



# design brief

## LIGHTING

### Summary

Commercial lighting systems offer extraordinary opportunities for cost-effective energy savings. Many of the design and equipment upgrades that reduce energy consumption also improve the visual environment and provide maintenance savings. The key steps to creating an efficient and effective lighting system are:

- Design to get the right amount of light for the task; distribute the light to prevent glare.
- Take advantage of natural daylight whenever possible but avoid direct sunlight; install appropriate controls for the electric lights.
- Use high-efficiency fluorescent systems as the primary light source for most commercial spaces and for many high-bay lighting applications.
- Use compact fluorescent and incandescent sources to round out the lighting system and provide visual interest.
- Use high-intensity discharge systems—particularly pulse-start metal halide—for outdoor lighting; consider ceramic metal-halide systems in applications where color quality is very important, such as retail outlets.

### SAVING ENERGY AND IMPROVING LIGHTING QUALITY AT THE SAME TIME

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The California region is blessed by regular sunlight, but this valuable resource is all too often ignored in commercial building design.

## Introduction

Lighting, whether it comes from the sun or from electric devices, enables our commercial world to operate. Lighting helps us work, play, travel, and interact. High-efficiency, high-performance lighting systems enhance a building's internal environment without adding unnecessary expense.

In the simplest terms, every lighting system consists of three elements: a lamp, a fixture or luminaire, and a control system. Each component is important, and each offers opportunities for improved performance and energy savings.

Commercial lighting is particularly important in California for several reasons. Lighting is directly responsible for nearly 40 percent of commercial electricity consumption and, in this warm climate, most heat generated by lighting must be removed by power-hungry air conditioners. The region is blessed by regular sunlight, but this valuable resource is all too often ignored in commercial building design. Lighting technology advances rapidly, with hundreds of new products introduced each year, so it's important to stay on top of new developments. The construction process is the best opportunity to capture the operating cost savings and improved visual environments that are available through top-notch design and technology.

## Quality Design Optimizes Quantity of Light

Quality design is the cornerstone of efficient lighting—the most efficient light sources mounted in the best luminaires may save energy, but they won't produce much value for building owners and occupants if they are applied improperly. Lighting in spaces where people work with video display terminals (VDTs) provides a good example. Bright, direct lighting fixtures that lack tight cutoff angles can create reflections on VDT screens, making them difficult to read. Lighting designers can prevent these kinds of problems by first considering such classic elements of lighting design as luminance ratios, room surface finishes, color rendering, and lighting quantities.

## Luminance Ratios

The eye sees differences in luminance, not absolute footcandle levels. (A footcandle is a unit of illuminance equal to one lumen per square foot.) A paper task could be adequately lit by overhead lighting. But if areas in the visual field are much darker (for example, dark wood paneling) or much brighter (such as unshaded south windows), the observer's eyes may not be comfortable.

*Luminance ratio* refers to the ratio of brightness levels in different areas in the field of view. The human visual system will generally judge that areas resulting in ratios of 3:1 or less are of equivalent brightness. Areas with 10:1 (or higher) ratios create dramatic contrast and, when excessive, create glare. Lower luminance ratios are necessary to create even, comfortable lighting for work spaces, and higher luminance ratios are appropriate for retail stores, theaters, or restaurants.

To reduce luminance ratios and improve lighting quality:

- Choose fixtures that hide the lamp and distribute its light by reflection, refraction, or diffusion.
- Place the light source behind or inside a cornice, cove, valance, or trough.
- Use indirect fixtures and bounce the light off the wall or ceiling (or both).
- Avoid high-contrast ratios—for example, avoid placing very light materials adjacent to very dark materials.
- Use matte paint or other diffuse room surface finishes, especially for the ceiling.
- Use lamps or fixtures with focused beam-spreads for accent lighting, to provide highlights without glare.
- Add dimming controls so that light output from a fixture can be reduced.

Lower luminance ratios are necessary to create even, comfortable lighting for work spaces, and higher luminance ratios are appropriate for retail stores, theaters, or restaurants.

**Figure 2: Example of diminished visibility due to reduced contrast**

This occurs when light strikes a task and produces shiny reflections that reduce or veil contrast between details of the task and the background, such as print or photos on paper. Lower contrast reduces visibility, which can cause eyestrain and impaired productivity.

There are many ways to minimize veiling reflections, including moving the light source, installing different reflectors or lenses, and moving or reorienting the task.

Courtesy: Platts

## Glare and Veiling Reflection

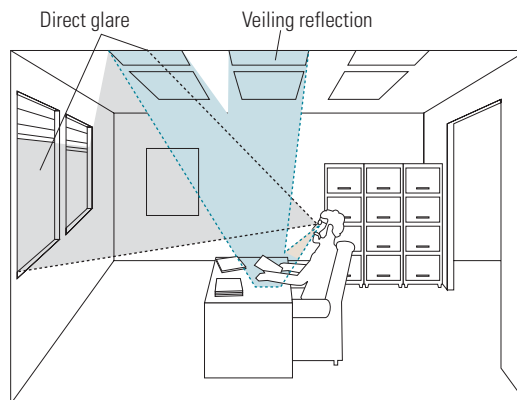
*Direct glare* is the presence of a bright surface (such as a bare lamp or the sun) in the field of view that causes discomfort or loss in visual performance. This type of glare can be addressed with “cutoff reflectors,” which prevent light from shining directly into an occupant’s eyes, or with window shades that block direct sunlight.

A specific type of reflected glare called *veiling reflection* is a more challenging issue for the lighting designer. Before computers became ubiquitous, veiling reflections were the most common visual problem associated with tasks on a horizontal work plane. A veiling reflection occurs when light strikes a task and produces shiny spots that overwhelm the task (**Figure 1**). The decrease in contrast reduces visibility (see **Figure 2**) and can cause eyestrain and impaired productivity.

To combat glare from veiling reflections, imagine that the occupant’s visual task is a mirror, and then don’t place bright fixtures such that they would appear in the mirror. Because it’s difficult to predict exactly where workstations and tasks will be placed, one solution is to avoid direct lighting fixtures entirely. This is partly why indirect lighting fixtures have become popular—they create large areas of moderate brightness rather than small areas of high brightness that may be reflected in such a way as to obscure visual tasks.

**Figure 1: Common sources of glare**

Veiling reflections commonly occur when the light source is directly above and in front of the viewer.



Courtesy: Platts

## Task/Ambient Lighting

In a task/ambient lighting scheme, ceiling-based fixtures provide a relatively low level of ambient light that is supplemented by workstation-based task lights that provide locally high light levels. The illumination levels will depend on the type of fixture used and the tasks being performed.

Here's an example of how task/ambient lighting can improve lighting quality while saving energy. Two scenarios are shown in **Table 1**. A typical uniform lighting design creates an average of 60 footcandles throughout the space, using very efficient T8 luminaires in the recessed ceiling. At 1.08 watts per square foot, this design meets the requirements of Title 24 (2005), California's energy-efficiency standard. The task/ambient design (see **Figure 3**),<sup>1</sup> on the

**Table 1: Task/ambient lighting**

This task/ambient lighting scheme costs no more to install than a standard one, but reduces installed lighting power by 35 percent.

	Typical (uniform)	Improved (task/ambient)
<b>Ambient lighting system</b>		
Design lighting level (foot-candles)	60	30
Luminaire quantity	18	9
Luminaire power (watts)	60	60
Total power (watts)	1,080	540
<b>Task lighting system</b>		
Task light quantity	0	10
Task light power (watts)	—	16
Total power (watts)	0	160
<b>Total system economics</b>		
Run time (hours per year)	2,000	2,000
Total system power density (watts per square foot)	1.08	0.70
Energy consumption (kilowatt-hours per year)	2,160	1,400
Incremental installation cost		0
Operating cost (\$/year)	\$216	\$140
Savings (\$/year)	—	\$76
Savings (percent)		35%
Payback		Immediate

- Notes:
- Ambient luminaire for both cases is a two-lamp T8 recessed troffer, electronic ballast, fixture coefficient of utilization = 0.80. Task light is a 13-watt compact fluorescent consuming 16 watts with ballast losses.
  - Calculations assume a 20 percent difference between initial and maintained lumens (from lamp phosphor degradation, thermal effects, and dirt).
  - Area of space = 1,000 square feet.
  - Task light quantity assumes one task light per 100 square feet.
  - Incremental cost for task/ambient system is zero or less, assuming \$75 per ceiling fixture and a task light budget of less than \$225 each.
  - Electricity cost = \$0.10 per kilowatt-hour.

Courtesy: Platts

Ceiling-based fixtures provide a relatively low level of ambient light that is supplemented by workstation-based task lights.

**Figure 3: Workstation combining task and ambient lighting**

Task/ambient lighting (like the arrangement shown here) is considerably more efficient than using bright overall illumination, and it creates a better visual environment for work involving video display terminals.



Courtesy: Pritchett Wilson Group [1]

other hand, cuts general illumination in half but adds plenty of local compact fluorescent task lights and saves 35 percent of energy. (In practice, the savings will be even greater because the task lights can be more easily turned off by occupants.) The installation cost of the task/ambient system is lower than that of the uniform system, because 10 task lamps cost less than 30 ceiling fixtures. Thus the payback is immediate.

### **Color and Spectral Content of Light Sources**

White light comes in many shades, because it is really a blend of light from throughout the visual spectrum. Over the past two decades, the development of new phosphor compositions has significantly boosted the quality of fluorescent light output. There are two common ways to describe the color of light from a source: correlated color temperature (CCT) and color rendering index (CRI).

