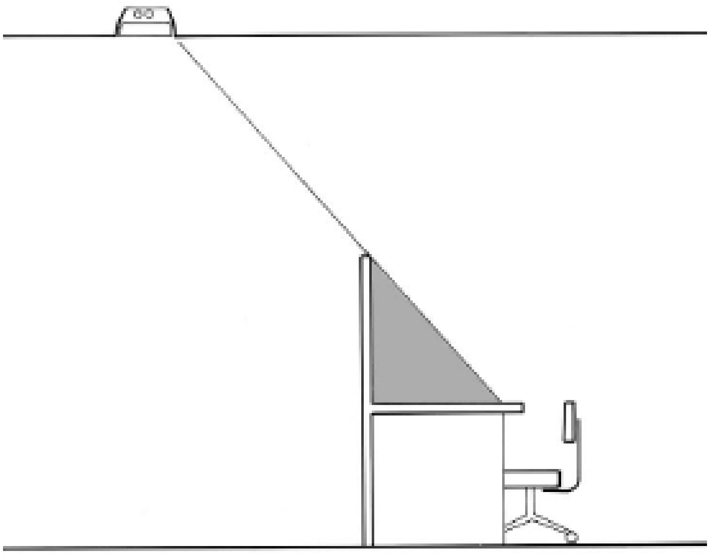

Figure 13.20 Some areas have noticeable shadows from office partitions, especially when partitions are located on three sides of the work surface.

Uplighting systems also increase the vertical illumination in a space. While this is desirable for many surfaces, it reduces image contrast on VDT screens. Although indirect lighting systems eliminate the most offensive image glare common with direct lighting on VDTs, they may introduce less-problematic veiling reflection and contrast reductions on the surface of the screen.

A well-designed indirect luminaire has a wide distribution. Multiple luminaires are located so that their light output will be evenly distributed across the ceiling without hot spots or areas of high luminance (figure 13.21). The goal is uniform ceiling brightness, where luminances and luminance ratios are consistent throughout the space.

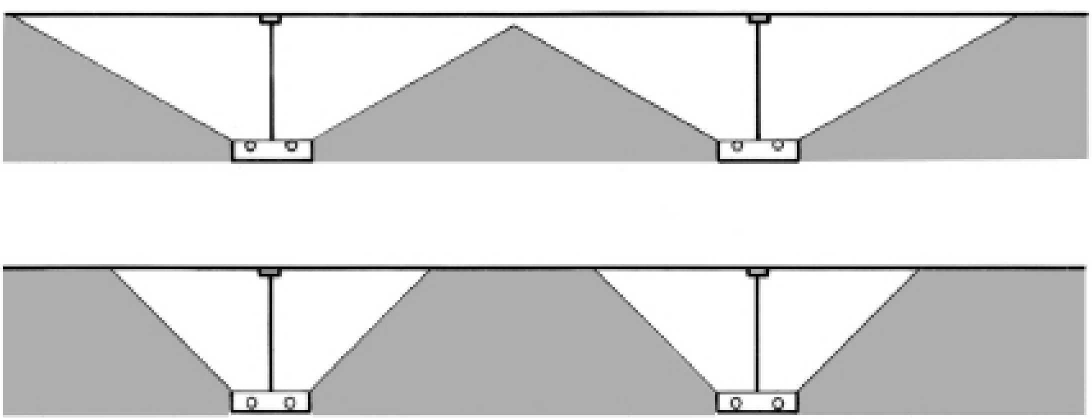

Figure 13.21 Above, properly located indirect luminaires with wide distributions produce even luminance; below, improperly located indirect luminaires with narrow distributions produce areas of uneven luminance.

To avoid distracting brightness variation in VDT screens, keep the variation in ceiling luminance to a ratio of less than 4 : 1. In addition, limit the average luminance of any 2 ft × 2 ft area of the ceiling to less than 850 cd/m^2, measured at any angle. Apply this same limit to windows, walls, and partitions that will be reflected in the VDT screen.

The diffuse light from indirect systems, however, reduces our sense of visual clarity, depth perception, and sense of orientation. This lack of highlight and shadow is mitigated by a greater use of surface color, wall lighting, or object lighting; these techniques add visual interest, thus enhancing perception of the environment.

Some indirect luminaires incorporate a luminous element that is visible from below. This is psychologically beneficial because people feel more comfortable when they can identify the source of light. This visible luminous element also increases the perception of brightness in a space and introduces visual highlight into a shadowless environment.

In a small office, only part of the ceiling will be reflected in the VDT screen. Here, it is the walls that are of concern. The walls of a small office must have sufficient luminance to avoid noticeable contrast between these walls and the ceiling, a condition that causes distracting contrast in VDT screens.

Downlighting Versus Uplighting

The appearance of a low-brightness direct lighting system differs considerably from an indirect lighting system. The direct system produces negligible luminance on the ceiling plane and provides great emphasis on the horizontal work surface, furniture, and floor coverings. The indirect system places luminance emphasis on the ceiling plane and deemphasizes the surfaces in the lower half of the room. A direct-indirect system accomplishes both.

LIGHTING ART

Lighting Three-Dimensional Objects

Three-dimensional objects are perceived as a result of the relationship between highlight and shadow. Concentrated beams create higher contrast and deeper shadows, emphasizing form and texture. Frontal lighting, located 30° to 45° from the center of an object in the horizontal plane and 30° to 45° from nadir in the vertical plane, models objects in a manner that replicates sunlight.

Lighting a vertical surface behind an object provides a luminous backdrop to separate the object visually from its background (figure 13.22), much the way an actor is separated from the scenery on a stage. Lighting an object from the side as well as from above provides added dimension to the piece.

Perception is disturbed when the expected relationship of highlight and shadow is reversed or when an object is lighted from a less conventional angle. Uplighting creates an ominous, ghoulish impression (see figures 3.27 and 3.28). Backlighting leaves an object in silhouette.

Paintings and Flat Works of Art

For lighting paintings and flat works of art, two principal methods exist: uniform illumination and nonuniform illumination.

Providing *uniform* lighting for all vertical surfaces that will receive art gives prominence to the architecture; no hierarchy is established among the individual works of art, allowing viewers to select their own focus. Objects can be changed without readjusting the lighting equipment (figure 13.23).

Providing *nonuniform* lighting focuses light on individual works while leaving the surround in comparative darkness. This gives prominence to the art over the architecture, creating a more dramatic environment. Every time the art changes, the

Figure 13.22 Lighting the vertical surface behind an object.

lighting equipment must also be adjusted (figure 13.24).

The placement of the light source depends upon the medium, surface texture, kind of frame, and enclosure (glass or plastic) of the object. For flat works mounted on a vertical surface, the optimum location for a light source is usually at an angle of 30° from nadir (straight down) to average eye level (5 ft 3 in AFF) (figure 13.25).

An aiming angle of less than 30° (more nearly vertical) creates disturbing shadows from the frame and distorts the object because it exaggerates its texture. An aiming angle greater than 30° (more nearly horizontal) results in reflected glare from the surface of the object, washing out detail. This greater angle also casts a shadow of the viewer on the artwork and causes the luminaire to be a source of glare to others moving through the space.

For nonuniform wall lighting, point-source object lights are ideal. When more than one luminaire is required because of the size of the work to be lighted, the square rule applies once again: the luminaires are spaced on centers closer than or equal to the distance away from the wall. The distance from the wall varies with the ceiling height (figure 13.26).

When a space with nonuniform vertical-surface illumination has frequently changing exhibits, a flexible lighting system is appropriate. Track systems are often selected because the track luminaires are easy to locate and aim (*focus*) as needed. The track

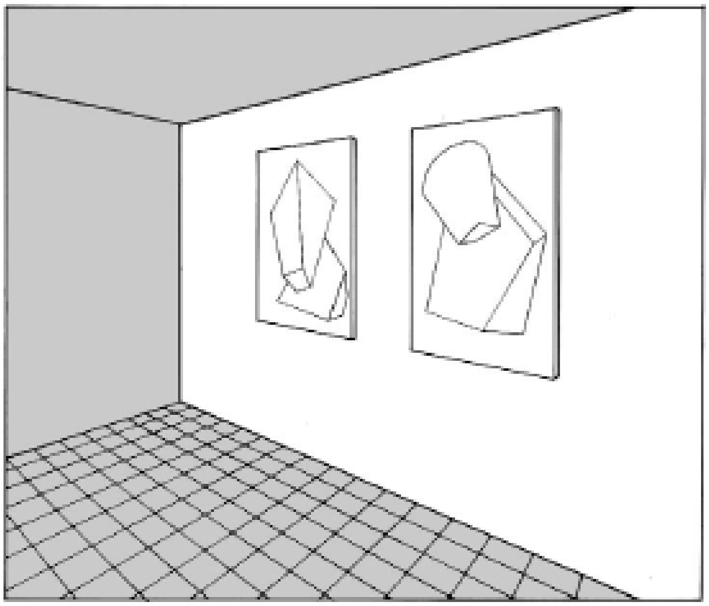

Figure 13.23 Uniform illumination for art.

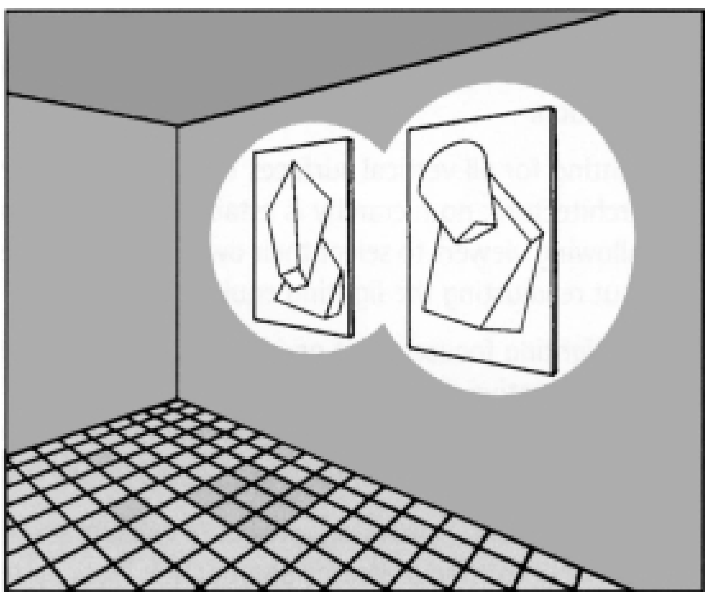

Figure 13.24 Nonuniform illumination for art.

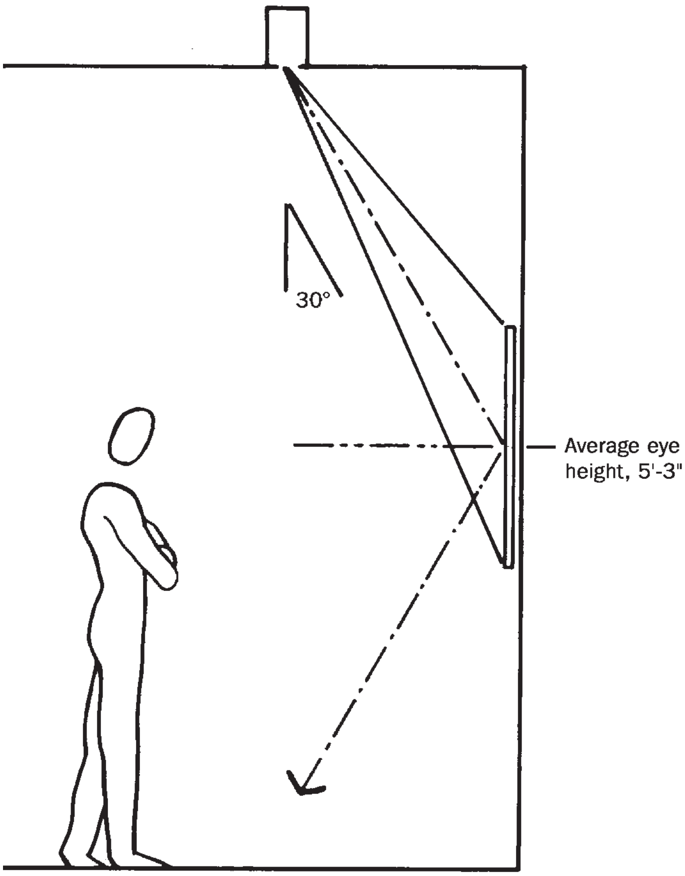

Figure 13.25 Optimum placement for lighting art.

itself also serves as the wireway, providing a simple method of power distribution.

With either method for lighting art, excellent color rendering is essential for the proper appreciation of objects. Continuous-spectrum, high-color-rendering sources allow the art to be viewed under spectral distribution conditions similar to those under which it was created.

Conservation of Materials

Conservation of materials is a fundamental concern in the lighting of art. All organic material is susceptible to pigment change and weakening from exposure to light and its accompanying heat. In the museum environment, these materials include paper, cotton, linen, parchment, leather, silk, wool, feathers, hair, dyes, oils, glues, gums, resins, and—because of similarities in chemical structure—almost all synthetic dyes and plastics.

