energydesignresources

design brief

LIGHTING

Many of the lighting upgrades that reduce energy consumption also improve the visual environment and provide maintenance savings.

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 follow:

- Design to get the right amount of light for the task, and distribute the light to prevent glare.
- Take advantage of natural daylight whenever possible, but avoid direct sunlight and install appropriate controls for the electric lights.
- Use high-efficiency fluorescent systems as the primary light source for most commercial spaces.
- Use compact fluorescent and incandescent sources to round out the lighting system and provide visual interest.
- Use high-intensity-discharge (HID) systems—particularly metal halide—for outdoor and high-bay lighting.

CONTENTS

Introduction

Whether it is natural light from the sun or artificial light from electric devices, lighting 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 an important part of the system, and each offers opportunities for improved performance and energy savings.

Hundreds of new lighting products are introduced each year.

Commercial lighting is particularly important in Southern California for several reasons. Lighting is directly responsible for nearly 40 percent of commercial electricity consumption, and in this warm climate most lighting heat 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 designs. 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 the spaces in which people work with video display terminals (VDTs) provides a good example. Bright fixtures that lack tight cutoff angles can create reflections on VDT screens, making it difficult to read the screen. Lighting designers may prevent these kinds of problems by first considering such classic elements of lighting design as luminance ratios, 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 the brightest object in the eye's field of view to the darkest. Ratios of three to one or less create even, comfortable lighting for work spaces, while ten-to-one (or higher) ratios create dramatic contrast that is appropriate for retail stores, theaters, or restaurants.

If areas in the visual field are too dark or too bright, the observer's eyes may not be comfortable.

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).
- Use lamps or fixtures with narrow beam-spreads to highlight only small areas.
- Raise the light source, or recess it into the ceiling.
- Add dimming controls so light output from a fixture can be reduced.

Glare and Veiling Reflections

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" that prevent light from shining directly into an occupant's eyes, or window shades that block direct sunlight.

Glare from reflected sources—called *veiling reflections*—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 reflections that overwhelm the task (**Figure 1**, below). Lower contrast reduces visibility (see **Figure 2**, left) and can cause eyestrain and impaired productivity.

To combat glare from veiling reflections, imagine that the occupant's visual task is a mirror; then, don't place bright fixtures such that they would appear in the mirror. Since it's difficult to predict exactly where workstations and tasks will be placed, one solution is to avoid bright 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.

Figure 2: Visibility diminishes as contrast is reduced

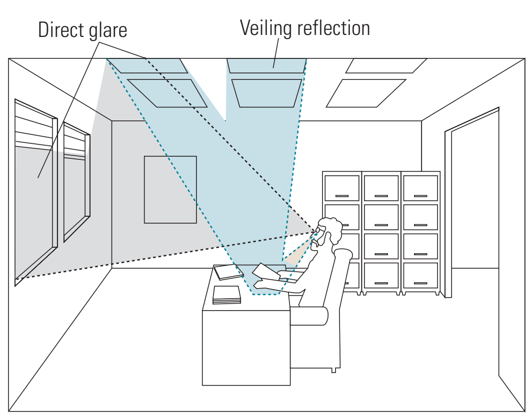
This occurs when light strikes a task and produces shiny reflections that reduce or veil contrast between details of the task and the background, such as print or photos on paper (Figure 2-2). As shown in Figure 2-3, lower contrast reduces visibility, which can cause eyestrain and impaired productivity.

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

Source: National Lighting Bureau

Figure 1: Common sources of glare

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



Source: E SOURCE

Task/Ambient Lighting

In a task/ambient lighting scheme, ceiling-based fixtures provide a relatively low level of ambient light (20 to 60 footcandles), and workstation-based task lights provide locally high light levels (about 75 footcandles).

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, California's energy efficiency standard. The task/ambient design (see **Figure 3**), on the other hand, cuts general illumination in half but adds

Table 1: Task/ambient lighting

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

	Typical (Uniform)	Improved (Task/Ambient)
Ambient lighting system		
Design lighting level (footcandles)	60	30
Luminaire quantity	18	9
Luminaire power (watts)	60	60
Total power (watts)	1,080	540
Task lighting system		
Task light quantity	0	10
Task light power (watts)	-	16
Total power (watts)	0	160
Total system economics		
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 C.U. = 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

Source: E SOURCE

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 creates a better visual environment for work involving video display terminals.

Source: EPA Green Lights

plenty of local compact fluorescent task lights, and saves 35 percent of energy. (In reality, 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 the uniform system since 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, as it is really a blend of light from throughout the visual spectrum. There are two common ways to describe the color of light from a source: color temperature and color rendering index (CRI).

Color temperatures of 3,500 K are a good middle ground.

