



# 6. Lighting

Revised November 2006

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## 6.1 Overview

A lighting upgrade is the second stage in the building upgrade process. The staged approach accounts for the interactions among all the energy flows in a building (**Figure 6.1**) and produces a systematic method for planning upgrades that maximize energy savings. When the staged approach is performed sequentially, each stage includes changes that will affect the upgrades performed in subsequent stages, thus setting the overall process up for the greatest energy and cost savings possible. In the staged approach to building upgrades, lighting upgrades come early in the process because the lighting system has a significant impact on other building systems, affecting heating and cooling loads and power quality.

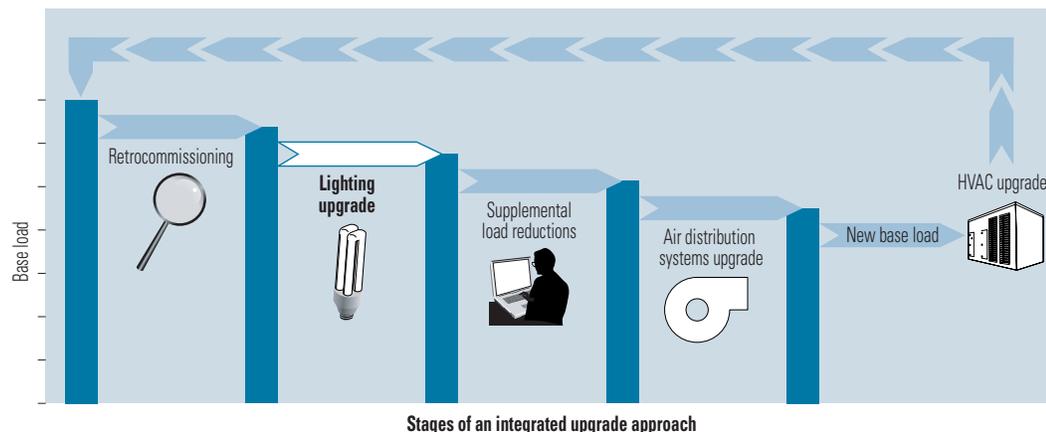
Lighting consumes close to 35 percent of the electricity used in commercial buildings in the United States and affects other building systems through its electrical requirements and the waste heat that it produces. Upgrading lighting systems with efficient light sources, fixtures, and controls can reduce lighting energy use, improve the visual environment, and affect the sizing of HVAC and electrical systems.

Any goals for a lighting upgrade should be consistent with overall company goals and energy policies. They should also include provisions for commissioning—to make sure that the installed systems work as intended—and retrocommissioning, to make sure that the installed systems continue to provide the intended benefits throughout their useful life (see U.S. Environmental Protection Agency [EPA], “Guidelines for Energy Management Overview,” [www.energystar.gov/index.cfm?c=guidelines.guidelines\\_index](http://www.energystar.gov/index.cfm?c=guidelines.guidelines_index)). It is also important to remember that, as the EPA’s guidelines point out, the upgrade is not an end point but a step along a path of continuous improvement. To ensure that a lighting upgrade leads to an effective and efficient system, follow these key guidelines:

- Design the system to get the appropriate amount of light for the tasks to be performed in the space in question.

**Figure 6.1: The staged approach to building upgrades**

The staged approach to building upgrades accounts for the interactions among all the energy flows in a building. Each stage includes changes that will affect the upgrades performed in subsequent stages, thus setting the overall process up for the greatest energy and cost savings possible. Lighting upgrades come early in the process, because the lighting system affects heating and cooling loads and power quality.



Courtesy: E SOURCE

- Distribute that light to prevent glare.
- Use daylight whenever possible but avoid direct sunlight, and install controls to reduce the use of electric lights in response to daylight.
- Use the most efficient light source for the application: high-performance fluorescent systems as the primary light source for most commercial spaces; compact fluorescent lamps in place of incandescent bulbs in most cases; and high-intensity discharge lamps where appropriate.
- Use automatic controls to turn lights off or dim lights as appropriate.
- Plan for and carry out the commissioning of all lighting systems to ensure that they are performing as required, and create a schedule to retrocommission systems periodically.
- Design lighting systems with ongoing maintenance in mind, and include a comprehensive plan for group relamping, fixture cleaning, and proper disposal of old lamps and ballasts.

Dozens of companies have followed these steps to improve their lighting systems. To see descriptions of buildings that have upgraded their lighting systems as part of an ongoing building upgrade process, visit [www.energystar.gov/index.cfm?fuseaction=labeled\\_buildings.showUpgradeSearch&building\\_type\\_id=ALL&s\\_code=ALL&profiles=0&also\\_search\\_id=UPGRADE](http://www.energystar.gov/index.cfm?fuseaction=labeled_buildings.showUpgradeSearch&building_type_id=ALL&s_code=ALL&profiles=0&also_search_id=UPGRADE), click on Stage 2, and submit.