Damage is related to wavelength. Ultraviolet (UV) radiation causes more damage, but much less UV than visible radiation is present in all light sources, including day-

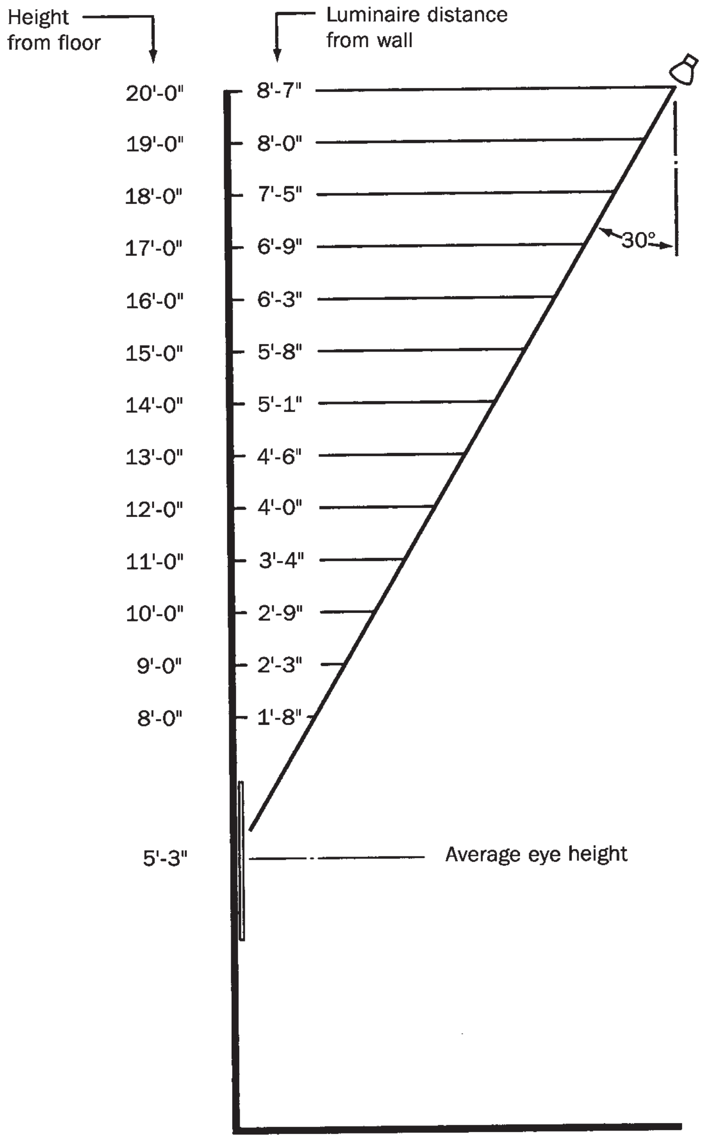

Figure 13.26 Typical luminaire mounting locations with 30° aiming angle.

light. A material that is fairly *fast* (more stable) but nevertheless susceptible to damage, such as the oil in paintings, will be changed mainly by UV radiation. But more sensitive dyes and pigments, which are damaged by either UV or visible radiation, will be changed mainly by the visible radiation, since it is more plentiful. In the museum environment, it is necessary to limit both UV and visible radiation.

Three steps will help to protect fugitive materials from the potential damage caused by light and heat: (1) evaluate daylight exposure, (2) evaluate electric light exposure, and (3) evaluate duration of exposure.

Evaluate the daylight first, because it contains a much higher proportion of UV than do electric sources. The highest-quality UV filters for daylight are made of acrylic and other plastics formulated to eliminate the transmission of UV but allow the passage of visible light. They are available as self-supporting sheets used in place of glass, thin acetate applied to glass, and varnish.

White paint is also a good UV absorber. If all light entering a room is reflected at least once from a white surface, the UV problem will be solved. Titanium dioxide pigment is best for this purpose, but zinc white is also a good absorber.

Second, evaluate the fluorescent and HID lamps. Although they emit UV radiation less strongly than daylight, all discharge lamps require UV filters. Fluorescent and HID lamps with correlated color temperatures above 3100 K need careful attention, because both UV radiation and short-wavelength visible radiation increases with color temperature. Plastic sheets of UV-absorbing material are available from manufacturers of color filters.

Incandescent lamps emit too little UV to require a filter. UV radiation from almost all incandescent lamps is less than 0.1 percent of the input wattage. Tungsten-halogen lamps emit slightly more UV below 300 nm, owing to their higher filament temperature. This is still a small amount; fortunately, ordinary glass, transparent to longer-wavelength UV, completely blocks this extra-short emission. (Tungsten-halogen lamps in U.S. luminaires will already have a lens or cover glass that provides safety protection in case of lamp breakage.)

It is more difficult to limit visible radiation than to limit UV radiation because the artwork will then be left in darkness. Museum practice suggests that for oil and tempera paintings, oriental lacquer, undyed leather, horn, bone, and ivory, maximum maintained illuminance is 15 fc on the surface. For objects especially sensitive to light, such as drawings, prints, watercolors, tapestries, textiles, costumes, manuscripts, and almost all natural history exhibits, maximum maintained illuminance is 5 fc.

With the quantity of light maintained at 5 to 15 fc, radiant heat is also controlled to reasonable limits. Lamps should be located outside exhibition cases and ventilated with air that avoids traveling directly past the exhibits. Dichroic cool-beam lamps are useful. Their color appearance is somewhat cooler than standard sources; the color rendering, however, is undisturbed.

Third, evaluate the time of exposure. *Exposure* is the simple product of illuminance and time. The same amount of damage will be produced by a large quantity of illuminance for a short time or a small quantity of illuminance for a long time. If the illuminance is halved, the rate of damage is halved. The optimal strategy is to reduce both illuminance and time of exposure.

With low illuminance values, warm versus cool colors of light are preferred. The low quantity of light is less important to the viewer than the balance of brightness between the works of art and the surround (the remaining space). Adaptation plays an important role in the enjoyment of art: the viewer's eyes must be adapted to the lower illuminance before entering the exhibit room.

BALANCE OF BRIGHTNESS

In chapter 2 we learned that lighting design involves the balance of three elements of light: ambient light, focal glow, and sparkle. The balance of these three elements causes a worker's task to be easily distinguished from the background, an artwork to stand out from its surround, and a conference or

Figure 13.27 Lighting opposite walls establishes a balance of brightness.

restaurant table to be the focus of its participants' attention. The result is known as the *balance of brightness*.

It is often desirable to light opposite walls in a space, thereby establishing a balance of brightness (figure 13.27). *Balance* is different from *symmetry*: lighting the opposing walls in the same manner is unnecessary, although one may choose to do so. Instead, one wall may be uniformly illuminated with a wall-wash system and the other will be nonuniformly illuminated with object lights (figure 13.28).

It is also desirable to balance the perimeter illumination of a space with its center. If a room's breadth is greater than its height, it is impossible to light it successfully solely from the walls. When diffusely lighted walls are distant from each other in a low-ceilinged space and they are the only source of illumination, the resulting environment is bland and gloomy. Downlighting is added to the center; otherwise all persons and objects in the center of the space will appear in silhouette (figure 13.29).

Remember that people interpret the overall environment chiefly through brightness relationships. Their subjective impressions of visual space are primarily a function of brightness patterns and pattern organization—the relationship of surfaces that are lighted or left in relative darkness.

Figure 13.28 Lighting opposite walls in different ways also provides a balance of brightness.

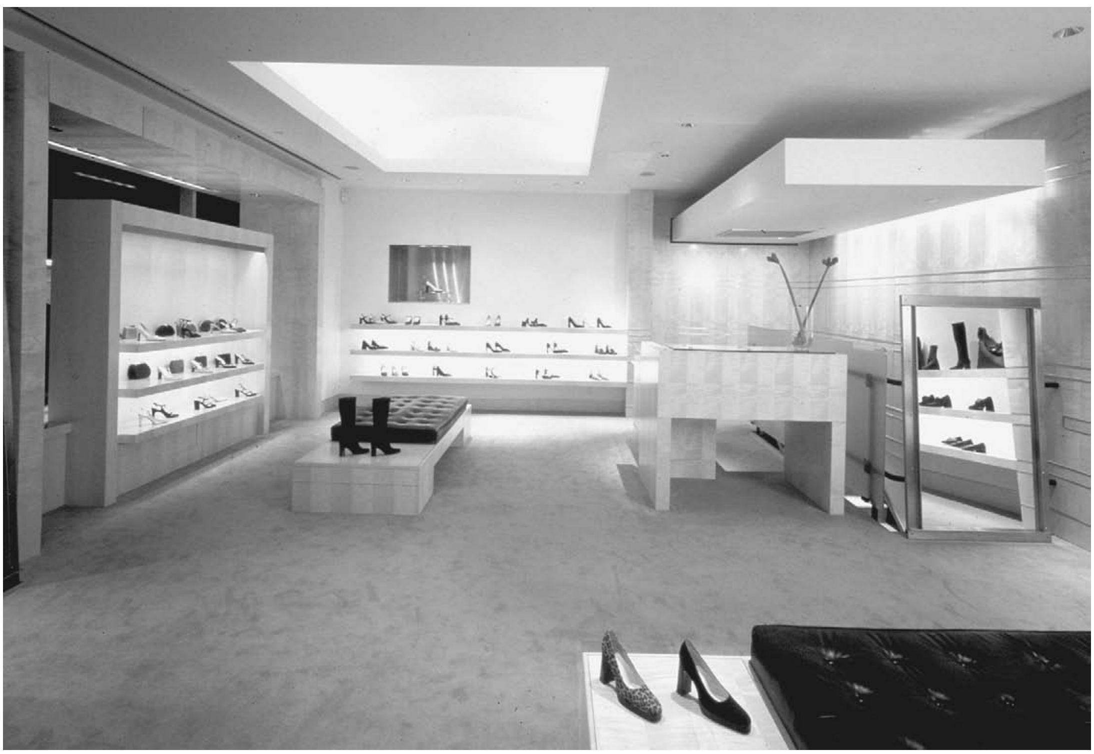

Figure 13.29 When lighted walls are distant from each other in a low-ceilinged space, downlighting addded to the center provides balance of brightness.

Some lighting patterns affect personal orientation and understanding of a room's surfaces and objects. Object-lighting and shelf-lighting influence attention and consciousness (figure 13.29); wall-lighting and corner-lighting enhance understanding of room size and shape (figure 13.30). Together, the resulting balance of brightness establishes or modifies our sense of enclosure.

Other lighting patterns involve the communication of ideas and impressions of activity setting or mood. Because the eye is involuntarily drawn to bright objects or to areas that contrast with the background, high-contrast settings are effective at directing attention and interest to selected detail while de-emphasizing other objects, areas, or surfaces (figure 13.31).

When the balance of brightness is purposefully established, designers provide an appropriate background for the intended activity or more: the purposeful manipulation of light can delight, enchant, and command attention (figure 13.32).

An Example

In a restaurant, if the lighting system is designed to illuminate horizontal surfaces, such as tabletops, while de-emphasizing the architecture, people and activities become

Figure 13.30 Wall-lighting and corner-lighting enhance understanding of room size and shape.

Figure 13.31 High contrast lighting is effective at directing attention and interest.

Figure 13.32 The purposeful manipulation of light can enchant and command attention.

the dominant feature. This lighting condition increases awareness of nearby detail, people, and movement, and encourages conviviality among patrons. The architecture will appear as a neutral or subordinate visual influence (figure 13.33).

The architectural environment, however, is interpreted by illuminating vertical and overhead surfaces. When lighting focuses the visual emphasis on these peripheral surfaces, the intensity of illumination on the tabletops is reduced; objects and people in the center fall into silhouette. Activity is then visually subordinate to the general space, inducing a more intimate atmosphere in which individuals feel a sense of privacy or anonymity (figure 13.34).

Successful restaurant design is the balance of the two: a convivial atmosphere in which one feels a sense of intimacy and privacy, where other guests at other tables become the background, and where your table is the most important one in the room (figure 13.35).

Luminance Ratios

In offices, controlling the luminance variations within limits ensures good visibility. Within these limits, variation is desirable and will make the office environment more pleasing. Luminance differences are specified in terms of the ratio between one luminance and the other (figure 13.36).

It is undesirable to maintain these ratios throughout the entire environment, however. For visual interest and distant eye focus (required for eye muscle relaxation periodically throughout the day), small areas that

Figure 13.33 When the lighting system illuminates horizontal surfaces, people and activities become dominant.

Figure 13.34 When the lighting system illuminates vertical and overhead surfaces, the architecture becomes dominant.

Figure 13.35 When the lighting system illuminates both horizontal and vertical surfaces, the brightness is balanced.

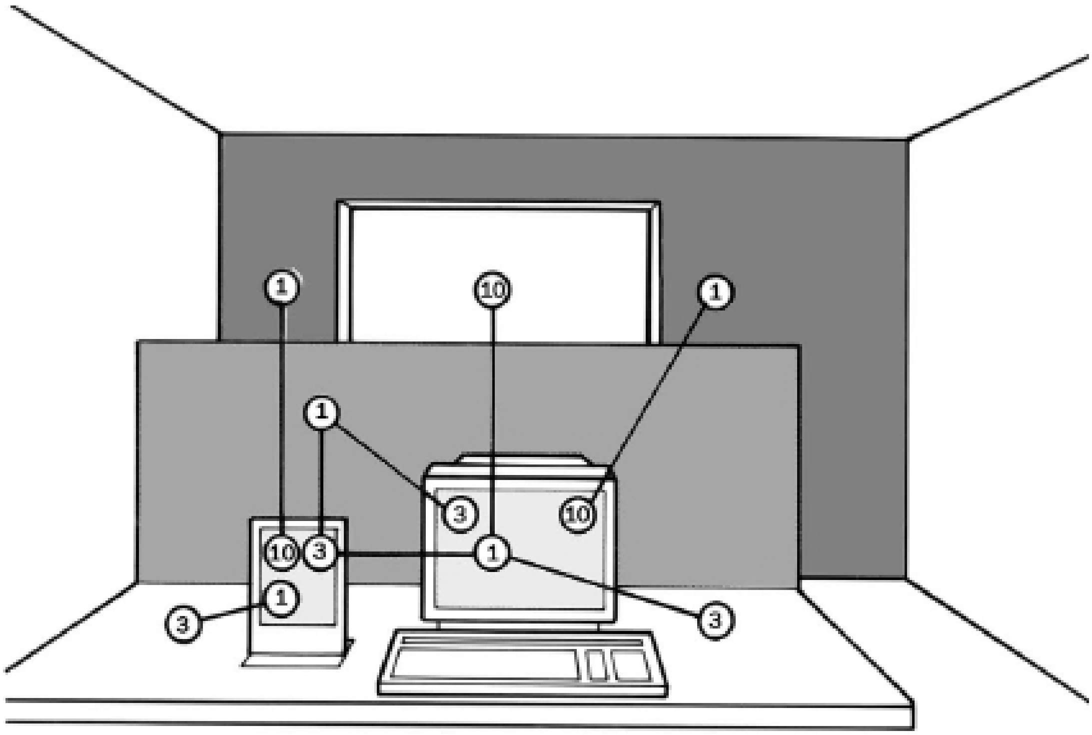

Figure 13.36 Maximum luminance ratios recommended for a VDT workstation.

exceed the luminance ratio recommendations are advantageous. These include artwork, accent finishes on walls or floors, accent finishes on chairs and accessories, and focal lighting.