Color temperature. 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 K. Fluorescents generally range from 3,000 K for "warm-white" lamps to about 4,000 K for "cool-white" lamps. (Daylight typically ranges from 5,000 to 10,000 K). Sources at about 3,500 K are a good middle ground that work well at a wide range of illuminances. This issue is especially important in retail stores and restaurants, where the appearance of objects, people, and food is very important.

Color rendering index (CRI). Measured on a scale of 0 to 100, CRI describes the ability of a light source to accurately render a sample of eight standard colors relative to a standard source. High-CRI light sources render colors better than low-CRI sources. Incandescent lights have a CRI of 100, cool-white fluorescents are 58 to 62; T8 fluorescents range from 75 to 98; and standard high-pressure sodium lamps have CRIs of about 27.

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. **Table 2** gives a sampling of lighting levels recommended by the Illuminating Engineering Society of North America (IESNA) for various activities.

IESNA recommendations are expressed in a range of three numbers. Which one to use in a given application depends on factors that include the type of visual task, the age of the observers, the importance of speed and accuracy in the task, and other details such as background reflectance.

Illumination level selection makes a big difference in a system's installed power and operating costs. With 10,000 square feet of D category office space, for example, choosing the medium-

Table 2: Recommended illuminance values for different activities

This table shows activities broken into nine general categories, with recommended illuminance ranges from 2 to 2,000 footcandles, designated by the letters A through I. IESNA then lists hundreds of specific tasks and assigns to each one of the letter codes.

Type of activity	Illuminance	Range of illuminances: Lux	Range of illuminances: Footcandles	Reference work-plane
Public spaces with dark surroundings	A	20–30–50	2–3–5	General lighting throughout spaces
Simple orientation for short, temporary visits	B	50–75–100	5–7.5–10	
Working spaces where visual tasks are only occasionally performed	C	100–150–200	10–15–20	
Performance of visual tasks of high contrast or large size	D	200–300–500	20–30–50	
Performance of visual tasks of medium contrast or small size	E	500–750–1,000	50–75–100	Illuminance on task preferably aided by task lighting
Performance of visual tasks of low contrast or very small size	F	1,000–1,500–2,000	100–150–200	
Performance of visual tasks of low contrast and very small size over a prolonged period	G	2,000–3,000–5,000	200–300–500	Illuminance on task obtained by a combination of general and high-intensity task lighting
Performance of very prolonged and exacting visual tasks	H	5,000–7,500–10,000	500–750–1,000	
Performance of very special visual tasks of extremely low contrast and small size	I	10,000–15,000–20,000	1,000–1,500–2,000	

Sample commercial, institutional, residential, and public assembly interiors

Auditoriums	Banks	Office	Conference rooms
Assembly C Social activity B	Lobby: General C Writing area D Teller stations E	Typical D VDTs Add task lights	Conferring D Critical seeing (refer to the individual task)

Source: IESNA

level recommended illumination level of 30 footcandles saves 40 percent and $720 per year in operating costs compared with the high-level recommendation of 50 footcandles (see **Table 3**). (Both of these systems are allowable under California's Title 24 energy efficiency standard.)

Daylighting

Daylighting offers significant energy savings and has a positive effect on building occupants.

Daylighting is a major opportunity for Southern California commercial buildings, offering significant energy savings and having a positive effect on building occupants. 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 more advanced technologies such as light pipes or specialized reflective materials.

Table 3: How much light?

The design lighting level for a space has a dramatic impact on energy use. In this example, using the "medium" IESNA recommendation rather than the "high" recommendation saves 40 percent of operating costs.

	Baseline (high recommendation)	Improved (medium recommendation)
Lighting system		
Design lighting level (footcandles)	50	30
Luminaire quantity	150	90
Luminaire power (watts)	60	60
Total power (watts)	9,000	5,400
System economics		
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

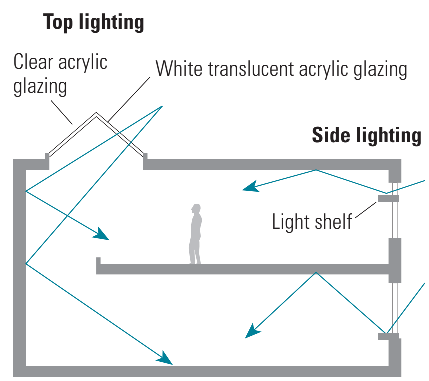
Source: E SOURCE

- *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.

- *Control electric lights accordingly.* Without lighting controls, daylighting won't save any energy. Automatic controls that sense ambient daylight are the best approach, but manual controls can also be effective. California's Title 24 energy code requires separate controls for daylit areas, and offers substantial energy budget credits for automatic daylighting controls. **Figure 5** shows how an automatic daylight control system saved 38 percent of lighting energy during a typical workday.