**CCT.** Correlated color temperature refers to the temperature of a blackbody radiator emitting light of comparable color. The scale may seem intuitively backward; the higher the color temperature, the “cooler” or bluer the light. Incandescent lamps have a color temperature of about 2,700 kelvin (K). Fluorescent lamps generally range from 3,000 K to about 4,100 K, although 2,700-K, 5,000-K, and 6,500-K temperatures are also available. (Daylight typically ranges from 5,000 to 10,000 K.) The “right” color temperature for an application may depend on the foot-candle level being maintained. Using lamps with high color temperature at low light levels makes spaces appear cold and dim. Conversely, using lamps with low color temperature at high levels of illumination will make a space look overly colorful. It is particularly important to consider this in dimming applications, because a light source that looks good at 50 footcandles may not look as good at higher or lower illuminances. This issue is especially important in retail stores and restaurants, where the appearance of objects, people, and food is very important. Another important consideration in selecting an appropriate color temperature is the presence of daylight. For spaces that are daylight, 5,000 K may be most appropriate.

**CRI.** Measured on a scale of 0 to 100, CRI describes the ability of a light source to render a sample of eight standard colors relative to a reference source. A CRI of 100 means that the source renders the eight standard colors in exactly the same way that the reference light source renders the same colors. CRI is an average value, so it will not describe how a light source renders a specific color. Generally speaking, however, high-CRI light sources render colors better than low-CRI sources. Incandescent lights have a CRI of close to 100; cool-white fluorescents have CRIs of 58 to 62; CRIs for T8 fluorescents range from 52 to 91, with most products having CRIs in the 70s or 80s; T5 lamps offer CRIs in the 80s; standard high-pressure sodium lamps have CRIs of about 27; standard metal-halide lamps offer CRIs of 65 to 70, and ceramic metal-halide lamps offer CRIs in the 80s and 90s. A CRI of 80 or greater is considered by the industry to provide excellent color rendering.

### How Much Light?

So far, we've covered items that affect the quality of lighting. Let's now look at the quantity, or footcandle illuminance levels, that make up an acceptable design. A good place to start is by examining the tasks that are involved. Chapter 10 of the Illuminating Engineering Society of North America (IESNA) *Lighting Handbook* (9th edition), includes a Lighting Design Guide that provides recommended illuminances for seven general application categories, divided into three sets of visual tasks. (See **Table 2**, page 8.)<sup>2</sup> The guide provides a methodology for combining these seven recommended illuminance levels with 22 other criteria to develop high-quality lighting for hundreds of different applications. IESNA also provides specific luminance recommendations for hundreds of indoor and outdoor activities in 17 Recommended Practices for various lighting applications.

Selection of illumination level makes a big difference in a system's installed power and operating costs. With 10,000 square feet of office space, for example, choosing an illumination level of 30 footcandles saves 40 percent and \$720 per year in operating costs compared with designing for a higher level of 50 footcandles (see

A CRI of 80 or greater is considered by the industry to provide excellent color rendering.

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**Table 2: Determination of illumination categories**

The *IESNA Lighting Handbook*, 9th edition, includes a “Lighting Design Guide” that provides recommended illuminances for seven general application categories divided into three sets of visual tasks. The guide also provides a methodology for combining these illuminance levels with 22 other criteria to develop high-quality lighting for hundreds of different applications.

Category	Description	Illuminance (foot-candles)
<b>Orientation and simple visual tasks</b> in public spaces where reading and visual inspection rarely take place and visual performance is not crucial. Higher levels recommended for tasks where visual performance might be required.		
A	Public spaces	3
B	Simple orientation for short visits	5
C	Working spaces where simple visual tasks are performed	10
<b>Common visual tasks</b> in commercial, industrial, and residential applications—where visual performance is important. Recommended illuminance levels differ based on the visual tasks being illuminated. Higher levels 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
E	Performance of visual tasks of high contrast and small size or low contrast and large size	50
F	Performance of visual tasks of low contrast and small size	100
<b>Special visual tasks</b> including tasks with critical elements of very small or very low contrast. Visual performance is critical. Recommended illuminance levels should be achieved with supplementary task lighting. Higher recommended levels are often achieved by moving the light source closer to the task.		
G	Performance of visual tasks near threshold	300–1,000

Courtesy: Platts; data from *IESNA Lighting Handbook* [2]

**Table 3).** (Both of these systems are allowable under California’s Title 24 energy-efficiency standard.)

### Daylighting

Daylighting is a major opportunity for California commercial buildings, offering significant energy savings and having a positive effect on building occupants. (See case study, p. 11.) California’s Title 24 energy code requires separate controls for daylit areas and offers substantial energy budget credits for automatic daylighting controls. The 2005 version of the code favors measures such as daylighting that save energy during periods of likely peak demand. In addition, the code now requires skylights with automatic daylighting controls that have a deadband feature for the top story of spaces larger than 25,000 square feet (ft<sup>2</sup>) with ceilings higher than 15 feet.<sup>3</sup>



**Table 3: How much light?**

The design lighting level for a space has a dramatic impact on energy use.

	Baseline	Improved
<b>Lighting system</b>		
Design lighting level (foot-candles)	50	30
Luminaire quantity	150	90
Luminaire power (watts)	60	60
Total power (watts)	9,000	5,400
<b>System economics</b>		
Run time (hours per year)	2,000	2,000
Total system power density (watts per square foot)	0.9	0.54
Energy consumption (kilowatt-hours per year)	18,000	10,800
Operating cost (\$/year)	\$1,800	\$1,080
Savings (\$/year)	–	\$720
Savings (percent)		40%

- Notes:
- Luminaire for both cases is a two-lamp T8 recessed troffer, electronic ballast, high-*n* fixture.
  - Calculations assume a 20 percent difference between initial and maintained lumens (from lamp phosphor degradation, thermal effects, and dirt).
  - Area of space = 10,000 square feet.
  - Electricity cost = \$0.10 per kilowatt-hour.

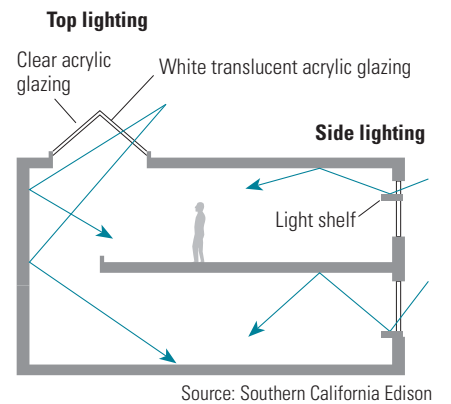
Courtesy: Platts

There are three basic principles for achieving good daylighting performance:

- *Get the light in.* This can be done with conventional vertical glazing, light shelves, skylights, and clerestory windows (see **Figure 4**) or through more advanced technologies such as light pipes or specialized reflective materials.
- *Avoid glare.* The real trick in daylighting design is to control the powerful effect of direct sunlight, which can cause very uneven luminance ratios that are distracting or even painful to occupants. Strategies include using translucent materials such as fiberglass-reinforced plastic and bouncing the direct light off surfaces such as painted walls, perforated metal, or fabrics. Skylights and windows can also be a source of glare, which can be avoided by coordination of luminances with other room surface finishes.

**Figure 4: Simple daylighting techniques**

This schematic shows a mix of top- and side-lighting, light shelves, high-reflectance ceilings, and wall diffusion to provide fairly uniform deep-plan daylighting without the glare of direct sun.



## DAYLIGHTING RESOURCES

The Energy Design Resources web site ([www.energydesignresources.com/category/daylighting](http://www.energydesignresources.com/category/daylighting)) offers a number of publications on and tools for daylighting design, including:

- *Design Guidelines:* Skylighting Guidelines and Daylighting Guidelines
- *Design Briefs:* Daylighting, Improving Mechanical System Energy Efficiency, Skylights with Suspended Ceilings, Lighting Controls, Options & Opportunities, Integrated Energy Design, Glazing, and Building Simulation
- *Online Tools:* EDR Charette

- *Control electric lights accordingly.* Without lighting controls, daylighting won't save any energy. Automatic controls that sense ambient daylight are the best approach, because they ensure that electric lighting will be reduced when enough daylight is available. **Figure 5** shows how an automatic daylight control system cut energy use by 30 percent and decreased demand during peak hours.<sup>4</sup>

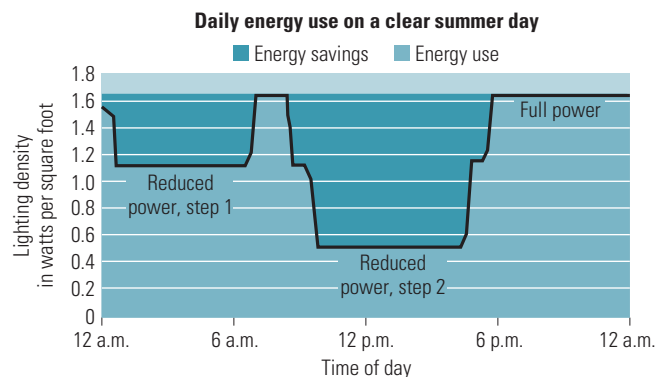
## Full-Size Fluorescent Lamps

Look up right now—if you're in an office building, you're probably looking at a fluorescent lamp. Fluorescent lighting systems combine high efficacy and long life with light quality ranging from acceptable to excellent. Fluorescent sources generally have few operational limitations for most indoor lighting applications. Problems such as startup flicker and poor light color were solved long ago, and new technology is giving specifiers a wider array of light packages—including very small and narrow lamps—and cutting the cost of dimming systems.

Full-size fluorescent systems are most appropriate for general lighting in commercial, institutional, and industrial spaces with low to medium ceiling height. The introduction of high-intensity fluorescent lamps and fixtures makes fluorescent systems a leading

**Figure 5: Skylights improve lighting energy profile at a grocery store**

A grocery store in Valencia, California, used skylights and photocells to reduce lighting energy use by 30 percent during a monitored two-week period. This lighting energy profile shows that electric light use decreased by two-thirds during peak daylight hours.



Courtesy: California Energy Commission [4]

### Figure 6: Intermediate school uses daylighting

These photos show a classroom (top) and the library (bottom) at the Georgina Blach Intermediate School. The indirect electric lighting dims in response to increasing daylight and helps to provide a glare-free environment.