The perception of brightness depends on surface reflectance as much as it does on illuminance. Consideration of surface finish reflectances is just as important as the lighting design.

Shadows

Lighting design includes shadows as well as light. Just as musicians make sounds to capture silence and architects develop complex shapes to envelop empty space, lighting designers illuminate with shadows (figure 13.37).

Light and dark are not antagonistic to each other. They are counterparts, like the yin and yang of Chinese cosmology that combine to produce all that comes to be. Without shade or darkness, light loses much of its meaning; patterns of light and shade render the prominences of surfaces and objects in the visual field (figure 13.38).

Again, three-dimensional form is perceived as a relationship of light and shadow. If a projecting corner formed by the meeting of two white planes is lighted so that the two sides look equally bright, the eye can no longer discern the edge of the corner. You may still recognize it because of the binocular function of your eyes or because you can see where the two planes intersect other planes. But you have lost an essential means of seeing that there is a corner.

It will not help to increase the light equally on both sides. If the light on one side is reduced to produce a marked difference in

Figure 13.37 Lighting design includes shadows as well as light.

the two planes, however, the corner becomes evident, even if the total intensity of light has decreased.

Only with shadows, then, can much of light be appreciated. Just as a good listener appreciates conversation by its pauses, we can appreciate light by its shadows.

ENERGY-EFFECTIVE DESIGN

Successful lighting design is *energy-effective* design. It uses the available watts to supply light where it is needed, when it is needed, and limits light from where it is unwanted (figure 13.39). Energy-effective design includes both careful control of light and careful control of brightness. It means making every watt count (figure 13.40).

Energy efficiency and lighting quality have sometimes been considered conflicting design objectives. Energy limits are just one of the many design constraints that designers face. Design means working within project parameters, whether they are space limitations, fixed budgets, time constraints, color palettes, or connected lighting power limits (figure 13.41).

Within a given power budget, the designer has unlimited freedom. Distributing light on room surfaces and objects in a way that facilitates orientation, aids perception,

Figure 13.38 Patterns of light and shade render the prominences of surfaces and objects in the visual field.

Figure 13.39 Energy-effective design uses the available watts to supply light where it is needed.

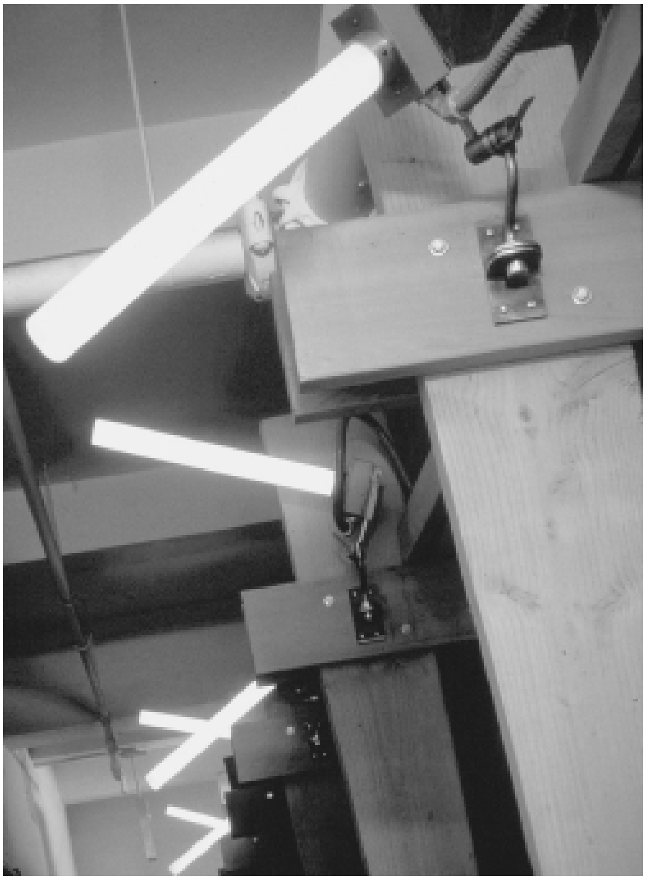

Figure 13.40 Energy-effective design includes careful control of light and brightness.

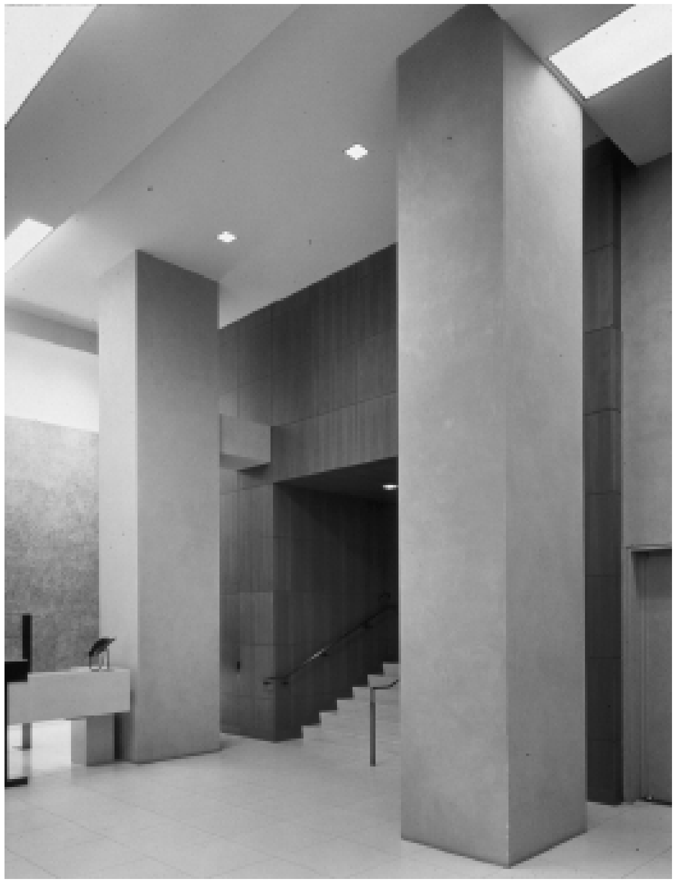

Figure 13.41 Design means working within the project parameters

and supports activities, is another way of saying that limited lighting watts are being distributed in the most effective way (figure 13.42). Stringent energy codes simply require more careful design to establish visually satisfying environments that also meet regulatory requirements.

INTEGRATING LIGHT AND ARCHITECTURE

To be successful, lighting design is integrated into the fabric of the architecture. It integrates the lighting concept with the architectural one (figure 13.43); it integrates the technology that produces light with the mechanical and structural systems that erect the building (figure 13.44). The objective is to use modern lighting techniques in a manner sympathetic to, and expressive of, the spirit of the architectural concept (figure 13.45).

When light and architecture are integrated, we are not aware of the mechanics of light production—only of a comfortable environment that encourages productivity and enhances well-being. Because light influences our sense of well-being, we are ultimately concerned with not only the quality of light, but the quality of life.

Figure 13.42 Limited lighting watts distributed in an effective way.

Figure 13.43 Integrating the lighting concept with the architectural concept.

Figure 13.44 Integrating the lighting technology with the mechanical and structural systems.

Figure 13.45 Modern lighting techniques used in a manner sympathetic to and expressive of the spirit of the architectural concept

Appendix

TABLE 1

TYPICAL COLOR RENDERING INDICES

Lamp Description	Color Rendering Index (CRI)	Color Temperature in Kelvin (K)
Incandescent and Tungsten-Halogen		
Incandescent	100	2800
Light blue incandescent	100	4000
Daylight incandescent	100	5000
Tungsten-halogen	100	3100
Tungsten-halogen with light blue filter	100	4000
Tungsten-halogen with blue filter	100	5000
Fluorescent		
Cool white	62	4100
Cool white deluxe	89	4100
Warm white	53	3000
Warm white deluxe	85	3000
Natural	90	3700
Lite white	51	4200
Daylight	79	6500
Daylight Deluxe	84	6500
Cool green	70	6450
RE–730	70–79	3000
RE–735	70–79	3500
RE–741	70–79	4100
RE–750	70–79	5000
RE–830	80–89	3000
RE–835	80–89	3500
RE–841	80–89	4100
RE–850	80–89	5000
RE–930	95	3000
RE–950	98	5000
Chroma 50	92	5000
Chroma 75	95	7500
T8/ADV/830	80–89	3000
T8/ADV/835	80–89	3500

Lamp Description	Color Rendering Index (CRI)	Color Temperature in Kelvin (K)
T8/ADV/841	80–89	4100
T8/ADV/850	80–89	5000
T12/ADV/830	82	3000
T12/ADV/835	82	3500
T12/ADV/841	82	4100
T12/ADV/850	82	5000
High-Intensity Discharge		
Standard mercury	20	5900
Mercury deluxe white	45	3900
Standard metal halide	65	4000
Standard coated metal halide	70	3800
Cool ceramic metal halide (39-70 W)	92	4000
Cool ceramic metal halide (100-400 W)	93	4000
Warm ceramic metal halide (39-70 W)	82	3000
Warm ceramic metal halide (100 W)	85	3000
Combined metal halide/HPS	90	4000
Standard high-pressure sodium	22	2000
Deluxe high-pressure sodium	65	2200
White high-pressure sodium	85	2700
Low-pressure sodium	0	1700

TABLE 2

INCANDESCENT LAMP DESIGNATIONS AND PROPERTIES

ANSI Lamp Designation	Design Volts	Watts	Design Life (Hrs.)	Initial Candle-power	Beam-Spread 50%	Beam-Spread 10%	Notes
Aluminum reflector (AR) lamps							
15ALR18/NSP6 (GBA)	6	15	2,000	5,200	6°	—	
15ALR18/SP14 (GBC)	6	15	2,000	1,900	14°	—	
20ALR12/NSP6 (GBD)	12	20	2,000	6,400	6°	—	
20ALR12/SP18 (GBE)	12	20	2,000	1,000	18°	—	
20ALR12/FL34 (GBF)	12	20	2,000	350	34°	—	
						—	
50ALR18/SP10 (GBJ)	12	50	2,000	12,000	10°	—	
50ALR18/NFL22 (GBK)	12	50	2,000	2,000	22°	—	
						—	
20AR70/SP8	12	20	3,000	7,700	8°	—	Filament shield
20AR70/FL25	12	20	3,000	900	25°	—	Filament shield
50AR70/SP8	12	50	3,000	12,500	8°	—	Filament shield
50AR70/FL25	12	50	3,000	2,600	25°	—	Filament shield
35AR111/SSP4/6V	6	35	3,000	30,000	4°	—	Filament shield
35AR111/SSP4	12	35	3,000	45,000	4°	—	Filament shield
35AR111/SP8	12	35	3,000	14,000	8°	—	Filament shield
35AR111/FL25	12	35	3,000	2,500	25°	—	Filament shield
50AR111/SSP4	12	50	3,000	50,000	4°	—	Filament shield
50AR111/SP8	12	50	3,000	20,000	8°	—	Filament shield
50AR111/FL25	12	50	3,000	3,500	25°	—	Filament shield
75AR111/SP8	12	75	3,000	30,000	8°	—	Filament shield
75AR111/FL25	12	75	3,000	5,300	25°	—	Filament shield
75AR111/WFL45	12	75	3,000	1,700	45°	—	Filament shield
100AR111/SP8	12	100	3,000	48,000	8°	—	Filament shield
100AR111/FL25	12	100	3,000	8,500	25°	—	Filament shield
100AR111/WFL45	12	100	3,000	2,800	45°	—	Filament shield
Mirror-reflector (MR) lamps							
20MR11/SP10 (FTB)	12	20	4,000	5,500	10°	—	

ANSI Lamp Designation	Design Volts	Watts	Design Life (Hrs.)	Initial Candle-power	Beam-Spread 50%	Beam-Spread 10%	Notes
20MR11/SP15 (FTC)	12	20	3,500	1,760	15°	—	
20MR11/FL35 (FTD)	12	20	4,000	700	35°	—	
35MR11/SP10 (FTE)	12	35	4,000	8,500	10°	—	
35MR11/SP15 (FTF)	12	35	3,500	3,000	15°	—	
35MR11/FL40 (FTH)	12	35	4,000	1,500	40°	—	
20MR16/NSP8 (ESX)	12	20	4,000	6,000	8°	—	
20MR16/FL40 (BAB)	12	20	4,000	700	40°	59°	
20MR16/VWFL60	12	20	4,000	350	60°	—	
20MR16/IR/SP8	12	20	5,000	6,500	8°	—	IR-reflecting
20MR16/IR/FL36	12	20	5,000	1,000	36°	—	IR-reflecting
35MR16/NSP8 (FRB)	12	35	4,000	11,000	10°	—	
35MR16/SP20 (FRA)	12	35	4,000	2,800	20°	—	
35MR16/FL40 (FMW)	12	35	4,000	1,400	40°	—	
35MR16/VWFL60	12	20	4,000	650	60°	—	
35MR16/IR/SP8	12	35	5,000	14,000	8°	—	IR-reflecting
35MR16/IR/NFL24	12	35	5,000	4,400	24°	—	IR-reflecting
35MR16/IR/FL36	12	35	5,000	2,200	36°	—	IR-reflecting
35MR16/IR/WFL60	12	35	5,000	1,050	60°	—	IR-reflecting
37MR16/IR/SP10	12	37	4,000	13,100	10°	—	IR-reflecting
37MR16/IR/NFL25	12	37	4,000	4,600	25°	—	IR-reflecting
37MR16/IR/FL40	12	37	4,000	2,500	40°	—	IR-reflecting
45MR16/IR/SP8	12	45	5,000	16,000	8°	—	IR-reflecting
45MR16/IR/NFL24	12	45	5,000	5,450	24°	—	IR-reflecting
45MR16/IR/FL36	12	45	5,000	2,850	36°	—	IR-reflecting
45MR16/IR/WFL60	12	45	5,000	1,300	60°	—	IR-reflecting
50MR16/NSP10 (EXT)	12	50	4,000	11,500	10°	24°	
50MR16/NFL25 (EXZ)	12	50	4,000	3,200	27°	49°	
50MR16/NFL30 (EXK)	12	50	4,000	2,500	32°	52°	
50MR16/FL40 (EXN)	12	50	4,000	2,000	40°	64°	
50MR16/WFL60 (FNV)	12	50	4,000	1,000	60°	—	
50MR16/IR/SP10	12	50	4,000	15,700	10°	—	IR-reflecting
50MR16/IR/NFL25	12	50	4,000	6,000	25°	—	IR-reflecting
50MR16/IR/FL40	12	50	4,000	3,000	40°	—	IR-reflecting
65MR16/NSP10 (FPA)	12	65	4,000	14,000	10°	—	