Figure 4: Simple daylighting techniques

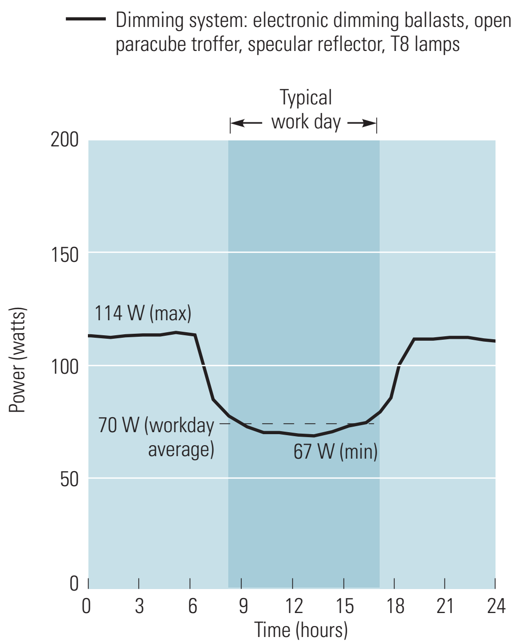
This schematic shows a mix of top- and side-lighting, light shelves, high-reflectance ceilings, and wall diffusion to provide fairly uniform deep-plan daylighting without the glare of direct sun.



Source: Southern California Edison

Figure 5: Dimming system reduces power consumption

In this office space with south-facing windows, dimming reduced lighting system power consumption from 114 watts to a workday average of 70 watts—a savings of 38 percent.



Source: Florida Solar Energy Center

Full-Size Fluorescent Lamps

Look up right now, and 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 pose no safety hazards and have few operational limitations. 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-sized fluorescent systems are most appropriate for general lighting in commercial, institutional, and industrial spaces with low to medium ceiling height. Those with high ceilings (more than 15 feet or so) are often better served by HID light sources. To apply fluorescents successfully, carefully consider options for

Daylighting Case Study

The Ocosta Junior/Senior High School (see **Figure 6**), built in 1988, is a 67,000-square-foot building located in Westport, Washington, within five miles of the Pacific Ocean. More than 40 skylights bring light deep into the building's interior spaces, and 87 percent of the school has access to daylight. Electric lighting is installed at a relatively efficient density of 1.35 watts per square foot, and photocells control 42 percent of the lights. During periods of bright daylight, 37.8 kW of connected lights are turned off by the photocell controls, creating a 99 percent reduction in lighting load connected to daylight sensors and a 42 percent reduction in whole building lighting load.

Figure 6: High school uses daylighting

The top photo shows the exterior of Ocosta Jr/Sr High School; the gymnasium is on the right. The bottom photo shows the inside of the gym, with skylights supplemented by electric lighting.

Photos by David Melody
Source: Burr Lawrence Rising and Bates, Architects

fixtures (direct versus indirect), lamps (diameter, length, and phosphor blend), and ballasts (electronic versus magnetic, rapid-start versus instant-start).

Direct Downlighting Fixtures

Direct downlighting with 2x4 or 2x2 fluorescent fixtures—the most common approach for general commercial lighting—provides good illumination on the horizontal task plane. But it leaves ceilings dark and creates glare potential for computer-based work, because the fixtures may present bright lamps or lenses that can be reflected in computer screens (**Figure 7**).

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 to 12 feet rather than 9 to 10 feet). Fixtures for indirect lighting (primarily pendants and cove lights) typically cost more than recessed troffers, but usually fewer fixtures are required.

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 Between Lamp and Ballast Options

A dizzying variety of fluorescent lamps is available, including "energy saver," cathode-cutout, premium, and "full-spectrum." The user must also choose color temperature (3,000 to 6,000+

Figure 7: Direct downlighting with conventional 2x4 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.

Source: E SOURCE

Figure 8: Indirect lighting with pendant fixtures

Indirect lighting brightens surfaces and works well in computer environments.

Source: E SOURCE

K), color-rendering level (60 to 80+), lamp diameter (T12, T8, or T5), light output level (standard, high-output [HO], or very-high-output [VHO]), and starting method (rapid-start or instant-start). For most general lighting applications, the best choices are:

- *T8 lamps (8/8ths of an inch in diameter).* T8s offer better efficiency, lumen maintenance, color quality, fixture optics, and lifecycle costs than T12 systems. T5 lamps and ballasts have some efficiency and optical advantages over T8s, and their use is becoming standard in Europe, but it will likely take another few years until this product family is complete enough to compete with T8 systems in the U.S.

- *Four-foot lamps.* This is the most common length and thus is the cheapest and easiest to buy and stock. Eight-foot lamps are slightly more efficient, but they break more easily and are somewhat difficult to transport.

- *Standard light output.* HO and VHO systems are generally more costly and less efficient, and they suffer greater lumen depreciation than do standard lamps. They also require heavy, oversized ballasts.