## 6.2 The Importance of Lighting

Lighting uses about 18 percent of the electricity generated in the U.S., and another 4 to 5 percent goes to remove the waste heat generated by those lights. Lighting in commercial buildings accounts for close to 71 percent of overall lighting electricity use in the U.S. With good design, lighting energy use in most buildings can be cut at least in half while maintaining or improving lighting quality. Such designs typically pay for themselves in energy savings alone within a few years, and they offer more benefits in terms of the potential for smaller and less costly cooling systems and more-productive work environments.

### Lighting and Your Building

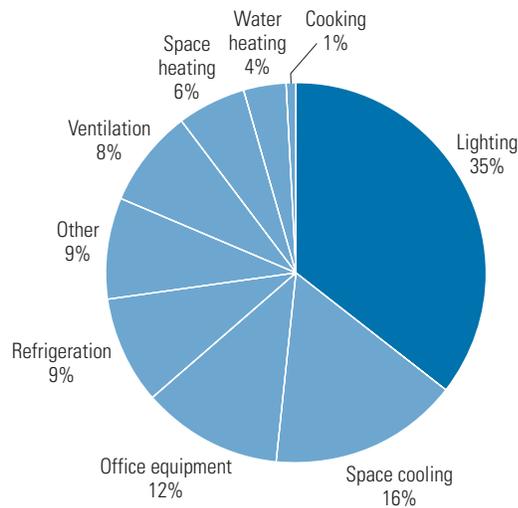
Lighting is a significant expense in operating a building. It is the largest cost component of a commercial building's electricity bill (**Figure 6.2**) and a significant portion of the total energy bill. When planning full-building upgrades, a lighting upgrade should come early in the process, because it can affect heating and cooling loads and power quality, which can make a significant difference in the specifications for other building systems.

**Heating and cooling loads.** Lighting systems produce large amounts of heat as well as light. Lighting is typically the largest source of waste heat, often called “heat gain,” inside commercial buildings. This internal heat gain may be useful when the building requires heating, but it is counterproductive when the building requires cooling. Energy-efficient lighting adds less heat to a space per unit of light output than inefficient lighting.

By reducing internal heat gain, efficient lighting also reduces a building's cooling requirements. Consequently, the existing cooling system may be able to serve future added loads. In addition, when it comes time to replace a building's cooling systems, the use of efficient lighting leads to reduced cooling loads, which can allow replacement chillers to be smaller and hence less costly to buy and operate.

### Figure 6.2: Lighting share of commercial building electricity use

Lighting takes a larger share of a building's electricity use than any other single end use—more than 35 percent.



Courtesy: E SOURCE; data from 2005 Buildings Energy Data Book

The net annual effect on HVAC energy use at a site depends on the type of building, the climate, the efficiency of heating and cooling systems, and the relative size of the heating and air-conditioning loads. Large buildings that are dominated by internal loads and use far more air conditioning than heating can experience a site energy HVAC bonus of 40 percent or more. This means that each kilowatt-hour (kWh) of reduction in annual lighting energy use yields an additional 0.4 kWh of annual reduction in HVAC energy by reducing cooling energy more than it increases required heating energy.

For small, envelope-dominated buildings—especially those in cold climates—the net impact may be an HVAC penalty, meaning that each kWh in lighting energy use increases HVAC energy by increasing the annual heating energy use more than it reduces cooling energy.

Lighting upgrades in most commercial buildings are likely to reduce cooling costs more than they increase heating costs, but the precise effect on any given building can be determined by computer simulation. Some simplified methods for approximating the effect are also available. For example, see Lawrence Berkeley National Laboratory (LBNL), *Interactions Between Lighting and Space Conditioning Energy Use in U.S. Commercial Buildings*, LBNL 39795, <http://enduse.lbl.gov/info/LBNL-39795.pdf>.

**Improve power quality.** Lighting also affects the power quality of a building's electrical distribution system. Poor power quality is a concern because it wastes energy, reduces electrical capacity, and can harm equipment and the electrical distribution system itself. Upgrading to lighting equipment with clean power quality (high power factor and low harmonic distortion) can improve the power quality in a building's electrical system. Furthermore, upgrading with higher-efficiency and higher-power-factor lighting equipment can also free up valuable electrical capacity. This benefit alone may justify the cost of a lighting upgrade (see sidebar).