Photo: Mark Luthringer Photography  
Courtesy: Gelfand Partners [5]

choice for areas with high ceilings (more than 15 feet)—the type of application that used to be the exclusive domain of high-intensity discharge light sources (see Design Briefs: High Intensity Fluorescent Lighting). To apply fluorescent lamps successfully, carefully consider options for fixtures (direct versus indirect),

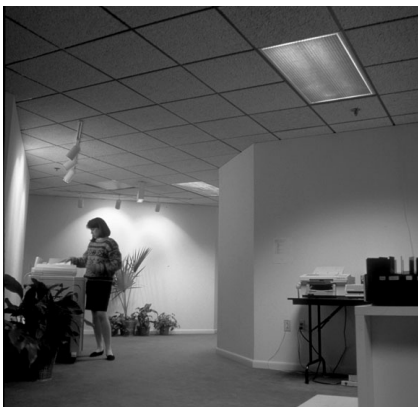
## DAYLIGHTING CASE STUDY

The Georgina Blach Intermediate School in Los Altos, California (**Figure 6**),<sup>5</sup> built in 2002, is one of the first schools in California to be designed and built to criteria developed by the nonprofit Collaborative for High-Performance Schools Inc. (CHPS). CHPS is a group of utility, government, and other organizations that provide high-performance design information, services, training, and incentives directly to California school districts and designers. One of the features encouraged by the CHPS program is daylighting, which not only helps schools cut their energy bills, but also provides an environment more conducive to learning than electric lighting alone.

Daylighting measures at the 71,500 ft<sup>2</sup> school, which serves 450 7th- and 8th-grade students, include clerestories, windows, and a control system with photocells and dimming ballasts that reduce electric light output when adequate daylight is available. Daylight and electric lighting working together provide 40 footcandles of illumination on all work surfaces—an approved change from the school district’s former standard of 70 footcandles solely from electric lighting. Thanks to daylighting and other measures—such as improved insulation, natural ventilation, cool roofs, premium-efficiency motors, and high-efficiency HVAC equipment—the school uses about 38 percent less energy than a school built strictly to meet Title 24 standards while providing a more comfortable, high-quality learning environment.

**Figure 7: Direct downlighting with conventional 2-by-4 bulb troffers**

Direct lighting looks good on a horizontal light meter, but it can create a dark-feeling space because it lights the floor rather than the walls and ceiling.



Courtesy: Platts

**Figure 8: Indirect lighting with pendant fixtures**

Indirect lighting brightens surfaces and works well in computer environments.



Courtesy: Platts

lamps (diameter, length, intensity, and phosphor blend), and ballasts (electronic versus magnetic, rapid-start or programmed rapid-start versus instant-start).

### Direct Downlighting Fixtures

Direct downlighting with 2-by-4 or 2-by-2 fluorescent fixtures—the most common and lowest first-cost approach for general commercial lighting—provides good illumination on the horizontal task plane. But it has its shortcomings. It leaves ceilings and wall surfaces dark, creating a cave effect; and it may cause glare for computer-based work, because the fixtures may present bright lamps or lenses that can be reflected in computer screens (**Figure 7**). These fixtures may also be a source of direct glare into an occupant's eyes.

### Indirect Lighting Fixtures

Indirect lighting with fluorescent lamps in coves, pendants, and coffers can make a space feel brighter with less light because it illuminates the ceiling and high walls (**Figure 8**). If the ceiling and walls are made of a light-colored material, little light is lost with this approach. Indirect light works well within a task/ambient lighting scheme and is also very appropriate for work areas that use video display terminals. To use indirect lights, it helps to have ceilings that are a bit higher than normal (10 feet or higher would be ideal, but 9 feet is acceptable). For lower ceiling heights, recessed direct/indirect fixtures—which provide a mixture of direct and indirect illumination—can be considered (**Figure 9**), or indirect fixtures can be integrated into or mounted onto office furniture (**Figure 10**).<sup>6</sup> With recessed indirect fixtures, the designer must adjust the contrast ratios between the ceiling plane and the reflector to avoid reflected glare in VDT screens. Fixtures for indirect lighting (primarily pendants and cove lights) typically cost more than recessed troffers, but usually fewer fixtures are required.

The introduction of T5 fluorescent lamps, which are thinner and offer a higher intensity of light output than T8s, has

widened the applicability of indirect lighting. The high light output of T5 lamps means that rows of indirect fixtures can be placed as much as 12 to 15 feet apart on ceilings as low as 9 feet (some manufacturers claim that the fixtures can be used on ceilings 8 feet 6 inches or lower) and still provide uniform ceiling illumination levels. Wider spacing means that fewer fixtures need to be used in a given space and the overall cost for an installation can be reduced accordingly.

Another advantage of indirect lighting: Because of the very even illumination created, a lower ambient lighting level may work for a given space. For example, 30 footcandles of indirect illumination may be sufficient in a location where 40 or 50 footcandles of direct lighting would be required to provide a similar ambience. This will lead to the same order of energy savings discussed in “How Much Light?” on page 7.

### Choosing Among Lamp and Ballast Options

A dizzying variety of fluorescent lamps is available, including “energy-saver,” premium, and high-performance or “super-T8” versions. The user must also choose color temperature (2,700 to 6,000+ K), CRI level (50 to 90+), lamp diameter (T12, T8, or T5), light output level (standard, high-output [HO], or very-high-output [VHO]), and starting method (rapid-start, programmed rapid-start, or instant-start). For most general lighting applications, the best choices are:

- *T8 lamps (eight-eighths of an inch in diameter).* T8s offer better efficiency, lumen maintenance, color quality, fixture optics, and life-cycle costs than T12 systems. The most efficient T8s are the high-performance type, also commonly called “super T8s” (**Table 4**, page 14).<sup>7</sup> High-performance T8 lamps can be installed to cost-effectively upgrade lower-quality T8s. “Energy-saver” and “reduced-wattage” T8s can also provide energy savings, but they have several shortcomings: They can only operate in spaces where temperatures are kept at a minimum of 60° Fahrenheit (F),

**Figure 9: Recessed direct/indirect fixture**

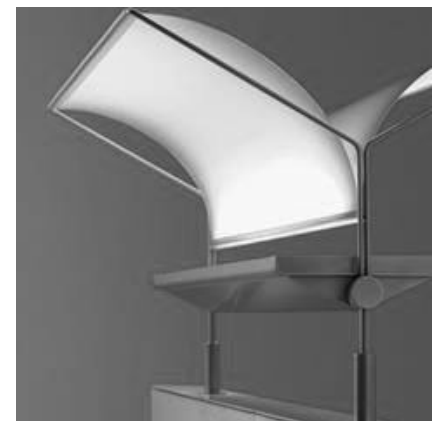
For lower ceiling heights, consider recessed direct/indirect fixtures.



Courtesy: Platts

**Figure 10: Furniture-mounted indirect fixture**

Furniture-mounted indirect fixtures can provide high-quality lighting in areas with low ceilings.



Courtesy: Steelcase Inc. [6]



they produce less light than full-wattage lamps, and they are not dimmable with current ballast technology.

- *T5 lamps (five-eighths of an inch in diameter).* T5 lamps are available only in metric lengths and are generally not a good retrofit option, although products are now entering the market that enable a T8-to-T5 conversion. T5s are a more effective choice in new construction or major renovations. Their efficacy is similar to that of T8 lamps, but their smaller size affords better optical control. The T5 lamp is currently designed for operation only on high-frequency, rapid-start, or programmed rapid-start electronic ballasts. T5 lamps also offer high lumen maintenance, putting out as much as 97 percent of their original light output at 40 percent of rated life. T5 lamps are also designed for a high optimal operating temperature, which improves performance in enclosed fixtures and warm spaces.
- *Four-foot lamps.* This is the most common length and thus is the cheapest and easiest to buy and stock. Eight-foot lamps are also common and are slightly more efficient, but they break more easily and can be difficult to transport.
- *Standard light output.* Standard-output lamps are generally more efficient and less costly than HO and VHO systems, and they are available with a wider range of color temperatures.

**Table 4: The T8 family tree**

Linear T8 fluorescent lamps are available with a wide variety of characteristics. The “higher-lumen” T8 lamps offer the highest output and the best color quality.

Lamp type	Nominal power (watts)	CRI	Efficacy (lumens/watt)
700 series	32	70s	<85
800 series	32	Low 80s	87–94
Higher lumen (super T8)	32	High 80s	94–100
Energy saver	30	High 80s	94–100
Reduced wattage	28	High 80s	94–100
Reduced wattage	25	High 80s	94–100

Note: CRI = color-rendering index.

Courtesy: Platts; data from Consortium for Energy Efficiency [7]

- *CRI in the 80s.* Light sources with a CRI in the 80s will provide sufficient color rendering for most purposes and are far superior to the old “cool-white” halophosphor lamps that had a CRI in the 60s. Fluorescent lamps with CRIs in the 90s are available, but they carry a substantial penalty in efficacy.
- *Correlated color temperature of 3,500 K to 4,100 K.* A CCT of 3,500 K is a good middle ground that can blend acceptably with warmer incandescents or earth tone color schemes; 4,100-K lamps may blend better with cooler daylight, HID sources, or blue-gray color schemes.

An equally large array of fluorescent ballasts is available. The best choices for ballasts are:

- *Electronic (high-frequency) ballasts.* Electronic ballasts are about 12 percent more efficient than conventional line-frequency magnetic ballasts (see **Figure 11**, page 16). They eliminate flicker and hum and are extremely cost-effective. The most efficient ballasts are “high-performance,” as defined by the Consortium for Energy Efficiency (**Table 5**).<sup>8</sup> There are a few locations where it is still best to use low-frequency magnetic ballasts: in recording studios, close to radio-frequency security systems (such as those in bookstores), and in other extremely sensitive electronic environments that

**Table 5: High-performance T8 ballasts**

According to the definition from the Consortium for Energy Efficiency, high-performance T8 ballasts must have a ballast efficacy factor (BEF) at least as high as the ones shown here.