- *CRI of 70 to 80.* For most purposes, this is plenty of color rendering and is far superior to the old "cool-white" halophosphor lamps. Lamps with a CRI of 80 or more are considerably more expensive—although the expense may be worthwhile for retail or other color-sensitive applications.

- *Color temperature of 3,500 K.* This is a good middle ground that can blend acceptably with warmer incandescents and cooler daylight and HID sources.

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 linefrequency magnetic ballasts (see **Figure 9**). They eliminate flicker and hum and are extremely cost-effective. There are a few locations where it is still best to use magnetic ballasts: in recording studios, near radio-frequency security systems (such as those in bookstores), and in other extremely sensitive electronic environments that may be disturbed by high-frequency emanations from electronic ballasts.

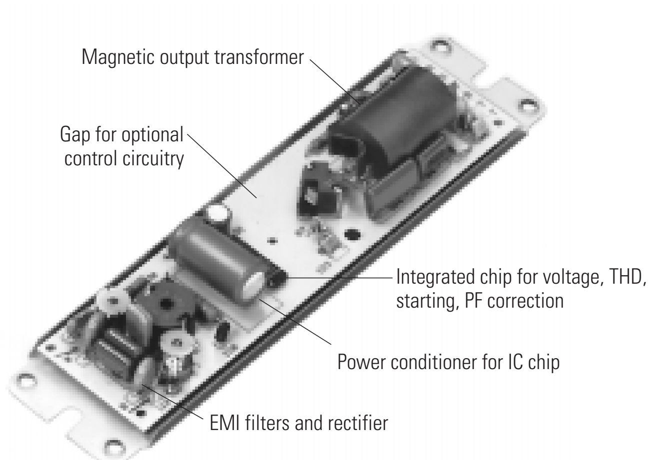
- *Rapid-start ballasts.* Instant starting shortens lamp life if the lights are turned on and off very frequently—an occurrence that is increasing with the use of occupancy sensors and other aggressive control strategies. (For lamps that burn for six hours or more per start, instant-start ballasts are slightly more efficient and are a good choice.)

- *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

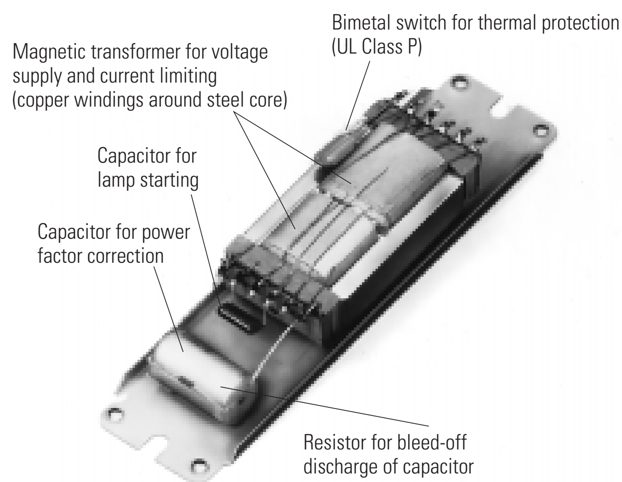
Figure 9: What's in a ballast?

Electronic ballasts (left) are more efficient than magnetic ballasts (right) because they operate at very high frequencies.

Integrated circuit electronic ballast



Standard magnetic ballast



Source: E SOURCE

task dimming (giving the occupant a rotary or sliding dimmer switch). 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 provided in Figure 5.

Compact Fluorescent Lamps

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

There are three types of CFL lamp–ballast systems, illustrated in **Figure 10**.

Integral units combine a lamp, ballast, and adapter (the Edison screw base—or other standard base in some countries—which fits the incandescent lamp socket) in a single sealed assembly, which must be discarded when the lamp burns out.

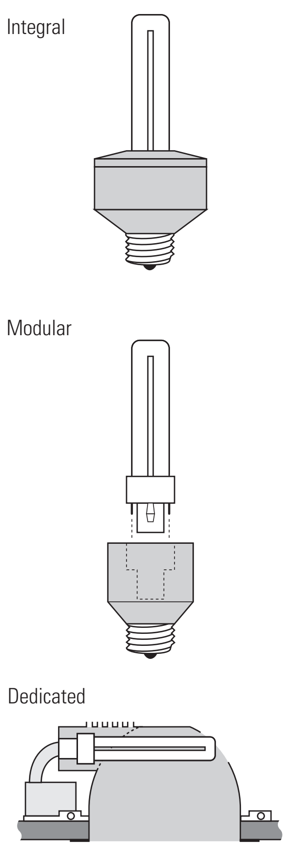
Modular units plug a separate lamp into an Edison or other style of adapter/ballast. When the lamp burns out, a low-cost replacement lamp can be installed in the same ballast base.