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## CASE STUDY: Lighting Upgrade Improves Electric Load

Columbia University found that upgrading lighting in two adjacent buildings on its campus freed up enough electrical capacity to allow the wiring of all the lighting circuits into one building's electric service. Purchasing the transformers for that one system then became a cost-effective way to place both structures on high-tension service, saving another 29 percent on the two buildings' electric bills. When the costs and savings of this option were combined with those of the lighting upgrades, overall payback remained at about 2.5 years, but total savings nearly doubled, demonstrating the synergistic effects that can result by using lighting upgrades for electric load management. This option was previously unavailable because purchasing the transformers for both buildings yielded an unacceptably high payback.

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## Lighting and People

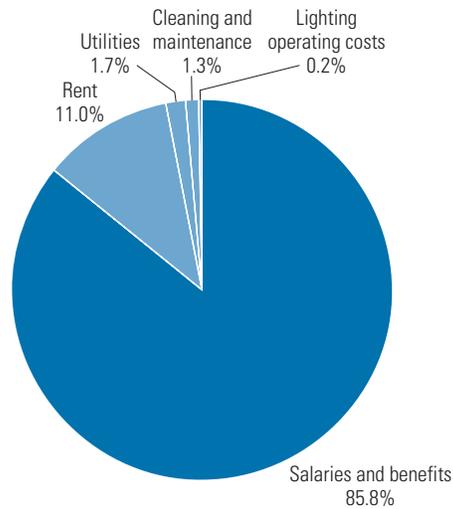
A lighting upgrade is an investment not only in reducing electricity consumption but also in improving the way a building supports its occupants. A building's lighting directly affects the comfort, mood, productivity, health, and safety of its occupants. Moreover, as the most visible building system, it also directly affects the aesthetics and image of the building. Successful lighting upgrades take into account the impact of energy-performance choices on building occupants and seek to marry efficiency with improved lighting quality and architectural aesthetics wherever possible. Although such effects are difficult to quantify, comfort, mood, productivity, health, safety, and other effects lighting has on people should be considered as part of every lighting upgrade.

**Productivity.** Improved lighting enhances visual comfort, reduces eye fatigue, and improves performance on visual tasks. Well-designed lighting may also increase productivity and reduce absenteeism. For example, one lighting upgrade—at a mail-processing center in Reno, Nevada—led to a 6 percent increase in worker output and a reduction in sorting errors. Most lighting upgrades are cost-effective based on energy savings alone, but because costs associated with a building's occupants greatly outweigh other building costs (**Figure 6.3**), any lighting change that improves the interior environment is worth investigating. Those effects are hard to quantify, but research efforts are helping to pin down the benefits (see, for example, the work of the Light Right Consortium, [www.lightright.org](http://www.lightright.org)).

**Safety.** Lighting also contributes to the safety of occupants and the security of buildings. Emergency lighting must be available during power outages, and minimum levels of light must be available at night when most lighting is turned off. In addition, safety codes require exit signs to highlight escape routes during fires or other emergencies. Outside lighting and indoor night lighting deter crime by exposing intruders' movements and permitting occupants to move safely through the building or to cars. A visually safe environment will not expose people to excessive levels of glare or large differences in luminance levels. Outdoor light levels may depend on local ordinances, but can generally be fairly low—the guidelines laid out by the Illuminating Engineering Society of North America (IESNA, [www.iesna.org](http://www.iesna.org)) suggest 0.5 to 5.0 foot-candles, depending on the level of activity and the potential hazards.

### Figure 6.3: Annual operating costs per square foot in a typical office space

Salary costs far outweigh the costs for lighting in a typical office building, so even small improvements in worker productivity, absenteeism, or staff retention will quickly offset the costs of a well-executed lighting upgrade.



Courtesy: E SOURCE; data from Right Light Consortium

## 6.3 A Whole-System Approach

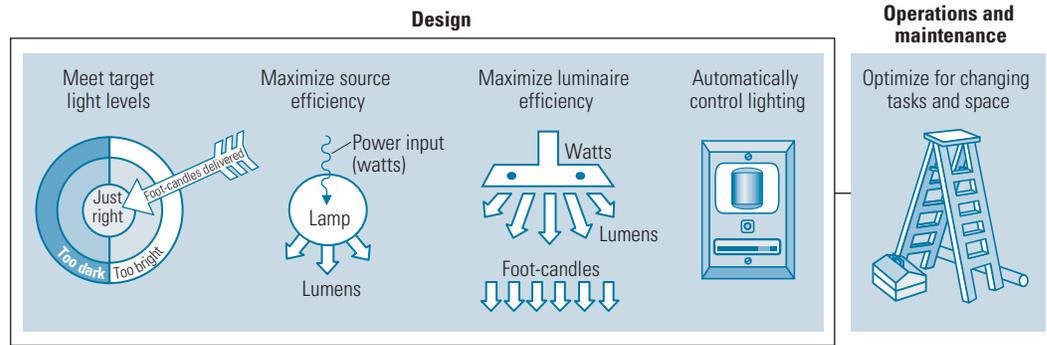
A comprehensive lighting upgrade achieves qualitative lighting objectives while maximizing efficiency and profitability. The process begins with the identification of the appropriate quality and quantity of light for various areas of a facility; proceeds through the selection of the best combination of light sources, luminaires, and controls; and includes provisions for maintenance and periodic reviews to ensure that goals for efficiency and quality continue to be met. This whole-system approach takes what is frequently regarded as a complex system of individual decisions and unites them into a strategic plan that ensures that each opportunity is addressed and balanced with other objectives (**Figure 6.4**).