Number of lamps in fixture	Instant-start ballast BEF			Programmed rapid-start ballast BEF		
	Low BF <sup>a</sup>	Normal BF <sup>b</sup>	High BF <sup>c</sup>	Low BF <sup>a</sup>	Normal BF <sup>b</sup>	High BF <sup>c</sup>
1	3.08	3.11	NA	2.84	2.84	NA
2	1.60	1.58	1.55	1.48	1.47	NA
3	1.04	1.05	1.04	0.97	1.00	NA
4	0.79	0.80	0.77	0.76	0.75	NA

Note: BEF = 100 × (BF/ballast input power in watts);  
 BF = ballast factor; NA = not applicable.  
 a. Low BF: ≤0.85.  
 b. Normal BF: 0.85 < BF ≤ 1.0.  
 c. High BF: ≥1.01.

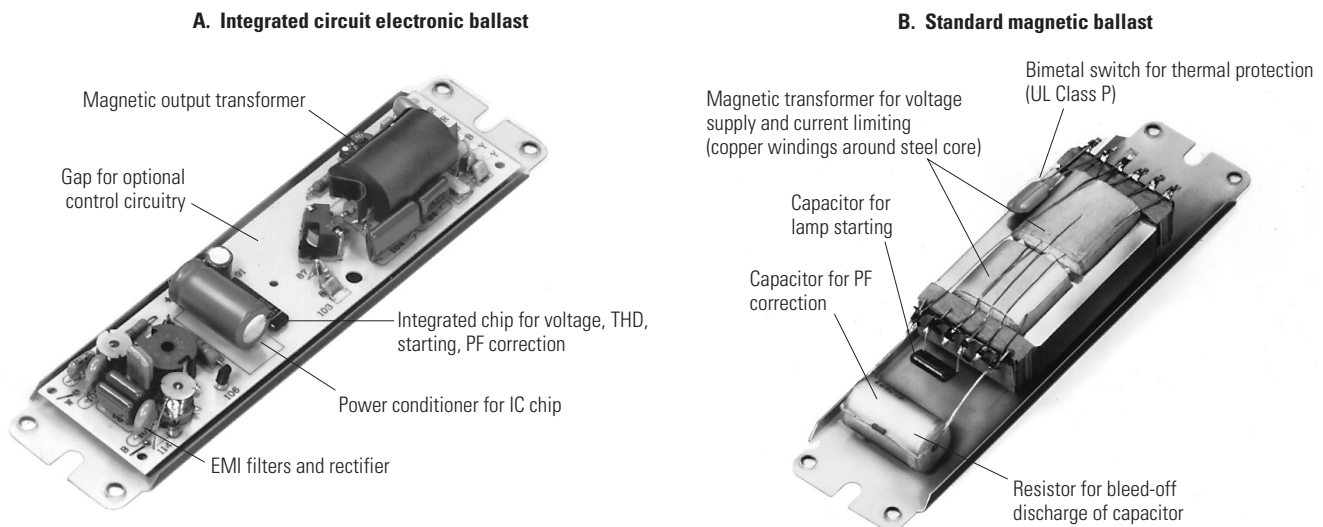
Courtesy: Platts; data from Consortium for Energy Efficiency [8]

may be disturbed by the ballasts' high-frequency emanations. High-efficiency low-frequency ballasts are available.

- *Instant-start ballasts.* This is the most efficient type of ballast, but it yields the shortest lamp life in most applications. It is a good choice for lamps that burn six hours or more per start.
- *Universal-input voltage.* Universal-input ballasts typically accept any input voltage between 120 and 277 volts. They make retrofitting easier and reduce stocking requirements, but they are slightly less efficient than dedicated-voltage ballasts.
- *Programmed-start ballasts.* Programmed-start ballasts, also known as programmed rapid-start ballasts, are improved versions of the older rapid-start technology that, in almost all cases, maximize lamp life but carry some penalty in efficiency. They are the best choice in applications where lights will frequently be turned on and off.

### Figure 11: What's in a ballast?

Electronic ballasts (A) operate at very high frequencies, which makes them more efficient than common magnetic ballasts (B).



Notes: EMI = electromagnetic interference; IC = integrated circuit; PF = power factor; THD = total harmonic distortion; UL = Underwriters Laboratories

Courtesy: Platts



- *Dimming ballasts where appropriate.* Fully dimmable fluorescent ballasts enable strategies such as automatic daylight dimming, lumen maintenance (automatically adjusting ballast power to compensate for the gradual loss of light output that all fluorescent lamps experience), occupancy-controlled and scheduled dimming, and manual task dimming (giving the occupant a rotary or sliding dimmer switch, or control through a personal computer). Several dozen models of continuously dimming ballasts for full-size fluorescent lamps are now available on the U.S. market, and prices are dropping into the low-\$30 range for two-lamp dimming ballasts. An example of dimming energy savings is shown in Figure 5.

Finally, make sure that lamps and ballasts are compatible. Most lamps are only compatible with one starting method; the exceptions are high-performance T8s, which can be rapid- or instant-started, and some rapid-start lamps can be preheat-started.

## Compact Fluorescent Lamps

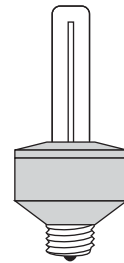
Compact fluorescent lamps (CFLs) can be used instead of incandescent lamps for many applications, including downlights, sconces, table lamps, task lights, and wall washers. Although CFLs have a much higher initial cost than incandescents, they are an exceptional bargain in the long run, with typical pay-backs of less than one year.

CFLs may be self-ballasted or pin-base (**Figure 12**). Pin-base units may be either modular or dedicated. Self-ballasted CFLs—also known as screw-base, screw-in, or integrally ballasted CFLs—are designed to replace incandescent lamps without requiring any modifications to the existing incandescent lamp fixtures. Self-ballasted CFLs combine a lamp, ballast, and base (the Edison screw base—or another standard base in some countries—which fits the incandescent lamp socket) in a single sealed assembly. The entire assembly is discarded when the lamp or ballast burns out.

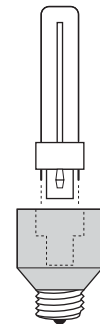
**Figure 12: CFL lamp–ballast systems**

Compact fluorescent lamps (CFLs) come in three different configurations: self-ballasted, modular, and dedicated. Both modular and dedicated lamps are pin-base configurations.

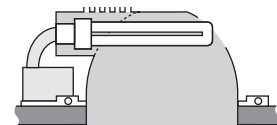
Self-ballasted



Modular (pin-base)



Dedicated (pin-base)



Courtesy: Platts

One of the most important commercial uses of CFLs is in recessed downlight cans.

Pin-base CFLs are designed to be used with a separate ballast. As with linear fluorescent systems, lamp and ballast must be compatible. Pin-base CFLs are available in lower-power versions designed to replace incandescent lamps and in higher-power versions designed to replace linear fluorescent lamps or even high-intensity discharge (HID) lamps.

Dedicated systems, also called hardwired systems, feature a ballast and pin-base fluorescent lamp socket that are permanently wired into a fixture by the fixture manufacturer or as part of a retrofit kit. The lamp can be replaced with another compatible pin-based CFL when it burns out. Because they are hardwired and not screwed into a standard screw-base socket, dedicated systems eliminate the possibility that a user will return to using an inefficient incandescent bulb.

With modular units, a separate lamp is plugged into an Edison or other style of adapter/ballast. With this design, when the lamp burns out, the entire assembly need not be discarded. Instead, a relatively low-cost replacement lamp can be installed in the same ballast base, which typically lasts for 40,000 to 60,000 hours of operation. Lamps for modular units have either two or four pins in their bases. The key disadvantage of modular units is that the pin base on the lamp and the matching socket on the adapter make modular CFLs larger than self-ballasted CFLs of equivalent light output. The development of low-cost electronic ballasts for self-ballasted CFLs has decreased the cost advantage and popularity of modular systems.

One of the most important commercial uses of CFLs is in recessed downlight cans. A wide range of fixtures is now available for this fixture class, some with very sophisticated reflector designs, excellent optical control, and dimming options.

The first cost of CFL systems may appear high compared with that of incandescent systems, but the energy savings and

reduced relamping costs earn back that money quickly. The longer the annual operating hours, the more attractive the economics of CFLs become, because more incandescent relamping costs are being avoided per year.

**Table 6** illustrates energy, lamp, and labor savings that result from replacing a 75-watt incandescent lamp with either a 19-watt spiral lamp or a 24-watt circline lamp.<sup>9</sup> (These lamps come close to the 3:1 wattage ratio discussed below.) The annual savings for a \$7 CFL are more than \$10 in energy costs and about \$10 in maintenance. Including labor for the installation, the CFLs in this application pay back in less than half a year.

Don't try to "stretch" CFL light output.

**Table 6: Economics of CFLs versus incandescent lamps**

Compact fluorescent lamps (CFLs) still cost more than incandescent lamps, but they more than make up for that difference in energy and maintenance savings.

	Baseline incandescent (75 W)	CFL spiral shape (19 W)	CFL circline (24 W)
<b>Performance</b>			
Initial light output (lm)	1,180	1,200	1,100
Design light output (lm)	1,062	960	880
Lamp lifetime (h)	750	10,000	10,000
Power input (W)	75	19	24
Initial efficacy (lm/W)	15.70	63.00	45.83
<b>Energy</b>			
Annual energy use (kWh/y)	187.5	47.5	60.0
Annual energy use (\$/y)	15.00	3.80	4.80
Annual energy savings (\$/y)	NA	11.20	10.20
<b>Maintenance</b>			
Lamp cost (\$/lamp)	1	7	7
Relamping labor cost (\$/lamp)	2.5	2.5	2.5
Annual lamp cost	3.33	1.75	1.75
Annual labor cost	8.33	0.63	0.63
Annual maintenance savings, lamp + labor (\$/y)	NA	10.42	10.42
<b>Summary</b>			
Annual operating cost, energy + maintenance (\$/y)	26.67	6.18	7.18
Annual operating cost savings (\$/y)	NA	20.49	19.49
Payback on first CFL installed (y)	NA	0.46	0.49

Notes: CFL = compact fluorescent lamp; h = hour; kWh = kilowatt-hour; lm = lumen; NA = not applicable; W = watt; y = year.