Dedicated systems—also called hardwired systems—consist of a ballast and fluorescent lamp socket that are permanently wired into a fixture by the fixture manufacturer or as part of a retrofit kit.

One of the most important commercial uses of compact fluorescents is for 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.

Figure 10: CFL lamp–ballast systems

There are three types of CFL lamp–ballast systems—integral, modular, and dedicated.



Source: E SOURCE

The first cost of CFL equipment may appear high compared with incandescents, but its energy savings and reduced relamping costs earn back that money quickly. The longer the annual operating hours, the more attractive the economics of CFLs becomes, because more incandescent relamping costs are being avoided per year.

Table 4 illustrates energy, lamp, and labor savings from using either a 21-watt 2D lamp or an 26-watt quad lamp instead of a 75-watt incandescent lamp. The annual savings for a $20 CFL are about $10 in energy costs and $9 in maintenance. Including labor for the installation, the first CFL in this application pays back in just over a year.

Table 4: Economics of CFLs versus incandescents

	Baseline incandescent 75W	CFL Option 1 21W 2D	CFL Option 2 26W quad
Performance			
Initial light output (lumens)	1,190	1,350	1,800
Design light output (lumens)	1,071	972	1,296
Lamp lifetime (hours)	1,000	10,000	10,000
Power input (W)	75	21	26
Efficacy (lumens/W)	15.9	64.3	69.2
Energy			
Annual energy use (kWh/year)	187.5	52.5	65
Annual energy use ($/year)	$15.00	$4.20	$5.20
Annual energy savings ($/year)	n/a	$10.80	$9.80
Maintenance			
Lamp cost ($/lamp)	$1.00	$20.00	$20.00
Relamping labor cost ($/lamp)	$5.00	$5.00	$5.00
Annual lamp cost	$2.50	$5.00	$5.00
Annual labor cost	$12.50	$1.25	$1.25
Annual maintenance savings (lamp+labor) ($/year)	n/a	$8.75	$8.75
Summary			
Annual operating cost (energy+maintenance) ($/year)	$30.00	$10.45	$11.45
Annual operating cost savings ($/year)	n/a	$19.55	$18.55
Payback on first CFL installed (years)	n/a	1.3	1.3

Notes:
- Design light output for incandescent lamp based on 10% lumen depreciation at 40% of rated life.
- Design light output for CFLs based on 0.90 ballast factor and 20% lumen depreciation at 40% of rated life.
- Annual operating time = 2500 hours
- Lamp costs: incandescent = $1; CFL = $20
- Lamp replacement labor cost = $2.50
- Electricity cost = $0.08/kWh

Source: E SOURCE

Compact fluorescents should be applied carefully. Key points include the following:

The best defense against "snap-back" is to install hardwired CFL fixtures.

- *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), a 3:1 ratio is more appropriate (a 25-watt CFL can replace a 75-watt incandescent).

- *Simplify lamp selection.* It is particularly important that a given facility standardize on just a couple of types of CFL lamps 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

High-intensity discharge (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 high-intensity discharge lamps: mercury vapor, metal halide, and sodium lamps.

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, excluding 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.

Mercury vapor lamps should be avoided because of their poor efficacy and light quality.

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 efficacy 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.
- Metal halide lamps produce relatively high levels of UV radiation that must be controlled with shielding glass in the lamp or fixture. Protection from possible explosion is also required.
- The smallest metal halide sources are 32-watt packages producing about 2,500 lumens—nearly as much as a four-foot fluorescent lamp.
- The color of metal halides' light output 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.

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 color rendering indices: the lowest CRI is about 21 (typically used for outdoor lighting); general-purpose indoor units are around 60; and the newer "white" versions boost CRI to 80 or higher. The most common application of HPS lamps is for roadway and parking lot lighting.

HPS lamps produce a familiar yellow light; they vary widely in their efficacy and color quality.

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 for outdoor lighting near observatories.

HID Applications

HID sources are now available in sizes of 35 to 2,000 watts from six primary manufacturers. More than 20 manufacturers offer HID fixtures for a variety of applications, from retail track lighting to industrial and sports lighting.

Table 5 lists typical applications for HID lamps. HIDs 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 of the important points for successful, energy-efficient installations:

Outdoor lighting. HIDs are the most common source for outdoor luminaires, which typically use a single bright lamp to cover a large area. 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 one footcandle (or less) is usually sufficient. For more information, refer to the IES Handbook.[1]

- Specify full-cutoff luminaires (those that don't spray light into the sky). Shining light above the horizontal plane is wasteful and annoys neighbors.

- Use whiter light sources. Recent research 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. Use time clock, photo cell, or pager controls to run the lights only when needed. Many outdoor lights do not need to stay on all night.