ANSI Lamp Designation	Design Volts	Watts	Design Life (Hrs.)	Initial Candle-power	Beam-Spread 50%	Beam-Spread 10%	Notes
65MR16/NFL25	12	65	4,000	4,000	25°	—	
65MR16/FL40 (FPB)	12	65	4,000	2,100	40°	—	
65MR16/VWFL60	12	65	4,000	1,050	60°	—	
71MR16/NSP15 (EYF)	12	71	4,000	11,500	15°	—	
71MR16/NFL25 (EYJ)	12	71	4,000	5,500	25°	—	
71MR16/FL40 (EYC)	12	71	4,000	2,200	40°	—	
75MR16/SP10 (EYF)	12	75	4,000	14,000	10°	—	
75MR16/FL36 (EYC)	12	75	4,000	2,500	36°	—	
Parabolic aluminum reflector (PAR) lamps							
35PAR14/H/FL	120	35	2,000	85	50°	—	
45PAR16/H/NSP10	120	45	2,000	5,000	10°	—	
45PAR16/H/NFL27	120	45	2,000	1,400	27°	—	
50PAR16/H/FL40	120	50	2,000	800	40°	—	
60PAR16/H/NSP10	120	60	2,000	5,700	10°	—	
60PAR16/H/NFL27	120	60	2,000	2,000	27°	—	
75PAR16/H/NSP10	120	75	2,000	7,500	10°	—	
75PAR16/H/NFL30	120	75	2,000	1,900	30°	—	
35PAR20/H/NSP10	120	35	2,500	3,000	10°	—	
35PAR20/H/NFL30	120	35	2,500	800	30°	—	
35PAR20/H/WFL40	120	35	2,500	500	40°	—	
50PAR20/H/NSP9	120	50	2,000	6,200	9°	—	
50PAR20/H/SP16	120	50	2,000	3,200	16°	—	
50PAR20/H/NFL30	120	50	2,000	1,400	30°	—	
50PAR20/H/WFL40	120	50	2,500	900	40°	—	
35PAR30L/H/NSP9	120	35	2,500	5,700	9°	—	
35PAR30L/H/WFL50	120	35	2,500	450	50°	—	
45PAR30/HIR/SP9XL	120	45	6,000	9,750	9°	—	IR-reflecting
45PAR30/HIR/FL25XL	120	45	6,000	2,025	25°	—	IR-reflecting
45PAR30/HIR/FL35XL	120	45	6,000	1,125	35°	—	IR-reflecting
50PAR30/H/NSP10	120	50	3,000	8,250	10°	—	
50PAR30/H/NFL30	120	50	2,000	1,950	30°	—	

ANSI Lamp Designation	Design Volts	Watts	Design Life (Hrs.)	Initial Candle-power	Beam-Spread 50%	Beam-Spread 10%	Notes
50PAR30/H/FL40	120	50	2,000	1,500	40°	—	
50PAR30/HIR/NSP9	120	50	3,000	13,000	9°	—	IR-reflecting
50PAR30/HIR/NFL25	120	50	3,000	2,900	25°	—	IR-reflecting
50PAR30/HIR/FL35	120	50	3,000	1,500	35°	—	IR-reflecting
50PAR30L/H/NSP9	120	50	2,000	8,800	9°	—	
50PAR30L/H/SP16	120	50	2,000	4,200	16°	—	
50PAR30L/H/NFL30	120	50	2,000	1,900	30°	—	
50PAR30L/H/FL40	120	50	2,000	1,250	40°	—	
50PAR30L/H/WFL60	120	50	2,000	550	60°	—	
60PAR30/H/NSP10	120	60	2,500	10,000	10°	—	
60PAR30/H/NFL30	120	60	2,500	2,800	30°	—	
60PAR30/H/FL40	120	60	2,500	1,850	40°	—	
75PAR30/H/NSP10	120	75	2,000	15,400	10°	—	
75PAR30/H/NFL25	120	75	2,000	3,100	27°	—	
75PAR30/H/FL35	120	75	2,000	2,000	35°	—	
75PAR30L/H/NSP9	120	75	2,000	15,400	9°	—	
75PAR30L/H/SP16	120	75	2,000	6,700	16°	—	
75PAR30L/H/NFL30	120	75	2,000	3,400	30°	—	
75PAR30L/H/FL40	120	75	2,000	2,200	40°	—	
75PAR30L/H/WFL60	120	75	2,500	1,100	50°	—	
25PAR36/VNSP5	6	25	1,000	19,700	—	5.5° × 4.5°	Filament shield
25PAR36/NSP9	12	25	2,000	2,600	10° × 8°	19° × 17°	Filament shield
25PAR36/WFL30	12	25	2,000	360	37° × 26°	49° × 41°	Filament shield
25PAR36/VWFL55	12	25	2,000	160	55°	—	Filament shield
35PAR36/H/VNSP5	12	35	4,000	25,000	5°	—	
35PAR36/H/NSP8	12	35	4,000	20,000	8°	—	
35PAR36/H/WFL30	12	35	4,000	900	25° × 35°	—	
36PAR36/H/VNSP5	12	36	4,000	17,000	5°	—	
36PAR36/H/NSP13	12	36	4,000	3,500	13°	—	
36PAR36/H/WFL32	12	36	4,000	1,000	32°	—	
50PAR36/NSP6	12	50	4,000	25,000	6°	—	Filament shield
50PAR36/NSP10	12	50	2,000	1,100	10°	20° × 17°	Filament shield
50PAR36/WFL35	12	50	2,000	1,300	37° × 27°	48° × 41°	Filament shield
50PAR36/VWFL55	12	50	2,000	1,100	55°	80° × 80°	Filament shield

ANSI Lamp Designation	Design Volts	Watts	Design Life (Hrs.)	Initial Candle-power	Beam-Spread 50%	Beam-Spread 10%	Notes
50PAR36/H/NSP5	12	50	4,000	35,000	5°	—	
50PAR36/H/NSP8	12	50	4,000	30,000	8°	—	
50PAR36/H/WFL30	12	50	4,000	1,300	25° × 35°	—	
45PAR38/H/NSP9	120	45	2,500	10,000	9°	—	
45PAR38/H/SP11	120	45	2,500	8,800	11°	—	
45PAR38/H/FL30	120	45	2,500	1,500	32°	—	
45PAR38/HIR/SP12XL	120	45	6,000	4,000	12°	—	IR-reflecting
45PAR38/HIR/FL40XL	120	45	6,000	1,100	40°	—	IR-reflecting
50PAR38/HIR/SP6	120	50	3,000	20,000	6°	—	IR-reflecting
50PAR38/HIR/SP9	120	50	3,000	14,000	9°	—	IR-reflecting
50PAR38/HIR/S/SP10	120	50	4,000	14,000	10°	—	IR, silverized reflector
50PAR38/HIR/S/FL25	120	50	4,000	3,000	25°	—	IR, silverized reflector
55PAR38/HIR/SP12XL	120	55	6,000	9,000	12°	—	IR-reflecting
55PAR38/HIR/FL40XL	120	55	6,000	2,000	40°	—	IR-reflecting
60PAR38/HIR/SP10	120	60	3,000	20,000	10°	—	IR-reflecting
60PAR38/HIR/SP12	120	60	3,000	12,000	12°	—	IR-reflecting
60PAR38/HIR/S/SP12	120	60	4,000	20,000	12°	—	IR, silverized reflector
60PAR38/HIR/FL30	120	60	3,000	3,600	29°	—	IR-reflecting
60PAR38/HIR/FL40	120	60	3,000	2,000	40°	—	IR-reflecting
60PAR38/HIR/WFL55	120	60	3,000	1,250	53°	—	IR-reflecting
70PAR38/HIR/SP10	120	70	3,000	16,000	10°	—	IR-reflecting
70PAR38/HIR/FL25	120	70	3,000	4,600	25°	—	IR-reflecting
75PAR38/H/NSP8	120	75	2,500	18,400	8°	—	
75PAR38/H/NFL25	120	75	2,500	4,000	26°	—	
80PAR38/HIR/SP10	120	80	3,000	25,000	10°	—	IR-reflecting
80PAR38/HIR/SP12	120	80	3,000	19,000	12°	—	IR-reflecting
80PAR38/HIR/SP25	120	80	3,000	5,500	25°	—	IR-reflecting
90PAR38/H/SP10	120	90	2,000	18,500	12°	—	
90PAR38/H/NFL25	120	90	2,000	4,000	25°	—	
90PAR38/H/3WSP12	120	90	2,500	14,300	12°		Side-prong base
90PAR38/H/3FL30	120	90	2,500	3,500	30°		Side-prong base
90PAR38/CB/H/FL25	120	90	2,500	4,100	25°		Cool-beam

ANSI Lamp Designation	Design Volts	Watts	Design Life (Hrs.)	Initial Candle-power	Beam-Spread 50%	Beam-Spread 10%	Notes
90PAR38/HIR/SP12XL	120	90	6,000	12,000	12°	—	IR-reflecting
90PAR38/HIR/FL40XL	120	90	6,000	2,800	40°	—	IR-reflecting
100PAR38/H/SP10	120	90	2,000	17,000	10°		
100PAR38/H/FL25	120	90	2,000	4,800	25°		
100PAR38/HIR/SP10	120	100	3,000	29,000	10°	—	IR-reflecting
100PAR38/HIR/FL25	120	100	3,000	6,300	25°	—	IR-reflecting
100PAR38/HIR/FL40	120	100	3,000	3,400	40°	—	IR-reflecting
120PAR38/3SP	120	120	2,000	9,200	18°		Side-prong base
120PAR38/3FL	120	120	2,000	3,600	30°		Side-prong base
120PAR38/H/SP10	120	120	3,000	22,500	10°	—	
120PAR38/H/NFL25	120	120	3,000	7,700	25°		
120PAR38/H/FL30	120	120	3,000	4,600	30°	—	
120PAR38/H/WFL55	120	120	3,000	2,000	55°	—	
150PAR38/2FL	120	120	2,000	3,400	24°	60°	Cool-beam
150PAR38/3SP	120	120	2,000	10,500	12°	30°	Side-prong base
150PAR38/3FL	120	120	2,000	3,400	24°	60°	Side-prong base
Q250PAR38/SP10	120	250	4,500	46,500	11°	—	
Q250PAR38/FL30	120	250	4,500	9,000	22°	—	
25PAR46/NSP5	6	25	1,000	55,000	—	5.5° × 4.5°	Filament shield
150PAR46/3MFL	125	150	2,000	8,000	26° × 13°	39° × 25°	Side-prong base
200PAR46/3NSP	120	200	2,000	31,000	12° × 8°	23° × 19°	Side-prong base
200PAR46/3MFL	120	200	2,000	11,500	27° × 13°	40° × 24°	Side-prong base
120PAR56/VNSP	12	120	2,000	60,000	8° × 6°	15° × 10°	
120PAR56/MFL	12	120	2,000	19,000	18° × 9°	29° × 15°	
120PAR56/WFL	12	120	2,000	5,625	35° × 18°	50° × 25°	
200PAR56/MFL	120	200	2,000	15,000	22° × 13°	34° × 22°	
240PAR56/VNSP	12	240	2,000	140,000	90° × 6°	17° × 10°	
240PAR56/MFL	12	240	2,000	46,000	19° × 8°	28° × 15°	
240PAR56/WFL	12	240	2,000	13,000	35° × 18°	50° × 27°	
300PAR56/NSP	120	300	2,000	68,000	10° × 8°	20° × 14°	
300PAR56/MFL	120	300	2,000	24,000	23° × 11°	34° × 19°	
300PAR56/WFL	120	300	2,000	11,000	37° × 18°	57° × 27°	
Q500PAR56/NSP	120	500	4,000	96,000	13° × 8°	32° × 15°	