- Design light output for incandescent lamp based on 10% lumen depreciation at 40% of rated life.
- Design light output for CFLs based on 20% lumen depreciation at 40% of rated life.
- Annual operating time = 2,500 h. Electricity cost=\$0.08/kWh.

Courtesy: Platts; data from Home Depot [9]

It is particularly important that a given facility standardize on just a couple of types of CFLs.

CFLs should be applied carefully. Key points to consider include:

- *Don't try to "stretch" CFL light output.* The light output of CFLs is sometimes less than expected because of the effects of temperature, ballast factor, mounting position, cycling, and lumen depreciation. Rather than the 4:1 ratio often published (a 25-watt CFL can replace a 100-watt incandescent lamp), a 3:1 ratio is more appropriate (a 25-watt CFL can replace a 75-watt incandescent lamp).
- *Simplify lamp selection.* It is particularly important that a given facility standardize on just a couple of types of CFLs to reduce stocking requirements and confusion at relamping time. One recently constructed small commercial building required two-pin 13-watt lamps, four-pin 18-watt lamps, two-pin 18-watt lamps, and screw-in 23-watt lamps; careful fixture specification could have reduced this array to only the 13-watt and a single type of 18-watt lamp.
- *Use hardwired fixtures.* "Snap-back" is a significant problem for CFL installations: the original lamps may be replaced with high-wattage incandescents by unaware maintenance staff. The best defense against this possibility is to use dedicated hardwired fixtures that will only accept pin-based CFL lamps.

## High-Intensity Discharge Lamps

HID lighting sources are the primary alternative to high-wattage incandescent lamps wherever an intense point source of light is required. Although HID lamps can provide high efficacy in a wide range of sizes, they have special requirements for startup time, restrike time, safety, and mounting position. There are three basic types of HID lamps: mercury vapor, metal halide, and sodium.

## Mercury-Vapor Lamps

Mercury-vapor lamps are the oldest style of HID lamp. Although they have long life and low initial cost, they have poor efficacy (30 to 65 lumens per watt, not including ballast losses) and exude a pale green color. Perhaps the most important issue concerning mercury-vapor lamps is how to best avoid them by using other types of HID or fluorescent sources that have better efficacy and color rendering.

## Metal-Halide Lamps

Metal-halide lamps are similar to mercury lamps, with an important improvement: The addition of iodides of metals such as thallium, indium, and sodium to the arc tube makes for much better color and an efficacy of up to 100 lumens per watt. Were it not for several limitations, metal-halide lamps might be considered the ideal light source. Here are some of those limitations:

- Starting the lamps takes three to five minutes, and restarting after a shutdown or power outage takes 10 to 20 minutes. Electronic ballasts have reduced, but not eliminated these delays (**Table 7**).<sup>10</sup>
- Metal-halide lamps produce relatively high levels of ultraviolet (UV) radiation that must be controlled with shielding glass in the lamp or fixture. Protection from possible explosion is also required.

**Table 7: Metal halide warm-up and restrike times**

Electronic ballasts have shortened warm-up and restrike times for pulse-start metal-halide lamps.

Lamp/ballast type	Warm-up time (minutes)	Restrike time (minutes)
Probe-start MH, magnetic ballast	4–5	10–20
Pulse-start MH, magnetic ballast	2–3	3–5
CMH, magnetic ballast	2–3	10–20+
Quartz pulse-start MH with electronic ballast	1–3	2–4
CMH with electronic ballast	1–3	10–20+

Notes: CMH = ceramic metal halide; MH = metal halide.

Courtesy: Platts; data from Stan Walerczyk [10]

The light output of metal-halide lamps is sensitive to lamp position.

- The color of the light output from a metal-halide lamp can shift, sometimes dramatically and randomly. Electronic ballasting and new lamp designs using ceramic arc tubes can limit this undesirable characteristic.
- The light output of metal-halide lamps is sensitive to lamp position. (Mercury-vapor and sodium lamps are not position-sensitive.) Three types of lamps are available: BU/BD lamps are intended to be operated in the base-up or base-down (vertical) position; HOR or H lamps are designed to operate in the horizontal position; and UNI or U lamps are designed for universal operation and may be installed in any position.

Several technology developments have made metal-halide systems more effective. Manufacturers of metal-halide lamps introduced pulse-start technology in the late 1980s and early 1990s to improve on the performance of older probe-start technology (see Table 7). Yet despite the improvements, probe-start metal-halide lamps still make up a big share of the market. More recently, electronic ballasts and ceramic metal-halide lamps have improved performance even further. Ceramic lamps offer improved CRI and lower lumen depreciation rates. Electronic ballasts improve efficiency and color-output stability, reduce lumen depreciation rates, and cut warmup and restrike times (**Table 8**). Many are also dimmable.

### Sodium Lamps

There are two types of sodium lamps: high-pressure sodium (HPS) and low-pressure sodium (LPS). HPS lamps produce a familiar yellow light; they vary widely in their efficacy and color quality. There are three basic grades of HPS lamps with different

**Table 8: Ceramics boost metal-halide performance**

Ceramic arc tubes boost the color quality and lumen maintenance of pulse-start metal-halide lamps.

Property	Quartz metal halide	Ceramic metal halide
CRI	65–70	90–95
EOL lumen maintenance (with electronic ballast, in %)	70	80

Note: CRI = color-rendering index; EOL = end of life. Data for 250- to 400-watt lamps.

Courtesy: Platts; manufacturers' data

CRI: the lowest is about 21 (typically used for outdoor lighting); general-purpose indoor units have a CRI of around 60; and the less-common “white” versions boast a CRI up to 80 or higher. Unfortunately, for HPS lamps, better color comes at a price of lower efficacy and shorter lamp life. The most common application of HPS lamps is for roadway and parking-lot lighting.

The applications of LPS lighting are extremely limited by the nearly monochromatic yellow light they produce. One of the few applications for LPS lamps is outdoor lighting near observatories, where the narrow wavelength band can more easily be filtered from the view of the telescope.

**HID Applications**

HID sources are now available in sizes from 20 to 2,000 watts, from seven primary manufacturers. More than 20 manufacturers offer HID fixtures for a variety of applications, from retail track lighting to industrial and sports lighting. **Table 9** lists typical applications for HID lamps, which operate well at temperatures down to -20°F, making them excellent for outdoor applications such as street lighting, billboards, and security illumination.

Here are the primary HID applications and some important points for successful, energy-efficient installations.

**Table 9: HID light sources and applications**

Excellent color properties and a wide range of sizes make metal-halide lamps the most versatile high-intensity discharge (HID) light source.

Application	Metal halide	Ceramic metal halide	High-pressure sodium	Low-pressure sodium
Interior, decorative	•	•		
Downlights	•	•		
Parking areas	•		•	•
General outdoor	•		•	•
Roadways or tunnels	•		•	•
Sports arenas	•	•		
High-bay spaces (hangars, warehouses, etc.)	•	•	•	
Low-bay spaces (supermarkets, light industrial, retail shops, etc.)	•	•	•	
Outdoor signage	•			

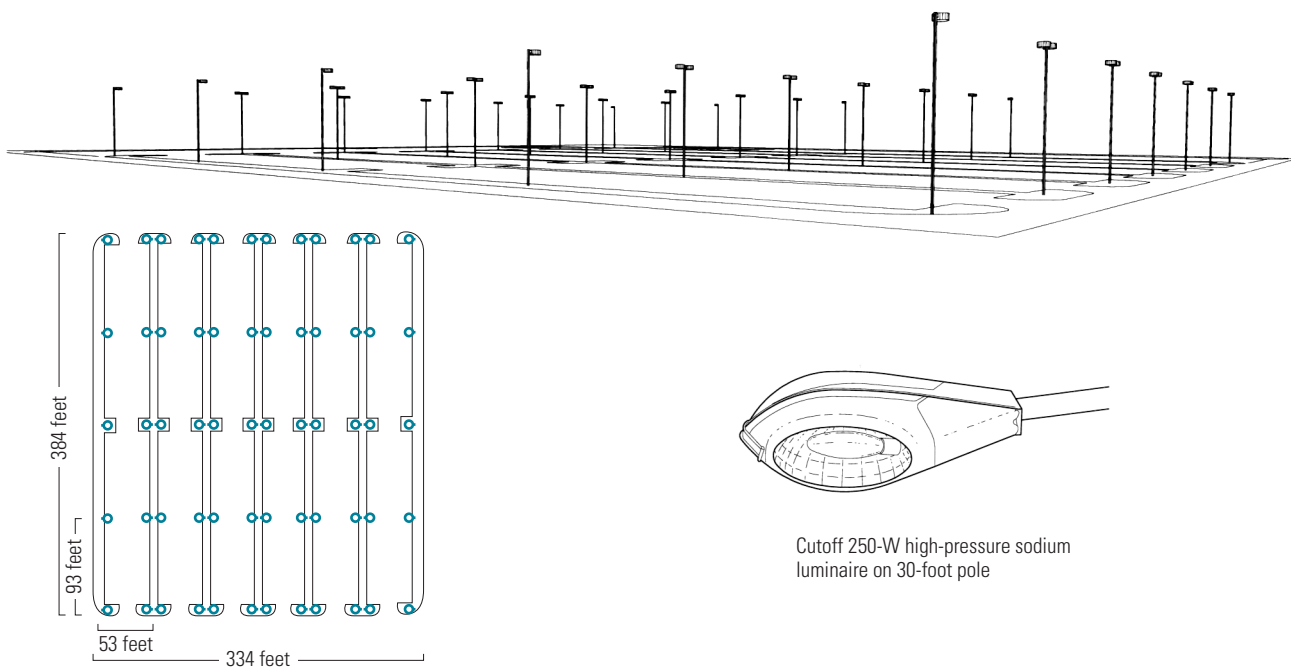
Courtesy: Platts

**Outdoor lighting.** HIDs are the most common source for outdoor luminaires, which typically use a single bright lamp to cover a large area. Note that in recent years, larger CFLs and induction lighting (see the “Induction Lamps” section, page 31) have become viable sources for outdoor lighting as well, offering good color quality and increased controllability. In designing outdoor lighting systems, remember the following:

- *Select an appropriate design illumination level.* Many parking lots and outdoor features are vastly overlit. An average of 1 footcandle (or less) is usually sufficient. For more information, refer to the *IESNA Lighting Handbook* and several of its recommended practices.<sup>11</sup>
- *Specify IESNA-cutoff luminaires or full-cutoff luminaires* (those that don’t spray light into the sky above the horizontal).