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 two footcandles (**Figure 11**). An alternative design used 24 175-watt metal halide lamps for average illuminance of one footcandle (**Figure 12**).

Shining light above the horizontal plane is wasteful and annoys neighbors.

Table 5: HID light sources and applications

Excellent color properties and a wide range of sizes make metal halides the most versatile HID light sources.

Application	Metal halide	High-pressure sodium	White high-pressure sodium	Low-pressure sodium	Mercury vapor
Interior-decorative	●		●		
-downlights	●		●		●[a]
Parking areas	●	●		●	
General outdoor	●	●		●	
Roadway/tunnel	●	●		●	
Sports arenas	●				
High-bay spaces (hangars, warehouses, etc.)	●	●			●[a]
Low-bay spaces (supermarkets, light industrial shops, etc.)	●	●			
Outdoor signage	●				●[a]

Note: a: Where access is difficult or dangerous.

Source: E SOURCE

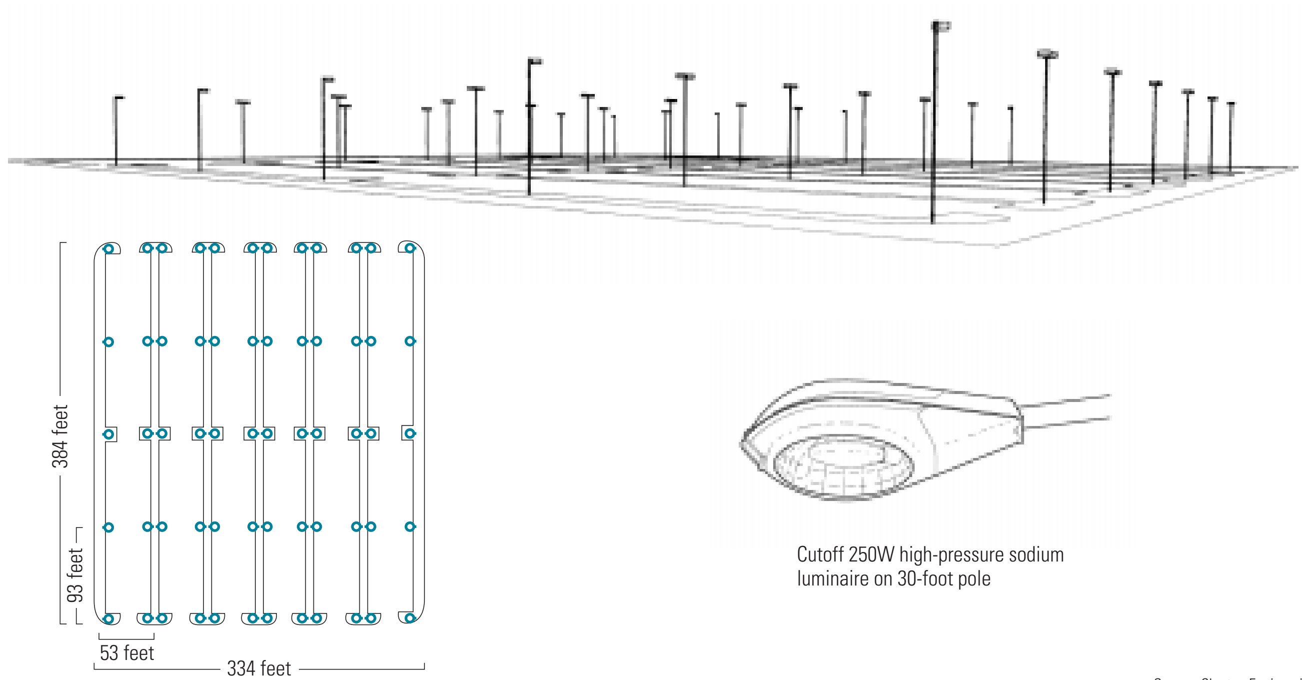
Table 6 compares the capital and operating costs of these two system designs; the whiter, dimmer, metal halide system cut installation cost by 42 percent and operating cost by 65 percent. This system fully complies with IESNA recommendations.

High-bay lighting. Industrial spaces and "box retail" stores with high ceilings are a good match for the intensity of HID lighting systems. Key considerations include these:

- Carefully evaluate fixture photometrics to achieve desired light levels and distribution. A wide variety of fixtures is available, including asymmetric units designed for lighting aisles.
- Design for easy maintenance. Try to use the same size and type of lamps throughout the facility, initiate group relamping, and consider details like open-fixture-rated lamps that don't require enclosed fixtures.