ANSI Lamp Designation	Design Volts	Watts	Design Life (Hrs.)	Initial Candle-power	Beam-Spread 50%	Beam-Spread 10%	Notes
Q500PAR56/MFL	120	500	4,000	43,000	26° × 10°	42° × 20°	
Q500PAR56/WFL	120	500	4,000	19,000	44° × 20°	66° × 34°	
500PAR64/NSP	120	500	2,000	110,000	12° × 7°	19° × 14°	
500PAR64/MFL	120	500	2,000	45,000	9° × 25°	35° × 19°	
500PAR64/WFL	120	500	2,000	10,500	20° × 55°	55° × 32°	
Q1000PAR64/NSP	120	1,000	4,000	135,000	8° × 20°	31° × 14°	
Q1000PAR64/MFL	120	1,000	4,000	82,000	10° × 30°	45° × 22°	
Q1000PAR64/WFL	120	1,000	4,000	23,000	20° × 60°	72° × 45°	
Reflector (R) lamps							
15R14SC/SP	12	15	2,000	135	14°	—	Single contact base
25R14SC/SP15	12	25	2,000	1,200	16°	32°	Single contact base
25R14SC/FL35	12	25	2,000	200	36°	102°	Single contact base
25R14/WFL60	120	25	1,500	150	60°	120°	
50BR19/25/SP	120	50	2,000	—	25°	—	
30R20/FL40	120	30	2,000	300	38°	—	
50R20/FL40	120	50	2,000	550	38°	—	
75R20/FL120	120	75	2,000	800	—	120°	
100BR25/25	120	100	2,000	—	25°	—	
65BR30/SP20	120	65	2,000	1,625	20°	—	
65BR30/SP20XL	120	65	2,500	1,575	20°	—	
65BR30/FL55	120	65	2,000	525	55°	—	
65BR30/FL55XL	120	65	2,500	510	55°	—	
85BR30/SP20	120	85	2,000	3,100	20°	—	
85BR30/FL55	120	85	2,000	700	55°	—	
65BR40/FL60	120	65	2,000	500	60°	—	
85BR40/SP20	120	85	2,000	3,100	20°	—	
85BR40/FL60	120	85	2,000	700	60°	—	

ANSI Lamp Designation	Design Volts	Watts	Design Life (Hrs.)	Initial Candle-power	Beam-Spread 50%	Beam-Spread 10%	Notes
120BR40/SP20	120	120	2,000	4,600	20°	—	
120BR40/FL60	120	120	2,000	1,000	60°	—	
300R40/SP40	120	300	2,000	14,000	40°	—	
300R40/FL120	120	300	2,000	2,900	120°	—	
Elliptical reflector (ER) lamps							
50ER30/FL30	120	50	2,000	1,300	28°	70°	
75ER30/FL30	120	75	2,000	1,800	28°	70°	
120ER30/FL30	120	120	2,000	2,900	28°	70°	

TABLE 3

FLUORESCENT LAMP DESIGNATIONS AND PROPERTIES

Lamp Description	Designation	Impres-sion	Light Output (%)	Color Temper-ature in Kelvin (K)	Color Render-ing Index (CRI)	Life (Hours)	Initial Lumens	Mean Lumens
Cool white	CW	Cool	100	4100	62	20,000+	3,050	2,650
Cool white deluxe	CWX	Cool	72	4100	89	20,000+	2,200	1,800
Warm white	WW	Warm	102	3000	52	20,000+	3,100	2,700
Warm white deluxe	WWX	Warm	68	2800	77	20,000+	2,200	1,805
Soft white	SW	Warm	68	3000	79	20,000+	2,150	1,800
Natural	N	Neutral	69	3700	90	20,000+	2,100	1,870
Lite white	LW	Cool	102	4200	51	20,000+	3,050	2,650
Daylight	D	Daylight	83	6500	79	20,000+	2,600	2,250
Daylight Deluxe	DX	Daylight	76	6500	84	20,000+	2,300	2,000
RE–730	730	Warm	105	3000	70	20,000+	3,200	2,880
RE–735	735	Neutral	105	3500	73	20,000+	3,200	2,880
RE–741	741	Cool	105	4100	70	20,000+	3,200	2,880
RE–750	750	Daylight	90	5000	76	20,000+	3,200	2,880
RE–830	830	Warm	108	3000	85	20,000+	3,300	2,970
RE–835	835	Neutral	108	3500	85	20,000+	3,300	2,970
RE–841	841	Cool	108	4100	85	20,000+	3,300	2,970
RE–850	850	Daylight	93	5000	85	20,000+	3,280	2,950
RE–930	930	Warm	66	3000	95	20,000+	2,100	1,870
RE–950	950	Daylight	66	5000	98	20,000+	2,100	1,870
Chroma 50	C50	Daylight	72	5000	92	20,000+	2,200	1,915
Chroma 75	C75	Daylight	66	7500	95	20,000+	2,000	1,720
T8/ADV/830	ADV830	Warm	105	3000	86	20,000+	3,300	2,970
T8/ADV/835	ADV835	Neutral	105	3500	86	20,000+	3,300	2,970
T8/ADV/841	ADV841	Cool	105	4100	86	20,000+	3,300	2,970
T8/ADV/850	ADV850	Daylight	105	5000	86	20,000+	3,300	2,970
T12/ADV/830	ADV30	Warm	118	3000	82	20,000+	3,600	3,100
T12/ADV/835	ADV35	Neutral	118	3500	82	20,000+	3,600	3,100
T12/ADV/841	ADV41	Cool	118	4100	82	20,000+	3,600	3,100
T12/ADV/850	ADV50	Daylight	118	5000	82	20,000+	3,600	3,100
Red	R	—	6	—	—	20,000+	195	60
Pink	PK	—	35	—	—	20,000+	1,160	695
Gold	GO	—	60	—	—	20,000+	2,400	1,765
Green	G	—	140	—	—	20,000+	4,400	2,200
Blue	B	—	35	—	—	20,000+	1,200	720

TABLE 4

EFFICACY OF ELECTRIC LIGHT SOURCES

Lamp Type	Wattage Range	Initial Lamp Efficacy (Lumens per watt)	Color Temperature in Kelvin (K)	Color Rendering Index (CRI)	Design Life (Hours)
Incandescent	6–1,500	4–24.5	2700–2800	100	750–4,000
Tungsten-halogen	5–1,500	10–22	2900–3100	100	1,000–6,000
Fluorescent	4–215	10–104.5	2700–7500	53–95	6,000–24,000+
Compact fluorescent	5–80	28–76	2700–4100	81–82	6,000–14,000
Mercury vapor	40–1,000	19–59	3300–5900	15–52	12,000–24,000+
Metal halide	32–1,500	35–100	3000–4400	65–96	3,000–20,000
High-pressure sodium	33–1,000	31–127	1800–2800	22–85	7,500–24,000+
Low-pressure sodium	18–180	58–185	1740–1750	0	14,000–18,000

TABLE 5

COMPARATIVE LUMINANCE OF INCANDESCENT AND FLUORESCENT LAMPS (APPROXIMATE CANDELAS PER SQUARE INCH)

Lamp Description	Shape	Characteristics	Luminance (cd/sq in)
	Incandescent		
150 W	A21	(IF)	150.0
	Fluorescent		
Preheat			
8 W	T5	(12")	8.1
15 W	T8	(18")	6.7
15 W	T12	(18")	4.1
20 W	T12	(24")	4.6
Rapid Start			
30 W	T12	(36")	5.3
32 W	T8	(48")	7.4
40 W	T8	(60")	7 4
40 W	T12	(48")	5.4
40 W	T12	(48" ES)	4.7
40 W	T12	(22 7/16" U-bent)	5.0
High Output			
24"	T12	(35 W)	6.1
48"	T12	(60 W)	7.3
72"	T12	(85 W)	7.3
96"	T12	(110 W)	7.3
96"	T12	(95 W ES)	6.6
Very High Output			
48"	T12	(116 W)	12.0
72"	T12	(162 W)	12.0
96"	T12	(212 W)	12.0
96"	T12	(185 W ES)	11.2
Instant Start			
40 W	T12	(48")	5.3
40 W	T12	(60")	2.3
Slimline			
42"	T8	(23 W)	5.3
64"	T8	(35 W)	5.3

Lamp Description	Shape	Characteristics	Luminance (cd/sq in)
72"	T8	(37.5 W)	5.0
96"	T8	(50 W)	5.0
48"	T12	(38.5 W)	5.0
72"	T12	(56 W)	5.0
96"	T12	(75 W)	5.0
96"	T12	(60W ES)	4.5
Circline			
20 W	T9	(6½” dia.)	5.9
22 W	T9	(8¼" dia.)	5.2
32 W	T9	(12" dia.)	4.8
40 W	T9	(16" dia.)	4.8

TABLE 6

RELATIVE OUTPUT OF COLORED LAMPS

Lamp Color Description	Light Output (%)	Lamp Color Description	Light Output (%)
Incandescent—tinted lamps		**Fluorescent**	
Clear	100	Cool white	100
White	85	Cool white deluxe	72
Ivory	73	Warm white	102
Flame tint	58	Warm white deluxe	72
Rose	35	Natural	69
Red	5	Lite white	104
Orange	35	Daylight	85
Yellow	65	Daylight Deluxe	76
Green	5	RE-730	93
Blue	3	RE-735	93
		RE-741	93
Incandescent—sign lamps		RE-750	90
Clear	100	RE-830	98
White	85	RE-835	98
Ivory	73	RE-841	98
Flame tint	58	RE-850	97
Rose	35	RE-930	66
Red	5	RE-950	66
Orange	35	Chroma 50	72
Yellow	65	Chroma 75	66
Green	5	T8/ADV/830	105
Blue	3	T8/ADV/835	105
		T8/ADV/841	105
Lumiline lamps		T8/ADV/850	105
Clear	100	T12/ADV/830	118
White	85	T12/ADV/835	118
		T12/ADV/841	118
		T12/ADV/850	118
		Blue	39
		Gold	79
		Red	6
		Pink	45
		Green	160
		Deep blue	17

TABLE 7

RELATIVE LAMP WATTS FOR APPROXIMATE EQUAL QUANTITY OF LIGHT

Filament (clear color)	30 W	Clear
	60 W	Pink
	90 W	Blue-white
	200 W	Red
	90 W	Amber
	36 W	Yellow or gold
	300 W	Green
	300 W	Blue
Filament (diffuse color)	30 W	Silica coat
	39 W	Pink tint
	36 W	Gold tint
	60 W	Green tint
	75 W	Blue tint
Fluorescent	10 W	Cool white
	22 W	Pink
	165 W	Red
	13 W	Yellow or gold
	11 W	Yellow-green
	6 W	Green
	22 W	Blue
	65 W	Deep blue

TABLE 8

RELATIVE BRIGHTNESS FOR EQUAL ATTRACTION

White light	10
Yellow light	12
Red light	3
Green light	4
Blue light	6

TABLE 9

RECOMMENDED WIRE SIZE AND SECONDARY WIRE LENGTH FOR LIGHTING CIRCUITS USING 120 V PRIMARY/12 V SECONDARY TRANSFORMERS

Wire Size (Gauge)	Watts (VA) per Circuit																								
	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500
	Maximum Secondary Wire Length in Feet																								
14	75	37	25	19	15	12	11	9	8	7	7	6	6	5	5	5	4	4	4	4	4	3	3	3	3
12	118	59	39	30	24	20	17	15	13	12	11	10	9	8	8	7	7	7	6	6	6	5	5	5	5
10	188	94	63	47	38	31	27	24	21	19	17	16	14	13	13	12	11	10	10	9	9	9	8	8	8
8	299	149	100	75	60	50	43	37	33	30	27	25	23	21	20	19	18	17	16	15	14	14	13	12	12
6	476	238	159	119	95	79	68	60	53	48	43	40	37	34	32	30	28	26	25	24	23	22	21	20	19

This chart is based on SPT-3 wire and a maximum 0.63 voltage drop at the end of the run.

Exceeding the maximum secondary wire lengths noted in the chart above will cause the voltage to drop along the length of the wire. Lamps positioned closer to the transformer will burn at a higher color temperature than those farther from it because the lamps nearest the transformer are receiving greater voltage than those farther away.

When dimming low-voltage loads, use dimmers designed for low-voltage magnetic loads with magnetic transformers and dimmers designed for electronic low-voltage loads with electronic transformers.

Based on the Recommended Wire Size and Voltage Drop chart from Acme Electric Corporation Catalog ATD-01. Used with permission from the Acme Electric Corporation Power Distribution Products Division.

TABLE 10

TRIGONOMETRIC FUNCTIONS: SINES AND COSINES OF ANGLES

$\theta°$	sin θ	cos θ	$\theta°$	sin θ	cos θ	$\theta°$	sin θ	cos θ	$\theta°$	sin θ	cos θ
0	0.0000	1.000	22	.375	0.927	45	.707	.707	68	.927	.375
			23	.391	.921	46	.719	.695	69	.934	.358
1	.0175	1.000	24	.407	.914	47	.731	.682	70	.940	.342
2	.0349	0.999	25	.423	.906	48	.743	.669			
3	.0523	.999	26	.438	.899	49	.755	.656	71	.946	.326
4	.0698	.998	27	.454	.891	50	.766	.643	72	.951	.309
5	.0872	.996	28	.470	.833				73	.956	.292
6	.105	.995	29	.485	.875	51	.777	.629	74	.961	.276
7	.122	.993	30	.500	.866	52	.788	.616	75	.966	.259
8	.139	.990				53	.799	.602	76	.970	.242
9	.156	.988	31	.515	.857	54	.809	.588	77	.974	.225
10	.174	.985	32	.530	.848	55	.819	.574	78	.978	.208
			33	.545	.839	56	.829	.559	79	.982	.191
11	.191	.982	34	.559	.829	57	.839	.545	80	.985	.174
12	.208	.978	35	.574	.819	58	.848	.530			
13	.225	.974	36	.588	.809	59	.857	.515	81	.988	.156
14	.242	.970	37	.602	.799	60	.866	.500	82	.990	.139
15	.259	.966	38	.616	.788				83	.993	.122
16	.276	.961	39	.629	.777	61	.875	.485	84	.995	.105
17	.292	.956	40	.643	.766	62	.883	.470	85	.996	.0872
18	.309	.951				63	.891	.454	86	.9976	.0698
19	.326	.946	41	.656	.755	64	.899	.438	87	.9986	.0523
20	.342	.940	42	.669	.743	65	.906	.423	88	.9994	.0349
			43	.682	.731	66	.914	.407	89	.9998	.0175
21	.358	.934	44	.695	.719	67	.921	.391	90	1.0000	0.0000