**Figure 13: Conventional parking lot design**

This design was going to be used for a new government laboratory parking lot surrounded by residential neighborhoods, until an environmental impact review led to the alternative design depicted in Figure 14. The conventional design uses 250-watt (W) high-pressure sodium lamps in full-cutoff cobra head fixtures. There are five rows and seven columns of luminaires. The five inner columns are 30 feet tall. The average illuminance is about 2.0 foot-candles, and the minimum is about 0.5 foot-candles. The ratio of maximum to minimum illuminance is 7:1.



Courtesy: Clanton Associates [12]

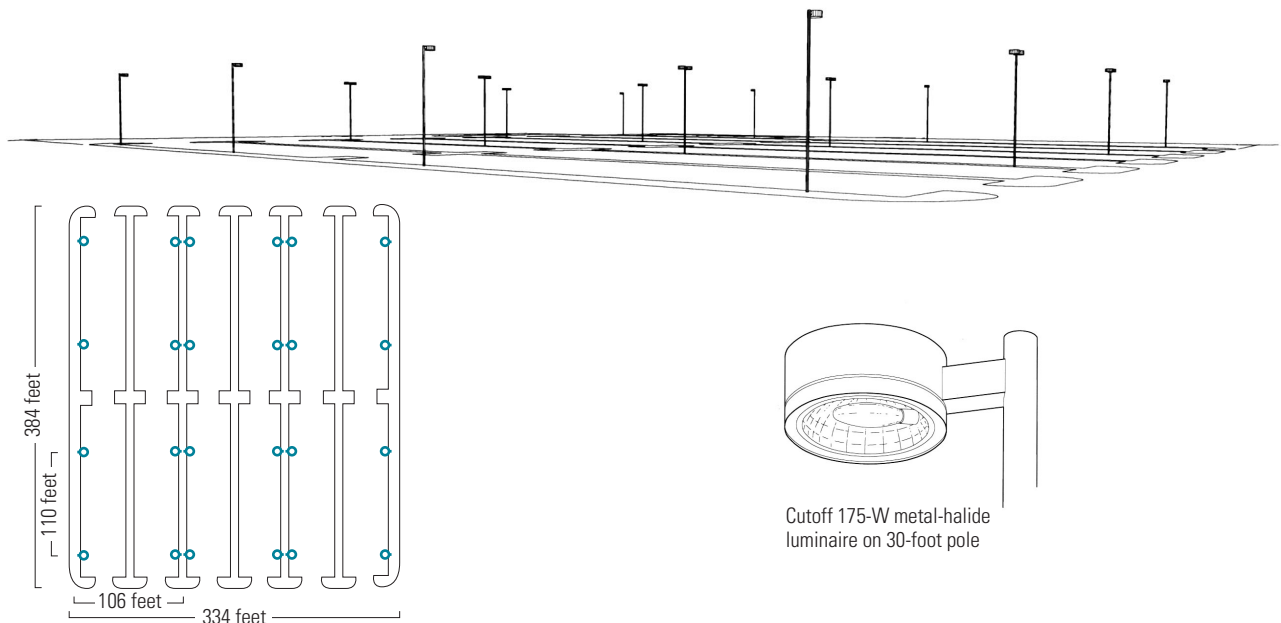


Shining light above the horizontal plane is wasteful and annoys neighbors. Title 24 requires that all outdoor luminaires that use lamps rated greater than 175 watts in areas such as parking lots, building entrances, sales and non-sales canopies, and all outdoor sales areas be full-cutoff.

- *Use whiter light sources.* Recent research, although not yet codified, shows that the whiter light produced by metal-halide lamps provides better “seeability” than an equivalent amount of yellowish light from sodium lamps.
- *Ensure accurate control.* Many outdoor lights do not need to stay on all night. Use time clock, photo cell, motion detector, or pager controls to run the lights only when needed or to dim as appropriate.

#### Figure 14: Efficient parking lot design

The alternative design uses 175-watt (W) metal-halide lamps. The “hockey puck” cutoff luminaires distribute light more efficiently than the cobra heads in the conventional design, allowing fewer poles and luminaires to be used. In this design, there are only four rows and four columns. The two outer columns use one luminaire per pole and the two inner columns use two luminaires per pole (24 luminaires and 16 poles total). As in the conventional design, the poles are 30 feet tall. The average illuminance is about 1.0 foot-candle, the minimum is about 0.3 foot-candles, and the ratio of maximum to minimum illuminance is about 9:1. Even better performance might be achieved by using 150-watt metal-halide lamps with electronic ballasts or induction lamps.



Courtesy: Clanton Associates [12]

A recent parking lot design provides an excellent example of these principles. The original baseline design used 60 250-watt HPS lamps to provide average illuminance of 2 footcandles (Figure 13, page 24).<sup>12</sup> An alternative design used 24 175-watt metal-halide lamps for average illuminance of 1 footcandle (Figure 14, page 25). Table 10 compares the capital and operating costs of these two system designs; the whiter, dimmer, metal-halide system cut installation costs by 42 percent and operating costs by 65 percent. This system fully complies with IESNA recommendations.

**High-bay lighting.** HID lighting was the primary source used in industrial spaces and big-box retail stores with high ceilings until about the year 2000, when high-intensity fluorescent lamps and fixtures began to take over. The fluorescent systems offered better efficacy, lower depreciation rates, better dimming

**Table 10: Economic comparison — conventional and efficient parking lot designs**

The efficient design uses fewer poles and luminaires than the conventional design. This is made possible by using higher-quality luminaires with better light distribution. Although the metal-halide lamps and luminaires used in the efficient design cost more per unit, using fewer of them reduces overall first costs by about 40 percent. Energy costs fall by about 70 percent in the efficient design due to fewer and lower-wattage lamps. Maintenance costs are slightly higher for the efficient design because the metal-halide lamps have a shorter life and must be replaced more frequently.

Conventional system			Efficient system		Savings	
Operation and maintenance			Cost	Cost	Dollars	Percent
Energy cost per year			\$6,412	\$1,766	4,646	72
Maintenance cost per year			\$723	\$746	-23	-3
Total annual O&M			\$7,135	\$2,512	2,512	65
Capital costs			Equipment	Equipment	Dollars	Percent
		Initial cost		Initial cost		
Lamps	60 250-W HPS (305 W with ballast losses)	\$19.20 each, \$1,152 total	24 175-W metal halide (210 W with ballast losses)	\$25.30 each, \$605 total	547	48
Luminaire	60 cobra head (full cutoff); 10 one-head, 25 two-head	\$246 per head, \$14,760 total	24 curvilinear (full cutoff) "hockey puck;" 8 one-head, 8 two-head	\$585 per head, \$14,054 total	706	5
Poles	35 poles; 10 one-head, 25 two-head, all 30 feet	\$732 each one-head \$840 each two-head \$28,320 total	16 poles; 8 one-head, 8 two-head	\$900 each \$14,400 total	13,920	49
Installation costs (total)	Trenching, foundation, head installation, pole installation, and wiring	\$38,311	Trenching, foundation, head installation, pole installation, and wiring	\$18,999	19,312	50
Total installed cost			\$82,543	\$48,058	34,485	42

Notes: HPS = high-pressure sodium; O&M = operations and maintenance; W = watt. 4,380 hours per operation; \$0.08 per kilowatt-hour; initial cost includes 20 percent contractor markup on equipment. HPS lamp life 24,000 hours; metal-halide lamp life 10,000 hours; annual maintenance includes \$50 per lamp spot-relamping labor.

Courtesy: Clanton Associates [12]

options, better color rendition, less glare, and faster start-up and restrike times. Fluorescent systems are still the best option in most cases, but the introduction of electronic ballasts and ceramic metal-halide lamps in the mid-wattage sizes (250 to 400 watts) have opened up several niches for HID lamps. Although these newest HID technologies are still expensive, they should be evaluated for these applications:

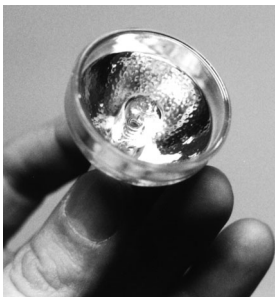
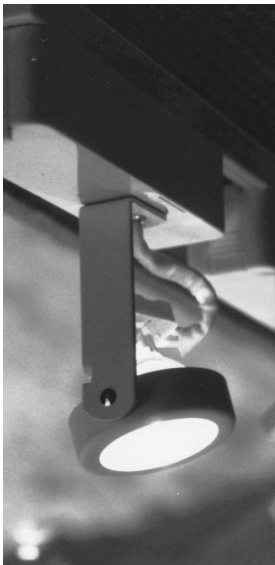
- *When color is crucial.* Ceramic metal-halide lamps, with their CRIs in the 90s, are a good fit for big-box retail stores, especially high-end outlets, and in quality control areas in some manufacturing and maintenance operations.
- *When it's too hot or too cold.* Light output of fluorescent systems is sensitive to temperature, whereas metal-halide lamp output is not. In unconditioned facilities under extreme conditions, advanced metal-halide technology provides higher efficacy and ensures that there are adequate levels of light for safe operation. New fluorescent lamp and fixture designs may change the picture.
- *No other choice.* In some cases, a facility can only use metal-halide lamps—fluorescents are not an option. Examples include where a building owner or manager simply prefers the look of a metal-halide fixture; corrosive environments, where it can be easier to seal the more compact metal-halide fixture; and where a single high-powered source is desired.