Figure 11: 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 12. The conventional design uses 250-watt high-pressure sodium lamps in full-cutoff cobra head fixtures. There are five rows and seven columns of luminaires. The five inner columns use two luminaires per pole, and the two outer columns use one luminaire per pole (60 luminaires and 35 poles total). The poles are 30 feet tall. The average illuminance is about two footcandles, and the minimum is about 0.5 footcandles. The ratio of maximum to minimum illuminance is seven to one.



Cutoff 250W high-pressure sodium luminaire on 30-foot pole

Source: Clanton Engineering

Table 6: 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, lower-wattage (175-watt) 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.

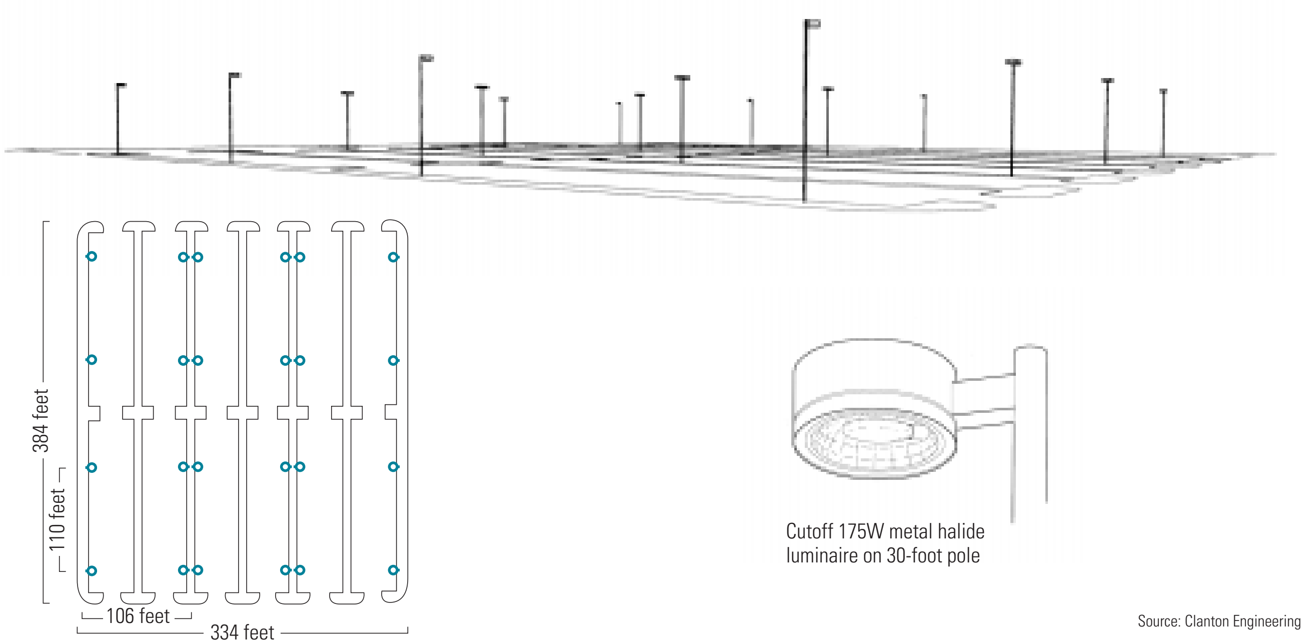
	Conventional system		Efficient system		Savings	
Operation and maintenance		**Cost**		**Cost**	**Dollars**	**Percent**
Energy cost per year		$6,412		$1,766	$4,646	72%
Maintenance cost per year		$723		$746	-$23	-3%
Total annual O&M		$7,135		$2,512	$2,512	65%
Capital costs	**Equipment**	**Initial cost**	**Equipment**	**Initial cost**	**Dollars**	**Percent**
Lamps	60 250W HPS (305W with ballast losses)	$19.20 each, $1,152 total	24 175W metal halide (210W 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:
4,380 hours per year operation, $0.08 per kWh, 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.

Source: Clanton Engineering

Figure 12: Efficient parking lot design

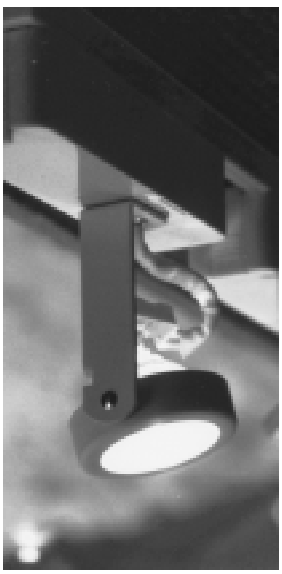
The alternative design uses 175-watt metal halide lamps. The "hockey puck" cutoff luminaires distribute light more efficiently than the cobra heads in the conventional design, allowing fewer poles and luminaires to be used. In this design there are only four rows and four columns. The two outer columns 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 one footcandle, the minimum is about 0.3 footcandles, and the ratio of maximum to minimum illuminance is about nine to one.