TABLE 11

LAMP LUMEN DEPRECIATION FACTORS

Lamp Description	Shape	Nominal Wattage	Lamp Lumen Depreciation (LLD) Factors
Incandescent			
Extended service	A, PS	15–70	0.85
General service	A, PS, S	To 40	0.85
		50–1,500	0.89
Projector	PAR 38-64	75–1,000	0.84
Reflector	R40	150–500	0.86
	R52-57	500–1,000	0.81
Rough service	A, PS	50–200	0.79
Showcase	T10	25–40	0.78
Silver-bowl	A, PS	200–500	0.75
Three-way	A, T	30–150	0.85
	PS	100–300	0.72
Tungsten-halogen	T	200–1,500	0.96
Vibration	A19	50	0.72
Fluorescent			
Cool white	T12	40	0.87
Cool white deluxe	T12	40	0.82
Warm white	T12	40	0.87
Warm white deluxe	T12	40	0.82
Natural	T12	40	0.89
Lite white	T12	40	0.87
Daylight	T12	40	0.87
Cool green	T12	40	0.82
RE-700 series	T8	40	0.90
RE-800 series	T8	25–40	0.93
	T12	30–40	0.90
Chroma 50	T12	40	0.87
Chroma 75	T12	40	0.86

Lamp Description	Shape	Nominal Wattage	Lamp Lumen Depreciation (LLD) Factors
Fluorescent, continued			
Compact, twin-tube	T4	5	0.84
Compact, twin-tube	T4	7–13	0.85
Compact, quad-tube	T4	13–26	0.85
Compact, triple-tube	T4	18–70	0.85
Compact, long twin-tube	T5	18–80	0.90
High-intensity discharge			
Standard mercury clear	E28	250	0.88
Mercury warm deluxe white	E28	250	0.81
Mercury deluxe white	E28	250	0.81
Standard clear metal halide	E28	175	0.74*
			0.69**
	BT56	1,000	0.76
Standard coated metal halide	E28	175	0.71*
			0.65**
	BT56	1,000	0.76
Ceramic metal halide	T7	150	0.89
Ceramic metal halide	T8	250	0.80
Ceramic metal halide	T6½	70	0.82
Deluxe high-pressure sodium	B17	70	0.80
White high-pressure sodium	B17	95	0.80
Low-pressure sodium	T16	55	0.87

*Vertical lamp orientation

**Horizontal lamp orientation

TABLE 12

LUMINAIRE MAINTENANCE CATEGORIES

PROCEDURE FOR DETERMINING LUMINAIRE MAINTENANCE CATEGORIES

To assist in determining luminaire dirt depreciation (LDD) factors, luminaires are separated into six maintenance categories (I through VI). To arrive at categories, luminaires are arbitrarily divided into sections—a *top enclosure* and a *bottom enclosure*—by drawing a horizontal line through the light center of the lamp or lamps. The characteristics listed for the enclosures are then selected as best describing the luminaire. Only one characteristic for the top enclosure and one for the bottom enclosure are used in determining the category of a luminaire. Percentage of uplight is based on 100% light output for the luminaire. The maintenance category is determined by the characteristics in both enclosure columns. If a luminaire falls into more than one category, the lower-numbered category is used.

Maintenance Category	Top Enclosure	Bottom Enclosure
I	1. None	1. None
II	1. None	1. None
	2. Transparent with 15% or more uplight through apertures	2. Louvers or baffles
	3. Translucent with 15% or more uplight through apertures	
	4. Opaque with 15% or more uplight through apertures	
III	1. Transparent with less than 15% upward light through apertures	1. None
	2. Translucent with less than 15% upward light through apertures	2. Louvers or baffles
	3. Opaque with less than 15% upward light through apertures	
IV	1. Transparent unapertured	1. None
	2. Translucent unapertured	2. Louvers or baffles
	3. Opaque unapertured	
V	1. Transparent unapertured	1. Transparent unapertured
	2. Translucent unapertured	2. Translucent unapertured
	3. Opaque unapertured	
VI	1. None	1. Transparent unapertured
	2. Transparent unapertured	2. Translucent unapertured
	3. Translucent unapertured	3. Opaque unapertured
	4. Opaque unapertured	

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TABLE 13

LUMINAIRE DIRT DEPRECIATION (LDD) FACTORS FOR SIX LUMINAIRE CATEGORIES (I THROUGH VI) AND FOR FIVE DEGREES OF DIRTINESS

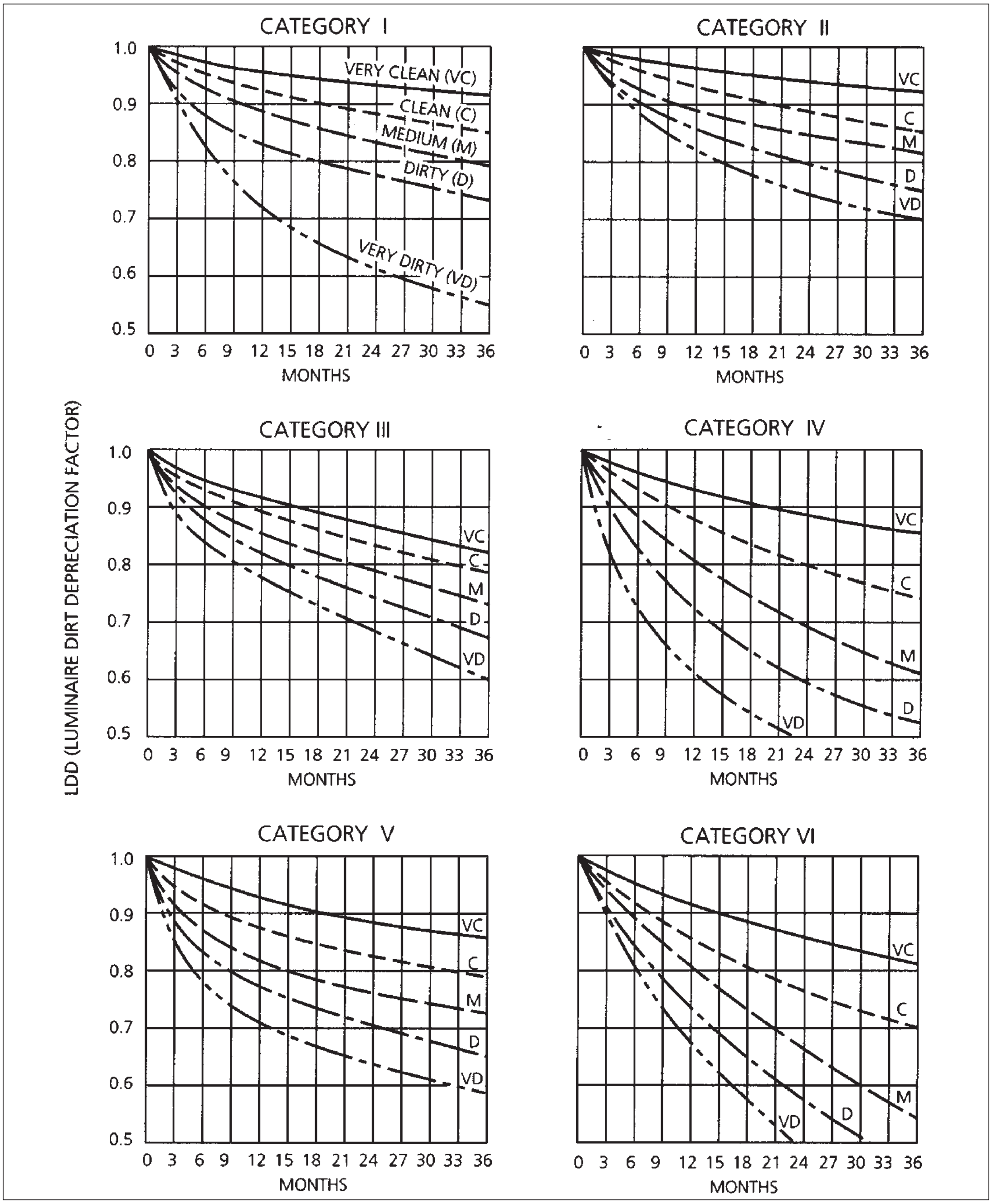

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TABLE 14

SAMPLE COEFFICIENT OF UTILIZATION TABLE

Coefficients of Utilization—Zonal Cavity Method Effective Floor Cavity Reflectance 0.20

RC	80				70				50			30			10			0
RW	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
0	86	86	86	86	84	84	84	84	80	80	80	77	77	77	74	74	74	72
1	82	80	78	76	80	78	76	75	75	74	72	72	71	70	70	69	68	67
2	77	74	71	68	76	72	70	67	70	68	66	68	66	64	66	64	63	62
3	73	68	64	61	71	67	63	60	65	62	59	63	61	58	61	59	58	56
4	69	63	58	55	67	62	58	55	60	57	54	59	56	53	57	55	53	51
5	64	58	53	49	63	57	52	49	55	52	49	54	51	48	53	50	48	47
6	60	53	48	44	59	52	48	44	51	47	44	50	46	44	49	46	43	42
7	56	48	43	39	55	48	43	39	47	42	39	46	42	39	45	41	39	38
8	52	44	39	35	51	43	38	35	42	38	35	42	38	35	41	37	34	33
9	48	39	34	31	47	39	34	31	38	34	31	38	33	31	37	33	30	29
10	44	36	30	27	43	35	30	27	35	30	27	34	30	27	33	29	27	26

Note: the coefficient of utilization values in this table are based on relative photometry which assumes a ballast factor of 1.0. Any calculations prepared from these data should include an appropriate ballast factor.

TABLE 15

RECOMMENDED ILLUMINANCE VALUES

	General Lighting			Task Lighting		
	Public Spaces	Simple Orien-tation	Occa-sional Visual Task	Large Visual Task	Small Visual Task	Very Small Visual Task
Activity	***3 fc***	***5 fc***	***10 fc***	***30 fc***	***50 fc***	***100 fc***
GENERAL						
Circulation						
Corridors		•				
Elevators		•				
Lobbies			•			
Stairs		•				
Service						
Toilets and washrooms		•				
Storage						
Active			•			
Inactive		•				
HOSPITALITY FACILITIES						
Bathrooms, for grooming				•		
Bedrooms, for reading				•		
Cleaning			•			
Dining			•			
Kitchen, critical seeing					•	
Laundry				•		
Sewing						•
INDUSTRY						
Assembly						
Simple				•		
Moderately difficult					•	
Difficult						•
Inspection						
Simple				•		
Moderately difficult					•	
Difficult						•
Locker rooms			•			

	General Lighting			Task Lighting		
	Public Spaces	Simple Orien-tation	Occa-sional Visual Task	Large Visual Task	Small Visual Task	Very Small Visual Task
Activity	***3 fc***	***5 fc***	***10 fc***	***30 fc***	***50 fc***	***100 fc***
OFFICES						
Accounting				•	*	
Conference rooms				•		
Drafting, high contrast					•	
Drafting, low contrast						•
General/private offices				•	**	
Lounges and reception			•			
RESIDENCES						
Bathrooms, for grooming				•		
Bedrooms, for reading				•		
Conversation areas	•					
Dining		•				
Kitchen, critical seeing					•	
Laundry				•		
Sewing					•	
SCHOOLS						
Assembly						
Auditoria			•			
Social activity		•				
Classrooms						
General				•		
Lecture demonstration						•
Science laboratories					•	
STORES						
Circulation			•			
Feature displays						•
Merchandise displays					•	
Sales transactions				•	***	
Wrapping and packaging				•		

*If #4 pencil or harder leads are used for handwritten tasks.
**If tasks involve poor copies, photographs, maps, or 6 point type.
***If handwritten carbon copies.
Based on the IESNA Lighting Design Guide, *IES Lighting Handbook, 9th Ed.* Used with permission from the Illuminating Engineering Society of North America.

TABLE 16

DETERMINATION OF ILLUMINANCE CATEGORIES

Orientation and simple visual tasks. Visual performance is largely unimportant. These tasks are found in public spaces where reading and visual inspection are only occasionally performed. Higher levels are recommended for tasks where visual performance is occasionally important.		
A	Public spaces	3 fc
B	Simple orientation for short visits	5 fc
C	Working spaces where simple visual tasks are performed	10 fc
Common visual tasks. Visual performance is important. These tasks are found in commercial, industrial, and residential applications. Recommended illuminance values differ because of the characteristics of the visual task being lighted. Higher values are recommended for visual tasks with critical elements of low contrast or small size.		
D	Performance of visual tasks of high contrast and large size	30 fc
E	Performance of visual tasks of high contrast and small size, or visual tasks of low contrast and large size	50 fc
F	Performance of visual tasks of low contract and small size	100 fc
Special visual tasks. Visual performance is of critical importance. These tasks are highly specialized, including those with very small or very low contrast critical elements. The recommended illuminance values are often achieved with supplementary task lighting. The higher recommended values are frequently achieved by moving the light source closer to the task.		
G	Performance of the visual task near the threshold	300 to 1,000 fc

Based on the Determination of Illuminance Categories, *IES Lighting Handbook, 9th Ed*. Used with permission from the Illuminating Engineering Society of North America.

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Credits

COLOR PLATES

1 Courtesy of GE Lighting.
2 Courtesy of GE Lighting.
3 Courtesy of GE Lighting.
4 Courtesy of GE Lighting.
5 Gagosian Residence, Francois de Menil Architect. Photo by Paul Warchol.
6 Prudential Insurance Company of America, Grad Associates. Photo by Peter L. Goodman.
7 Prudential Insurance Company of America, Grad Associates. Photo by Peter L. Goodman.
8 Gagosian Residence, Francois de Menil Architect. Photo by Paul Warchol.
9 Courtesy of GE Lighting.
7 Courtesy of GE Lighting.
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29 Courtesy of GE Lighting.
30 Courtesy of GE Lighting.
31 Courtesy of Philips Lighting.