**Retail, accent, and specialty lighting.** A new generation of compact metal-halide systems has been developed for track lighting in retail and other locations. Other fixtures such as sconces, pendants, and even torchieres have been created for specialty applications and, with electronic ballasts, they offer high efficiency, minimal color drift, and high lumen maintenance. Color drift is still a problem with dimming. Recently, low-wattage self-ballasted metal-halide lamps have been introduced, providing a high-efficiency, long-life alternative to halogens for retail lighting.

Recently, low-wattage self-ballasted metal-halide lamps have been introduced.

**Figure 15: Halogen incandescent spotlight**

Although halogen lamps like the MR-16 shown here are often thought to be “efficient” light sources, their efficacy is only slightly better than regular incandescents. For retail and other applications for which high contrast and color rendering are required, however, they are still an important light source.



Courtesy: Platts

**Remote lighting applications.** HID lamps are the best option for driving light engines that feed fiber-optic networks or light pipes, which carry light over some distance to one or more outlets or distribute it evenly along the way. Remote lighting can provide very high efficiency while solving problems such as heat or UV damage and maintenance access. HID-fed light pipes are now being installed in facilities such as museums and jewelry stores.

## Incandescent Lamps

For a number of years, incandescent lamps have been challenged by alternative sources with lower life-cycle costs. For some applications, however, incandescents are still the best choice. They have low initial cost, provide easy dimming, and still come in a wider array of sizes, shapes, wattages, and distribution patterns than any other light source. Refinements in incandescent technology continue to boost their performance, allowing for their selective use in energy-efficient design.

Several developments have improved the incandescent lamp, including halogen encapsulation (**Figure 15**). Surrounding the incandescent filament with a quartz-glass capsule containing

### CASE STUDY: INEFFICIENT SOURCE MAKES AN EFFICIENT SYSTEM

When the Tucson Medical Center (TMC) shifted to “patient-focused care,” paperwork tasks moved from a central office to small fold-down tables outside each patient’s door, creating a lighting challenge for facility engineers. The indirect cove lighting in the hallway was never designed to accommodate detailed taskwork, so Steve Bragg, a member of the TMC facilities team, worked with vendors, engineers, and contractors to devise this elegant solution: Pulling the table down from the wall activates a single 20-watt MR-11 spotlight mounted on the wall above, providing excellent task illumination. Because each table is self-retracting and is used for only a few minutes per shift, the energy consumption of this lighting system is extremely low. The hospital staff has been delighted with the results.

bromine or iodine gas allows the lamp to operate at a higher temperature, which improves its efficacy. The halogen cycle also recycles vaporized tungsten back onto the filament, extending lamp life.

Another refinement is the halogen infrared (HIR) lamp. HIR lamps feature a multilayer, microns-thin, spectrally selective optical coating on the outside of a lamp's quartz or glass filament capsule. The coating transmits visible light but reflects infrared (heat) radiation back onto the filament, allowing the filament to operate with less electrical power while maintaining the same temperature.

However, the efficiency benefits of halogen technology are often overstated. Efficiency for most halogen lamps ranges from 8 to 25 lumens per watt, with only the highest-wattage HIR lamps exceeding 30 lumens per watt. The most common sizes operate at about 12 to 17 lumens per watt. Compared with fluorescent and HID sources (60 to 100 lumens per watt or more), this is still dismal. The moral: Use incandescent sources—including halogen incandescent lamps—sparingly, and only when their benefits can't be matched by other sources.

## Other Light Sources

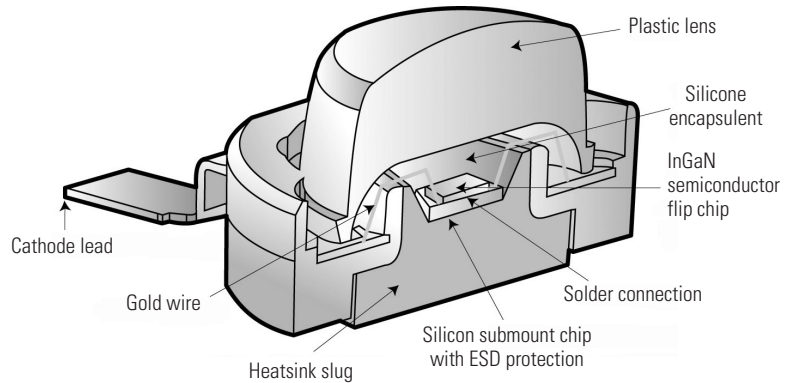
Two other light sources bear consideration for some applications: light-emitting diodes (LEDs) and induction lamps.

### LEDs

LEDs are solid-state electronic devices that create light (**Figure 16**, page 30).<sup>13</sup> They offer several advantages over conventional light sources, including long life and vibration resistance. The small size of LED sources and the directional nature of the output from an LED are also advantages in some cases. These characteristics have enabled LEDs to displace incandescent lamps in some applications, but efficiency still needs to improve significantly and costs need to decrease before LEDs are a cost-effective replacement for higher-efficiency sources such as fluorescent lamps.

### Figure 16: LED operation

Light-emitting diodes (LEDs) use solid-state electronics to create light. Major elements in the packaging of an LED include a heat sink to dissipate the energy that is not converted into light, a lens to direct the light output, and leads to connect the LED to a circuit. The drawing shows a cross section of a Luxeon LED from Lumileds Lighting.



Notes: ESD = electrostatic discharge; InGaN = indium gallium nitride.

Courtesy: Lumileds Lighting [13]

The most successful early applications for LEDs have been those where they replace filtered incandescent bulbs, such as in traffic signals and exit signs. That's because the filtering of the light emitted makes an already inefficient source even less efficient. The efficacy of incandescent lamps is relatively low: about 17 lumens per watt for a conventional 100-watt bulb. When incandescent lamps are used to produce colored light, an absorptive filter is placed in front of the white light source to absorb all colors except those that are required for the application. When red light is needed for, say, a traffic signal or automotive brake lamp, this absorptive filter reduces the efficacy of the incandescent lamp-plus-filter combination to less than 5 lumens per watt. LEDs, on the other hand, are naturally narrow-band sources, and the color of the light they generate is based on the materials used to construct the LED instead of on a filter. Modern, high-brightness red LEDs operate with an efficacy of 15 to 30 lumens per watt, which makes them much more efficient sources of red light than filtered incandescent lamps. The other area where high-brightness LEDs have displaced other light sources is large outdoor displays. And retail accent lighting is a

growing area for LEDs, because LEDs provide the ability to vary color, create sparkle, and aim the light precisely.

For general illumination, LEDs still have a long way to go. As of 2005 the most efficient white LEDs available offered an efficacy of about 25 lumens per watt at ideal operating conditions, and about 22 lumens per watt at real-world conditions—not much more than a typical incandescent lamp. Also, producing white light with LEDs still costs far more than it does with other light sources (**Table 11**).<sup>14</sup>

### Induction Lamps

Induction lamps, also called electrodeless lamps, differ from other discharge lamps in the manner in which they provide excitation. In a fluorescent lamp, an electric field is generated to ionize molecules of mercury gas. The ionized mercury emits UV radiation that strikes the phosphor coating on the inside surface of the lamp, causing it to emit photons of visible light. In a conventional lamp, the electric field is produced by a voltage imposed between two electrodes. An electrodeless lamp differs because the electric field results from varying magnetic fields in a phenomenon known as Faraday's Law of Induction—the same law that is the basis of electric generators. In practice, the electrodeless system consists of a high-frequency power generator, a coupling device that generates a magnetic field (essentially an antenna), and a glass housing that contains the gases and phosphor coating. Electrodeless lamps could be fluorescent or HID by type, although all of the electrodeless products commercially available today are fluorescent.

The main advantages of induction lighting are the ability to produce a substantial amount of light in a relatively compact package and long lamp life due to the elimination of the electrodes. The major drawbacks of induction lamps include high cost and luminaire design challenges. In applications where maintenance costs are high, systems with well-designed fixtures can be cost-effective.

Induction lighting can be a good choice anywhere that relamping and maintenance are difficult or hazardous.

**Table 11: Cost of light sources**

It costs far more to produce 1,000 lumens of light with a light-emitting diode (LED) than it does with other light sources.

Source	Cost (\$/thousand lm)
Incandescent, 40 W	25
Fluorescent, F32T8	1
Metal halide, 175 W	2
CFL, self-ballasted	20
LED	150

Notes: CFL = compact fluorescent lamp; lm = lumen; W = watt. Includes replacement costs over 20,000 operating hours; does not include costs of energy.

Courtesy: Platts; data from Victor Roberts [14]

Lighting plays a role in LEED in a number of categories.

Existing induction-lamp products are aimed at two distinct market niches. The higher-wattage versions available (55 to 165 watts) offer very long life (up to 100,000 hours) and can be a good choice anywhere that relamping and maintenance are difficult or hazardous. These lamps have been used in all of the following locations:

- Escalator wells
- High-ceilinged spaces, such as those found over open mall areas and in warehouses and factories
- Parking garages
- Roadways, including bridges, tunnels, underpasses, and signs
- Exterior pedestrian lighting

Lower-wattage induction lamps (20 and 23 watts) are also available as direct replacements for medium-base incandescent and compact fluorescent lamps. They offer efficacies of about 50 lumens per watt, CRIs of 82, and an expected life of 15,000 hours.

## Lighting and LEED

Lighting plays a role in the Leadership in Energy and Environmental Design® (LEED) rating system. LEED is a rating system created by the U.S. Green Building Council (USGBC) to accelerate the development and implementation of green building practices. The USGBC is a nonprofit organization founded to promote the construction of environmentally responsible buildings. It established LEED to serve as a brand for high-performance buildings and to provide a common standard for measuring the sustainability or “greenness” of a building.

A building earns a LEED rating (certified, silver, gold, or platinum) based on how many points it earns in the following categories: Sustainable Sites, Water Efficiency, Energy & Atmosphere, Material Resources, Indoor Environmental Quality,



Innovation & Design Process. Lighting plays a role in LEED in a number of these categories:

**Sustainable Sites.** A LEED point is available in this category for reducing light pollution. Such measures as eliminating exterior uplights and using full-cutoff luminaires can help meet the LEED requirements.