Source: Clanton Engineering

Figure 13: Halogen incandescent spotlight

Although halogen lamps like the MR-16 shown here are often thought to be "efficient" light sources, they actually are 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.



Source: E SOURCE

- Take advantage of control opportunities. Even though HIDs can't be dimmed as readily as fluorescent and incandescent sources, new ballasts and control systems are making it easier to pursue strategies such as daylight dimming and occupancy control.

Retail, accent, and specialty lighting. A new generation of compact metal halide and white sodium 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, so don't assume that HIDs are limited to street and warehouse lighting. (To prove this point, one HID manufacturer is even building a demonstration house lit entirely by metal halide sources.[2])

Remote lighting applications. HID lamps are the best option for driving light engines that feed fiber optic networks or light pipes. Remote lighting can provide very high efficiency while solving problems such as heat and UV damage and maintenance access. HID-fed light pipes are now being installed in many applications such as museums and jewelry stores.

Incandescent Lamps

For several years, incandescent lamps have been challenged by alternative sources with lower lifecycle 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 designs.

Several developments have improved the incandescent lamp, including halogen encapsulation (**Figure 13**). Surrounding the incandescent filament with a quartz-glass capsule containing bromine or iodine gas allows the lamp to operate at a higher temperature, which improves its efficiency. The halogen cycle also recycles vaporized tungsten back onto the filament, extending lamp life.

However, the efficiency benefits of halogen technology are often overstated. Halogen efficiency ranges from 8 to 25 lumens per watt, with the most common sizes operating at about 12 to 17 lumens per watt. Compared with fluorescent and HID sources (60–100+ lumens per watt), 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.

The efficiency benefits of halogen technology are often overstated.

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 (**Figure 14**). Since 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.

This example highlights the importance of design philosophy in energy efficient lighting. A conventional solution to this problem would have been to use higher ambient lighting levels in the hallways or group-switched downlights over the doorways. Even using efficient fluorescent sources, this approach would have had a significant energy penalty compared with Bragg's task-based design, which uses a much less efficient incandescent source.

Figure 14: Halogen MR-11 perfect for low-duty application

A single MR-11 spotlight illuminates fold-down work tables in this Tucson hospital.

Source: Tucson Medical Center

For More Information

California Energy Commission
1516 9th Street
Sacramento, CA 95814-5512
tel 800-772-3300
fax 916-653-7480
web www.energy.ca.gov
The California Energy Commission 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.

Center for Lighting Education and Applied Research (CLEAR)
Cal Poly Pomona, Attention: Marvin Abrams, College of Engineering
3801 West Temple Avenue
Pomona, CA 91768
tel 909-869-2505
web 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.

Green Lights/Energy Star Buildings Program
Atmospheric Pollution Prevention Division
U.S. Environmental Protection Agency [6202J]
401 M Street SW
Washington, DC 20460
tel 888-782-7937
fax 202-233-9569
web www.epa.gov/greenlights.html
Green Lights is a voluntary program sponsored by the EPA to encourage the use of efficient lighting technologies. In exchange for agreeing to pursue energy efficient lighting upgrades, Green Lights partners receive recognition and technical support.

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
web 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 manu-

al of lighting design. The IESNA also offers training programs that cover basic and advanced lighting technologies.

International Association of Lighting Designers
Merchandise Mart, Suite 487
Chicago, IL 60654
tel 312-527-3677
fax 312-527-3680
web www.iald.org
The IALD is the trade association for lighting designers.

Lighting Research Center
c/o Rensselaer Polytechnic Institute
Watervliet Facility
877 25th Street
Watervliet, NY 12189
tel 518-276-8716
fax 518-276-2999
e-mail lrc@rpi.edu
web 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. LRC also provides technical support to the EPA's Green Lights program and its partner companies.

National Council on the Qualification of Lighting Professionals
401 East-West Highway, Suite 305
Bethesda, MD 20814
tel 301-654-2121
fax 301-654-4273
e-mail info@ncqlp.org
web www.ncqlp.org
The NCQLP is the official administrator of the new LC certification, which establishes industry professionals as "lighting certified." Applicants must meet certain criteria and pass a comprehensive exam to earn the LC designation.

Southern California Edison Customer Technology Applications Center (CTAC)
6090 North Irwindale Avenue
Irwindale, CA 91702
tel 800-336-2822
web www.sce.com
CTAC offers a number of opportunities for those interested in lighting technologies, including educational seminars, product exhibitions, and a demonstration laboratory.

Notes

1 *Lighting Handbook*, 8th Edition (New York: Illuminating Engineering Society of North America).

2 Venture Lighting International, Inc., 32000 Aurora Road, Solon, OH 44139-2814, tel 216-248-3510, fax 216-349-7777, web www.adlt.com/venture.

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