LUMINAIRE DRAWINGS

Many of the drawings in Chapter 12 are based on luminaires originally manufactured by Edison Price Incorporated. The following illustrations are based on luminaires first designed by Edison Price:

Figure 12.7 for the First Unitarian Church, Rochester, 1963.
Figure 12.8 for the Hartford Fire Insurance Building, 1961.
Figure 12.11 for the CIT Building Headquarters Lobby, 1958.
Figure 12.13 for the Philadelphia Academy of Music, 1957.
Figure 12.15 for the Knoll Chicago Showroom, 1954.
Figure 12.17 the first parabolic, low-brightness, fluorescent downlight was designed for the Upjohn Executive Headquarters Building, 1961.
Figure 12.19 for the Chicago Civic Center, 1965.
Figure 12.21 for the Munson-Williams-Proctor Museum, 1960.
Figure 12.22 for the Museum of Modern Art, 1958.
Figure 12.24 for the Munson-Williams-Proctor Museum, 1960.
Figure 12.25 for the Lyndon Baines Johnson Library, 1971.
Figure 12.26 for the Lyndon Baines Johnson Library, 1971.
Figure 12.28 for 9 West 58 Street, New York City, 1971.
Figure 12.31 for the Seagram Building Lobby,1957.
Figure 12.47 for the Yale Art Gallery Building, 1953.
Figure 12.49 for St. John's College, 1965.

PHOTOGRAPHS

The lighting for all projects was designed by Gary Gordon LLC except figures 13.9, 13.33, 13.34, and 13.35, as noted below.

Figure 2.1 Prudential Insurance Company of America, Grad Associates. Photo by Peter L. Goodman.
Figure 2.2 Armenian Evangelical Church, Lee H. Skolnick Architect. Photo by Stan Reiss.
Figure 2.3 Offices for Gary Gordon LLC, Donna Selene Seftel Architect.
Figure 2.4 One Fifth Avenue Restaurant, Pentagram Architectural Services. Photo by Peter Mauss/Esto.
Figure 2.5 Martinez Valero Shoe Store, Zivkovic Associates. Photo by Ashley Ranson.
Figure 2.6 City Bakery, Turett Collaborative Architects. Photo by Paul Warchol.
Figure 2.7 Australia Broadcasting Corporation, Zivkovic Associates Architects. Photo by Ashley Ranson.

Figure 2.8	Private Residence, Frank and Marcotullio Design Associates. Photo by Michael Gordon.
Figure 2.15	Club Monaco, Deborah Berke Architect. Photo by Catherine Bogert.
Figure 2.16	Marketplace at Newport, Turett Collaborative Architects. Photo by Paul Warchol.
Figure 2.17	One Fifth Avenue Restaurant, Pentagram Architectural Services. Photo by Peter Mauss/Esto.
Figure 2.18	Tommy Boy Records, Turett Collaborative Architects. Photo by Paul Warchol.
Figure 3.3	Private residence, Sidnam|Petrone Architect. Photo by Peter L. Goodman.
Figure 3.5	Armenian Evangelical Church, Lee H. Skolnick Architect. Photo by Stan Reiss.
Figure 3.7	Lillian Vernon Residence, Hardy Holzman Pfeiffer Associates. Photo by Gideon Louis.
Figure 3.8	Sedona Store, Andaloro Associates. Photo by George Mott.
Figure 3.10	Morton Productions, BumpZoid. Photo by Langdon Clay.
Figure 3.12	Armenian Evangelical Church, Lee H. Skolnick Architect. Photo by Stan Reiss.
Figure 3.14	Yale University School of Art, Deborah Berke Architect. Photo by Catherine Bogert.
Figure 3.16	Offices for Omon Ltd., Zivkovic Associates Architects. Photo by Ashley Ranson.
Figure 3.17	Lillian Vernon Residence, Hardy Holzman Pfeiffer Associates. Photo by Gideon Louis.
Figure 3.18	Gagosian Residence, Francois de Menil Architect. Photo by Paul Warchol.
Figure 3.19	Yale University School of Art, Deborah Berke Architect. Photo by Catherine Bogert
Figure 3.20	City Bakery, Turett Collaborative Architects. Photo by Paul Warchol.
Figure 3.22	Photo by Photosphere.
Figure 3.24	Photo by Photosphere.
Figure 3.25	Photo by Photosphere.
Figure 3.26	Photo by Photosphere.
Figure 3.27	Photo courtesy of GE Lighting.
Figure 3.28	Photo courtesy of GE Lighting.
Figure 12.57	The New Gotham Lobby, Stephen Alton Architects. Photo by Eduard Hueber.
Figure 12.58	Armenian Evangelical Church, Lee H. Skolnick Architect. Photo by Stan Reiss.
Figure 12.59	Neuman and Bogdanoff, Pentagram Architectural Services. Photo by Peter Mauss/Esto.
Figure 12.60	Findler Residence, Bruce Bierman Design. Photo by Andrew Bardwin.
Figure 12.61	The New Gotham Lobby, Stephen Alton Architects. Photo by Eduard Hueber.
Figure 13.1	Offices for Gary Gordon LLC, Donna Selene Seftel Architect.
Figure 13.2	Club Monaco, Deborah Berke Architect. Photo by Catherine Bogert.
Figure 13.3	Prudential Insurance Company of America, Grad Associates. Photo by Peter L. Goodman.
Figure 13.7	Gagosian Residence, Francois de Menil Architect. Photo by Paul Warchol.
Figure 13.8	Residence for Adam R. Rose and Peter R. McQuillan, Stuart Mager Incorporated. Photo by David Mager.
Figure 13.9	Photo courtesy of Halo Lighting.
Figure 13.11	Findler Residence, Bruce Bierman Design. Photo by Andrew Bardwin.
Figure 13.22	Prudential Insurance Company of America, Grad Associates. Photo by Peter L. Goodman.
Figure 13.27	Gagosian Residence, Francois de Menil Architect. Photo by Paul Warchol.
Figure 13.28	Lillian Vernon Residence, Hardy Holzman Pfeiffer Associates. Photo by Gideon Louis.
Figure 13.29	Martinez Valero Shoe Store, Zivkovic Associates. Photo by Ashley Ranson.
Figure 13.30	Club Monaco, Deborah Berke Architect. Photo by Catherine Bogert.
Figure 13.31	Martinez Valero Shoe Store, Zivkovic Associates. Photo by Ashley Ranson.
Figure 13.32	St. Mark's Bookshop, Zivkovic Associates Architects. Photo by Ashley Ranson.

Figure 13.33 Four Seasons Restaurant, Philip Johnson Architect. Lighting design by Richard Kelly. Photo courtesy of GE Lighting.
Figure 13.34 Four Seasons Restaurant, Philip Johnson Architect. Lighting design by Richard Kelly. Photo courtesy of GE Lighting.
Figure 13.35 Four Seasons Restaurant, Philip Johnson Architect. Lighting design by Richard Kelly. Photo courtesy of GE Lighting.
Figure 13.37 Club Monaco, Deborah Berke Architect. Photo by Catherine Bogert.
Figure 13.38 The New Gotham Lobby, Stephen Alton Architects. Photo by Eduard Hueber.
Figure 13.39 Tommy Boy Records, Turett Collaborative Architects. Photo by Paul Warchol.
Figure 13.40 Tommy Boy Records, Turett Collaborative Architects. Photo by Paul Warchol.
Figure 13.41 The New Gotham Lobby, Stephen Alton Architects. Photo by Eduard Hueber.
Figure 13.42 Club Monaco, Deborah Berke Architect. Photo by Catherine Bogert.
Figure 13.43 St. Mark's Bookshop, Zivkovic Associates Architects. Photo by Ashley Ranson.
Figure 13.44 Prudential Insurance Company of America, Grad Associates. Photo by Peter L. Goodman.
Figure 13.45 Marketplace at Newport, Turett Collaborative Architects. Photo by Paul Warchol.

Glossary

"Accent" light: an advertising term misapplied to adjustable, directional luminaires that are properly termed object lights. See *object light*.

Accommodation: the automatic adjustment of the eye for seeing at varied distances, accomplished by changes in focus.

Acuity (*also called* **visual acuity**): the ability of the eye to make out fine detail.

Adaptation: the change in the sensitivity of the visual system based on the amount of light the retina has been exposed to in the recent past. *Dark adaptation* is an increase in visual sensitivity that occurs over time in darkness.

Ambient light: general or background illumination.

Ampere: measurement of the rate of flow of an electric current; it is equivalent to the steady current produced by one volt applied across a resistance of one ohm.

Anodize: to coat a metal (usually aluminum) with a protective film by subjecting it to electrolytic action.

Aperture (of a luminaire): the diameter of the opening of a recessed luminaire.

Apparent color temperature: See *correlated color temperature*.

Axial (filament): a filament situated in the direction of the lamp axis.

Baffle: a single opaque or translucent element to shield glare at normal viewing angles in one direction, along a single axis. For small-aperture luminaires, a baffle around the perimeter provides shielding from all directions. See also *louvers*.

Ballast: an auxiliary device for an electric discharge source that provides the proper starting voltage and regulates the lamp operating current. All fluorescent and HID lamps require a ballast for proper operation.

Ballast factor: the ratio of light output produced by lamps operated by a commercially-available ballast to light output produced by lamps powered by a laboratory-reference ballast.

Beam angle: the angle between the two directions for which the intensity is 50% of the maximum, as measured in a plane through the beam centerline. See also *field angle*.

Beam-spread: the angular cone of light created by the distribution of the lamp or luminaire, in the plane of the beam axis. See also *beam angle* and *field angle*.

Borosilicate: a silicate glass containing oxide of boron that has high heat-resistance.

Brightness: a subjective experience that occurs in the consciousness of a human observer, a result of the intensity of light falling on a given region of the retina at a certain time, the intensity of light that the retina has been subject to in the recent past, and the intensities of light falling on other regions of the retina. See also *luminance*.

Bulb: the outer hard, soft, or quartz glass envelope of an electric lamp, which may contain a vacuum, elemental inert gas, or metal, and a means of light generation. Also, the layman's term for an electric lamp.

Candela (cd): the unit of luminous intensity emitted in a specific direction by a source, equal to one lumen per steradian.

Candlepower: a vernacular term for luminous intensity expressed in candelas.

Candlepower distribution curve: properly called a *luminous intensity distribution curve*, it depicts the amount of luminous intensity (expressed in candelas) generated in each direction by a light source in a plane through the center of the source.

Capacitive: the part of an electric circuit that exhibits the ability to store charge.

Capacitor: an electric circuit element included in some magnetic ballasts that consists of two metallic plates, separated and insulated from each other, used for storing charge temporarily.

Cathode: one of two electron-emitting electrodes hermetically sealed into a fluorescent lamp, consisting of metal cylinders (cold cathode) or coiled tungsten wire (hot cathode), and usually coated with an electron-emissive material.

Clerestory: a window located in the upper portion of a wall that admits natural light into the center of a room.

Coefficient of utilization: the ratio of the number of lumens expected to reach the work plane divided by the number of lumens generated by the bare lamps of a specific luminaire in a specific room.

Color constancy: knowledge of the normal color of objects. We tend to see surface and object colors as the same despite changes to the color of light illuminating the surface or object.

Color rendering index (CRI): the comparison between the color-rendering ability of a given light source and a reference light source, expressed as an R_a factor on a scale of 1 to 100.

Color rendition: how surface and object colors appear under a given light source, in comparison with their color appearance under a reference light source.

Color spectrum: the continuum of color formed when a beam of white light is dispersed (as by a prism) so that its component wavelengths are arranged in order.

Color temperature: the color appearance of the light that emanates from a source, measured in Kelvin (K). Not a measure of the surface temperature of a lamp, it is the absolute temperature of a laboratory blackbody radiator when its visible radiation matches the color of the light source.

Contrast: the relationship between the intensities of an object and its surrounding areas; the degree of difference between light and dark. See also *luminance contrast.*

Correlated color temperature (CCT): the color appearance of the light that emanates from an electric light source with a discontinuous spectrum, measured in Kelvin (K).

Cove: a concave or canted interior corner or molding, especially at the transition from wall to ceiling; sometimes used to shield light sources that distribute light across the ceiling plane.

Current: the flow of electricity in a circuit; the rate of flow of an electric current is measured in *amperes* (amps, A).

Cutoff: measured up from *nadir*, the angle of the first line of sight at which the bare light source is not visible.

Daylighting: the illumination of indoor spaces by natural light.

Dichroic: the property of transmitting certain wavelengths of light while reflecting those not transmitted, usually with little absorption.

Diffraction grating: a glass or polished metal surface that has a large number of very fine parallel grooves or slits, used to change the directions and intensities of a group of wavelengths of reflected or transmitted light.

Diffuse light: a distribution of light that is dispersed in a wide pattern and not incident from any particular direction.

Diffuser: a glass or plastic material that disperses light from a source in all directions, eliminating the directional quality of the beam; in fluorescent downlights, used to redirect light from the glare zone down toward work surfaces.

Dimmer: a device that provides variation in the intensity of a luminaire by controlling the voltage or current available.

Direct glare: excessive light misdirected toward the eye. It refers to glare from the direct view of luminaries or bare lamps. See also *reflected glare*.

Direct/indirect: light emitted in a downward and upward direction, with little or no light emitted at angles near the horizontal.

Direct (light): a distribution of light emitted in a downward direction.

Downlight: a recessed, surface-mounted, or pendant-mounted luminaire which emits light in a downward direction with no upward component of light.

Downlighting: a distribution of light emitted in a downward direction.

Discharge source: a lamp that produces light by the passage of an electric current through a vapor or gas, rather than through a tungsten wire as in incandescent lamps. (These include cold-cathode, fluorescent, high-pressure sodium, low-pressure sodium, mercury vapor, metal halide, and neon lamps.)

Efficacy: the ratio of lumens produced to electricity consumed when referring to a light source, expressed in lumens per watt.

Efficiency: the ratio of lumens emitted by a luminaire to that emitted by the lamp(s) contained within it, expressed as a percentage.

Ellipsoidal: in the shape of an ellipse, which has two focal points. In a reflecting contour, a ray of light originating at one focal point is reflected through the second focus.

Emissive material: in electric lamps, a substance that discharges electrons, usually applied as a coating to the cathode of a discharge source.

Energy-effective: when referring to electric lighting, using the available watts to supply light where it is needed and when it is needed, and limit light from where it is unwanted.