**Energy & Atmosphere (E&A).** Lighting plays a role in meeting two of the prerequisites for E&A points: commissioning and minimum energy performance. Lighting controls must be commissioned to function properly. In addition, all LEED buildings must meet either the local energy code requirements or the provisions of ASHRAE/IESNA 90.1-1999, whichever is tighter. (Note: the next version of LEED will be based on the 2004 version of ASHRAE/IESNA 90.1.) In addition, the more efficient a building is, the more points it will be awarded, up to an additional 10 points. Although lighting is not called out specifically, the more efficient the lighting systems are, the more efficient the whole building will be. Also, within the E&A category, points are awarded for measurement and verification, and lighting control systems often provide measurement and verification capabilities that can be used to help achieve credit.

**Indoor Environmental Quality.** Lighting plays a role in two areas in the Indoor Environmental Quality category. First, credits are given for providing individuals and groups with the ability to control thermal, ventilation, and lighting systems in order to improve their productivity, comfort, and well-being. Second, credits are available for the use of daylighting and the provision of outdoor views.

**Innovation & Design Process.** This is a general category in which innovative lighting approaches that advance the state of the art or provide a benefit that is not already rewarded under existing LEED points may receive credit. For example, the Southern California office of the Natural Resources Defense Council received credit in this category for using fluorescent lighting with low mercury content.

LEED credits are available for the use of daylighting and the provision of outdoor views.

It is important to note that LEED is a rating system, not a “how-to” manual for sustainable design. Therefore, in going for LEED certification, it is best to design a sound building first, and then see where points may be available.

## FOR MORE INFORMATION

### **California Energy Commission (CEC)**

1516 9th Street  
Sacramento, CA 95814  
tel 916-654-4287  
web [www.energy.ca.gov](http://www.energy.ca.gov)

The CEC publishes the state's energy-efficiency standard, Title 24, which specifies minimum energy and equipment requirements for new buildings, including many provisions for lighting systems.

### **California Lighting Technology Center**

Contact: Don Aumann  
1554 Drew Avenue  
Davis, CA 95616  
tel 530-757-3493  
fax 530-757-3443  
e-mail [daumann@ucdavis.edu](mailto:daumann@ucdavis.edu)  
web [www.cltc.ucdavis.edu](http://www.cltc.ucdavis.edu)

The California Lighting Technology Center partners with lighting manufacturers, professionals, and electric utilities to develop and demonstrate energy-efficient lighting products and design.

### **Center for Lighting Education and Applied Research (CLEAR)**

Contact: Dr. R. Frank Smith, College of Engineering  
Cal Poly Pomona  
3801 West Temple Avenue  
Pomona, CA 91768  
tel 909-869-2528  
web [www.csupomona.edu](http://www.csupomona.edu)

CLEAR is one of the few college-level lighting curricula in the country. Students can earn a minor degree in illumination engineering by taking a series of classes in general illumination, controls, lamp design and fabrication, and lighting systems design. Courses are also open to the public through the college's open enrollment program.

### **Energy Star**

U.S. Environmental Protection Agency, Climate Protection Partnerships Division  
Energy Star Programs Hotline & Distribution (MS-6202)

1200 Pennsylvania Ave. NW

Washington, DC 20460

tel 888-782-7937

web [www.energystar.gov](http://www.energystar.gov)

Energy Star is a labeling service that acknowledges the top tier of energy-efficient appliances and electronics. Lighting products with the Energy Star label are two-thirds more efficient than standard products.

### **EPRI Lighting Research Office (LRO)**

3574 Atherstone Road

Cleveland Heights, OH 44121-1356

tel 216-291-1884

fax 216-382-6242

e-mail [lighting@ieee.org](mailto:lighting@ieee.org)

web [www.epri.com/lro](http://www.epri.com/lro)

The LRO funds and manages lighting research worldwide.

### **Illuminating Engineering Society of North America**

120 Wall Street, 17th floor

New York, NY 10005

tel 212-248-5000

fax 212-248-5017

e-mail [iesna@iesna.org](mailto:iesna@iesna.org)

web [www.iesna.org](http://www.iesna.org)

IESNA is the technical society for the lighting industry. The society publishes recommended practices for office lighting, outdoor lighting, and dozens of other applications, and also produces the *Lighting Handbook*, a comprehensive manual of lighting design. In addition, IESNA offers training programs that cover basic and advanced lighting technologies.

**International Association of Lighting Designers (IALD)**

Merchandise Mart, Suite 9-104

200 World Trade Center

Chicago, IL 60654

tel 312-527-3677

fax 312-527-3680

web [www.iald.org](http://www.iald.org)

The IALD is the trade association for lighting designers.

**Lighting Research Center**

c/o Rensselaer Polytechnic Institute

21 Union Street

Troy, NY 12180

tel 518-687-7100

fax 518-687-7120

e-mail [lrc@rpi.edu](mailto:lrc@rpi.edu)

web [www.lrc.rpi.edu](http://www.lrc.rpi.edu)

The Lighting Research Center performs extensive testing of lighting fixtures such as downlights and exit signs, and it publishes reports that help specifiers sift through different lighting technologies.

**National Council on the Qualification of Lighting Professionals (NCQLP)**

526 King Street, #405

Alexandria, VA 22314

tel 703-518-4370

fax 703-706-9583

e-mail [info@ncqlp.org](mailto:info@ncqlp.org)

web [www.ncqlp.org](http://www.ncqlp.org)

The NCQLP is the official administrator of LC certification, which establishes industry professionals as “lighting certified.” Applicants must meet certain criteria and pass a comprehensive exam to earn the LC designation.

**The Pacific Energy Center (PEC)**

851 Howard Street  
San Francisco, CA 94103  
tel 415-973-2277  
fax 415-896-1290  
e-mail pecinfo@pge.com  
web www.pge.com/pec

The PEC, which is run by Pacific Gas and Electric Co., offers educational programs, design tools, advice, and support to create energy-efficient buildings and comfortable indoor environments, predominantly in commercial buildings.

**Southern California Edison Customer Technology Applications Center (CTAC)**

6090 North Irwindale Avenue  
Irwindale, CA 91702  
tel 800-336-2822  
web www.sce.com/ctac

CTAC offers a number of opportunities for those interested in lighting technologies, including educational seminars, product exhibitions, and a demonstration laboratory.

**Southern California Lighting Technology Center (SCLTC)**

Contact: Gregg Ander  
6042 North Irwindale Avenue, Suite B  
Irwindale, CA 91706  
tel 626-633-7171  
fax 626-633-7196  
e-mail gregg.ander@sce.com  
web www.sce.com

The vision of the SCLTC, which is run by Southern California Edison, is to foster the application of energy-efficient lighting and daylighting in partnership with the lighting industry, lighting professionals, and the design/engineering community.

## Notes

- 1 John C. Pritchett (July 26, 2005), The Pritchett Wilson Group Inc., Manlius, NY, 315-682-4220, [www.pwgtasklighting.com](http://www.pwgtasklighting.com).
- 2 Mark S. Rea, ed., *IESNA Lighting Handbook*, 9th edition (New York: Illuminating Engineering Society of North America, 2000).
- 3 Title 24 is available online at [www.energy.ca.gov/title24](http://www.energy.ca.gov/title24).
- 4 California Energy Commission, "Modular Skylight Wells: Design Guidelines for Skylights with Suspended Ceilings," PIER Program, 500-03-082-A-13 (October 2003), from [www.energy.ca.gov/reports/2003-11-17\\_500-03-082\\_A-13.pdf](http://www.energy.ca.gov/reports/2003-11-17_500-03-082_A-13.pdf) (accessed February 18, 2005).
- 5 Ken Rackow (August 15, 2005), Marketing, Gelfand and Partners, Architects, San Francisco, CA, 415-346-4040, [ken@gelfand-partners.com](mailto:ken@gelfand-partners.com), [www.gelfand-partners.com](http://www.gelfand-partners.com); photo: Mark Luthringer Photography.
- 6 Debra Bailey (July 8, 2005), Director, Corporate Communications, Steelcase Inc., Grand Rapids, MI, 616-698-4397, [dbailey2@steelcase.com](mailto:dbailey2@steelcase.com).
- 7 Afroz Khan (March 24, 2005), Commercial Program Manager, Consortium for Energy Efficiency (CEE), Boston, MA, 617-589-3949 ext 208, [akhan@cee1.org](mailto:akhan@cee1.org).
- 8 CEE, "CEE High-Performance T8 Specification," from [www.cee1.org/com/com-lt/com-lt-specs.pdf](http://www.cee1.org/com/com-lt/com-lt-specs.pdf) (accessed August 30, 2005).
- 9 Prices from Home Depot, West Roxbury, MA (visited January 9, 2005).
- 10 Stan Walerczyk, Lighting Wizards, Walnut Creek, CA, 925-944-9481, [stan@lightingwizards.com](mailto:stan@lightingwizards.com).
- 11 Mark S. Rea, ed. [2].
- 12 Nancy Clanton (July 27, 2005), President, Clanton & Associates, Boulder, CO, 303-530-7229, [nancy@clantonassociates.com](mailto:nancy@clantonassociates.com).
- 13 Steve Landau (May 4, 2005), WW Marcom Manager, Lumileds Lighting, San Jose, CA, [steve.landau@lumileds.com](mailto:steve.landau@lumileds.com), [www.lumileds.com](http://www.lumileds.com).
- 14 Victor Roberts, "Solid State Lighting: Status & Future Directions," presentation at E SOURCE Forum, Colorado Springs, CO (November 12, 2004).



Energy Design Resources provides information and design tools to architects, engineers, lighting designers, and building owners and developers. Energy Design Resources is funded by California utility customers and administered by Pacific Gas and Electric Co., San Diego Gas and Electric, Southern California Edison, and Southern California Gas, under the auspices of the California Public Utilities Commission. To learn more about Energy Design Resources, please visit our web site at [www.energydesignresources.com](http://www.energydesignresources.com).

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