Exitance: the total quantity of light emitted, reflected, or transmitted in all directions from a surface. Properly defined as *density of flux leaving a surface*, it is measured in lumens per square foot (lm/ft^2) or lumens per square meter (lm/m^2).

Fenestration: The arrangement, proportioning, and design of windows and doors in a building for the admission of daylight.

Fiber optics: thin, flexible fibers of glass or plastic that are enclosed by a material of a lower index of refraction, transmitting light throughout their length by internal reflection.

Field angle: the angle between the two directions for which the intensity is 10% of the maximum, as measured in a plane through the beam centerline. See also *beam angle*.

Filament: the fine tungsten wire in an electric lamp, which acts as a conductor and becomes incandescent by the passage of an electric current.

Filter: a transparent material that modifies the color or quantity of light by transmission or reflection.

"Fixture": layman's term for a luminaire. See *luminaire*.

"Floor lamp": layman's term for a torchère. See *torchère*.

Fluoresce: the emission of visible light caused by the absorption of radiation of shorter wavelengths followed by a nearly immediate re-radiation at a longer wavelength.

Fluorescent lamp: a low-pressure, mercury-vapor, electric-discharge lamp having a phosphor coating on its inner surface that transforms the ultraviolet energy generated by the discharge into visible light.

Flux: see *luminous flux*.

Focused light or focal glow: concentrated light of greater intensity on a particular area or object, compared to its background illuminance, intentionally establishing a hierarchy between foreground and background.

Footcandle (fc): the unit measurement of illuminance equal to one lumen per square foot, originally defined with reference to a standardized candle burning at one foot from a given surface.

Footlambert (fL): unit measurement of reflected light from a perfectly diffusing surface that emits or reflects one lumen per square foot; equal to $1/\pi$ candela per square foot; now deprecated.

Fresnel (pronounced fra-nel′) lens: a thin, optical lens that consists of a series of concentric lens sections regressed into a planar array; in luminaires, it produces a concentrated beam of light while also reducing the brightness of the source.

General diffuse: a multidirectional lighting distribution produced by luminaires that deliver both upward and downward components of light.

Glare: the sensation produced by an extreme luminance within the normal field of view that is sufficiently greater than the luminance to which the eyes are adapted.

High-bay lighting: interior lighting where mounting height is greater than approximately 25 ft above the floor.

High contrast: a lighting condition characterized by a large proportion of focused light (on an object or the foreground) and a small amount of diffuse light (the background).

High load: an elevated degree of psychological stimulation or arousal, caused by activities or environments that are complex, crowded, asymmetrical, novel, unfamiliar, surprising, or random.

High-pressure sodium: a high-intensity discharge lamp in which light is produced by radiation from the combined vapors of mercury and sodium, with the latter dominating the yellow-amber color.

Hue: spectral color; light of a specific wavelength.

Hydroform: a method of machine-forming metal that consists of a draw ring, flexible die, punch, and a pressurized forming cavity. (In luminaires, it is used to form reflectors from aluminum.)

Illuminance: the density of light received at a point on a surface. Properly defined as *density of flux incident on a surface measured perpendicular to the surface*, it is measured in footcandles (fc).

Incandescence: the emission of light from an object as a result of its being heated.

Incandescent lamp: an electric lamp in which a filament produces light when heated to incandescence by an electric current.

Incident: light rays falling upon or striking a surface.

Included angle: formed between or within two intersecting straight lines.

Indirect: an upward distribution of light which produces illumination on the horizontal workplane via reflection from the ceiling and upper walls.

Inductive: the property of an electric circuit in which an electromagnetic charge is induced in it as the result of a changing magnetic flux.

Infrared: wavelengths in the region of the electromagnetic spectrum immediately above the visible spectrum, from 770 to 10^6 nm.

Intensity: the physical energy of light emitted in a specific direction by a source. Properly called *luminous intensity* and defined as *flux per solid angle in a given direction*, it is measured in candelas (cd).

Interreflection: the multiple reflection of light by the various room surfaces before it reaches the workplane.

Iodide: a salt of hydriodic acid, a compound of iodine; used in metal halide lamps.

Ionize: to convert into ions; a group of atoms that carry a positive or negative electrical charge as a result of having lost or gained one or more electrons.

Isofootcandle plot: a computer-generated diagram on the Cartesian coordinate system showing contour lines of varying illuminance values from a specific luminaire in a specific application; a shaded plan with gray scales representing the range of illuminance values.

Kelvin: the unit of absolute temperature used to designate the color temperature of a light source.

Kilowatt: a unit of power equal to 1,000 watts.

Lamp: a source that converts electricity into light; it is the technical word for what is commonly referred to as a "light bulb."

Lampholder: the component of a luminaire that accepts the lamp base and supplies it with electricity; it is the technical word for what is commonly referred to as a "socket."

Laser: acronym for *l*ight *a*mplification by *s*timulated *e*mission of *r*adiation; most lasers are oscillators (generators or sources of light) not amplifiers, producing a monochromatic beam of radiation by steady oscillation maintained in a resonator.

LED: acronym for *l*ight-*e*mitting *d*iode; a semiconductor diode that emits light when voltage is applied to it.

Lens: a glass or plastic element used in luminaires to control the direction and distribution of transmitted light by refraction.

Light: a narrow band of electromagnetic energy, ranging from approximately 380 nanometers (nm) to 760 nm, which stimulates receptors in the eye that enable vision.

Lime glass: glass with a high calcium oxide content consisting of silica, alumina, and iron that has greenish hue.

Louver: a series of baffles or shielding elements used to shield glare at normal viewing angles, usually arranged in a geometric pattern to provide shielding from many directions with minimum interference to the desired beam distribution.

Low contrast: a lighting condition characterized by a large proportion of diffuse light and a small amount of focused light.

Low load: a small amount of psychological stimulation or arousal, resulting from activities or environments that are simple, uncrowded, symmetrical, conventional, familiar, unsurprising, or organized.

Low-pressure sodium: a discharge lamp in which light is produced by radiation from sodium vapor, with a monochromatic yellow color.

Lumen (lm): the unit measurement of luminous flux equal to the light emitted in a solid angle by a uniform point source of one candela intensity.

Luminaire: a complete lighting unit consisting of a housing; lamp(s); light controlling elements; brightness controlling element; lampholder(s); auxiliary equipment, such as ballast or transformer, if required; and a connection to the power supply.

Luminance: the objective measurement of intensity of light entering the eye, per unit of projected area. It is the accepted term for light that is reflected from a surface in a given direction (back towards the eyes). Properly defined as *intensity of flux leaving a surface in a given direction*, it is measured in candelas per square foot (cd/ft^2) or candelas per square meter (cd/m^2).

Luminance contrast: the ratio of the luminance of an object or the foreground to the luminance of its immediate background or surround.

Luminous: emitting or reflecting energy in the visible portion of the electromagnetic spectrum.

Luminous flux: light emitted in all directions by a source. Properly defined as *time rate flow of light*, it is measured in lumens (lm).

Matte: a dull finish or surface lacking in luster, gloss, shine, or highlights.

Mercury lamp (properly called a **mercury vapor lamp**): a high-intensity discharge lamp in which light is produced by an electric discharge through mercury vapor.

Metal halide: a high-intensity discharge lamp in which light is produced by an electric discharge through the combined vapors of mercury and metal halides, which are introduced into the arc tube as compound iodides.

milliAmpere: a unit of electric current equal to one thousandth of an ampere.

Monochromatic: having or consisting of only one color or hue, or radiation of a single wavelength or very small range of wavelengths.

Motion sensor: see *occupancy sensor*.

Nadir: straight down (0-degree angle).

Nanometer: a unit of wavelength equal to one billionth (10^{-9}) of a meter.

Object light: an adjustable, directional luminaire that provides an asymmetric distribution of light aimed at one or several objects. Also called "spot lights," they are used to provide focal glow and add contrast to a setting.

Occupancy sensor: a device that provides on-off control of luminaires in response to the presence or absence of occupants in a space, sensed by audio, ultrasonic, passive infrared, or optical means.

Ohm: the standard unit of electrical resistance of a conductor, such that a current of one ampere in its circuit produces a decrease in voltage across it of one volt.

Opaque: blocking the passage of light; neither transparent nor translucent.

Parabolic: having the form of a parabola, a plane curve generated by the intersection of the surface of a cone with a plane parallel to one of its sides.

Pendant (luminaire): a luminaire that is suspended from the ceiling by a support cable, chain, cord, rod, or stem.

Phosphor: a chemical substance that converts invisible ultraviolet radiation into visible light.

Photometer: an instrument for measuring luminous intensity, luminous flux, illuminance, or luminance.

Photometry: the science that measures light.

Photosensor: a light-sensing device used to control luminaires and dimmers in response to detected illuminance values.

Photopic: vision, using the cones of the retina, under relatively high illuminance values.

Prism: a transparent body with three rectangular plane faces, or sides, and two equal and parallel triangular ends or bases, used to refract or disperse a beam of light.

Quad-phosphor: a combination of four narrow spectra, rare-earth phosphors used in fluorescent lamps to produce a wide-range spectrum of visible light. The individual phosphors correspond to the short-, middle-, and long-wavelength regions of the visible spectrum.

Reflected glare: excessive uncontrolled luminance reflected from objects or surfaces in the field of view.

Reflection: the return of light from a surface. *Specular reflection* occurs when the surface alters the direction of a beam of light without changing its form; the angle of reflection is equal to the angle of incidence. *Spread reflection* partially disperses this reflected beam. *Diffuse reflection* occurs when an incident ray of light is reflected in all directions.

Refraction: the deflection of a light ray when it passes obliquely from one medium (such as air) into another (such as water) in which it travels at a different speed.

Relamp: to replace a lamp or lamps.

Restrike: after a high-intensity discharge lamp is extinguished, it must cool sufficiently to reduce the vapor pressure to a point where the arc can be reignited.

Scotopic: vision, using the rods of the retina, under relatively dim light.

Semi-specular: an irregular surface that partially disperses or spreads the reflected beam, with the greatest intensity of light reflected at an angle near the angle of incidence.

Shielding angle: the zone within which shielding (baffles or louvers) conceals the light source and controls glare.

Sight line: the line extending from an observer's eye to the point at which a bare light source first becomes visible.

Skylight: 1. the diffused and reflected light of the sky; it is light from the sun redirected by the atmosphere. 2. an opening in the roof of a building, glazed with a transparent or translucent material, that is designed to admit natural light.

Slimline: a linear fluorescent lamp with a single-pin base that is capable of being operated at more than one current and wattage.

Soffit: the exposed underside of any overhead component of a building, such as an arch, balcony, beam, cornice, lintel, or vault.

Spacing criterion (SC) or **spacing-to-mounting-height ratio (S/MH)**: an estimated maximum ratio of luminaire spacing to luminaire mounting height above the workplane, necessary to achieve uniform, horizontal illuminance.

Spectral: of, relating to, or made by the color spectrum or electromagnetic spectrum.

Specular: having the reflecting properties of a mirror; a smooth reflecting surface. The angle of reflection is equal to the angle of incidence.

Splice: the electrical connection of luminaire wires to the building branch circuit wires.

Stroboscopic: when rapidly moving objects are observed under discharge sources, blurred "ghost" images are sometimes observed that cause the objects to appear slowed, stopped, or moving in reverse.

Torchère: a portable luminaire suitable for standing on the floor, which directs most, or all, of its light upward.

Toroidal: doughnut-shaped.

Total internal reflection: occurs when light passes into a transparent medium, such as glass or plastic, at an appropriate angle so that it travels inside the medium repeatedly reflecting from side to side.

Transformer: a device with two or more coupled windings, used to convert the supply of electric power at one voltage in a primary circuit to a lower voltage in a secondary circuit.

Translucent: having the property of transmitting diffused light but obscuring vision, so that objects beyond cannot be seen clearly.

Transmission: the passage of light through space or a medium; it is altered by the reflections at each surface of the medium, and by the absorption and reflection within the medium.

Transparent: having the property of transmitting light without altering its distribution, so that objects beyond are seen clearly.

Triphosphor: a combination of three narrow spectra, rare-earth phosphors used in fluorescent lamps to produce a wide-range spectrum of visible light. The individual phosphors correspond to the peak spectral sensitivities of human vision: blue-violet, pure green, and orange-red.

"Troffer": layman's term for a recessed, rectilinear fluorescent downlight; perhaps derived from "trough" and "coffer."

Trough: a long, narrow opening, usually in the ceiling plane; sometimes called a *slot*.

Tungsten-halogen: an incandescent lamp with a selected gas of the halogen family sealed into it to stop evaporated tungsten from depositing on the bulb wall.

Ultraviolet (UV): radiant energy having a wavelength shorter than wavelengths of visible light and longer than those of x-rays; within the range of 10 nanometers (nm) to 380 nm.

Uplight: a luminaire that emits light in an upward direction toward the ceiling, with no downward component of light.

Uplighting: a distribution of light emitted in an upward direction.

Valance: a longitudinal shielding panel mounted over a window with draperies to conceal light sources that provide both uplight and downlight.

Veiling reflection: a reflection of incident light that partially or completely obscures the details on a surface by reducing its contrast. See also *reflected glare*.

Visual comfort: the degree of visual satisfaction produced by the luminous environment, resulting from the reduction of glare and distracting luminance in the field of view.

Visible spectrum: wavelengths of electromagnetic energy, ranging from approximately 380 nanometers (nm) to 760 nm.

Volt: the standard unit of measurement for electrical potential; when applied across a resistance of one ohm, it will result in a current flow of one ampere.

Wall-washer: a luminaire with an asymmetric distribution used for illuminating vertical surfaces from ceiling to floor without noticeable variation in intensity.

Watt: the unit of electrical power; it is equal to the power produced by a current of one ampere across a potential difference of one volt.

Wattage: the amount of power expressed in watts.

Wavelength: the distance between one peak or crest of a wave of light, heat, or other energy, and the next corresponding peak or crest.

Workplane: the plane on which visual tasks are usually done; a horizontal plane 2 ft 6 in. above the floor, unless otherwise indicated.

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