Many lighting-efficiency efforts are oriented toward the installation of specific pieces of equipment, such as electronic ballasts or compact fluorescent downlights. But as with many other types of complex systems, the interactions among system elements in lighting equipment create energy and power savings that can be greater than the sum of their parts. **Table 6.1** illustrates the effects of pursuing incrementally more-aggressive upgrades while maintaining profitability and lighting quality and quantity. Starting with a system of fixtures containing four energy-saver T12 lamps, an upgrade to standard T8 lamps and electronic ballasts can produce energy savings of more than 25 percent; using high-performance T8 lamps boosts savings to more than 40 percent.

The next option begins to capture some system interactions. Each fixture is equipped with a specular reflector and a new acrylic flat prismatic lens. Because these are significantly better at getting light out of the fixture than the old white-painted luminaire and aged diffuser, the fixture can be delamped by 50 percent—to two high-performance T8 lamps—and still provide virtually the same amount of light for the task. Adding reflectors and new lenses to the fixtures enables

**Figure 6.4: Comprehensive lighting upgrade strategy**

A whole-system approach takes a complex system of individual decisions and unites them into a strategic approach that ensures that each opportunity is addressed and balanced with other objectives. The approach also includes provisions for monitoring and maintenance so that efficiency is maintained and the lighting system accommodates any changes in the use or configuration of the space.



Source: EPA

**Table 6.1: Performance comparison of fluorescent retrofit options**

Packages of lighting-efficiency measures such as high-performance lamps and ballasts, delamping, and controls achieve deep savings with attractive economics. In each case, it is assumed that a minimum illumination level of 25 foot-candles is maintained and that lamps are replaced at burnout.

Retrofit option	Base case: Energy-saving T12 lamps with magnetic ballasts	Case 1: T8 lamps with electronic ballasts	Case 2: High-performance T8s with electronic ballasts	Case 3: Case 2 + specular reflector + lens + 50% delamping	Case 4: Case 3 + occupancy sensing and daylight dimming
Average maintained foot-candles	25	30	28	25	26
Power per fixture (W)	156	116	90	45	49
Annual energy use (kWh)	7,507	5,568	4,320	2,160	1,275
Energy savings (%)	NA	26	42	71	83
Annual operating cost (\$)	826	612	475	238	175
Upgrade cost (\$)	NA	1,165	1,320	1,560	2,150
Simple payback (years)	NA	5.5	3.8	2.7	3.3

Notes: kWh = kilowatt-hour; NA = not applicable; W = watt.

Courtesy: *E SOURCE Lighting Technology Atlas* (2005)

Assumptions:

1. Fixture cleaning occurs at end of the rated life, base case. Assuming burn hours of 4,000 hours per year and a 20,000-hour rated life, that works out to five years between cleanings and a total dirt loss of 30 percent.
2. The specular reflector retrofit kit is designed to maintain the same spacing ratio.
3. The existing diffuser has yellowed and gathered sufficient adhesive dirt (which isn't easily removed during routine cleaning) to reduce transmittance by another 10 percent.
4. Energy costs: demand = \$10 per kilowatt per month (all 12 months of the year); consumption = 7¢ per kWh (all times of day).

delamping—a reduction in the number of lamps required per fixture—with little loss in light levels, for a savings of 71 percent compared to the base case. Adding occupancy sensors and daylighting controls can boost savings to more than 80 percent compared to the base case, and more than 50 percent compared to a system with standard-grade T8 lamps and electronic ballasts.

Another option is to replace existing fixtures with new fixtures, rather than upgrading the various elements. Upgrading the elements can be less costly and less disruptive to ongoing operations, but new fixtures are a good approach if you want to convert from direct to indirect lighting, use a different type of light source (for example, replace high-intensity discharge lighting with fluorescent lighting), incorporate some of the advanced lighting control technologies, or provide lower levels of ambient lighting while increasing task lighting levels.

## 6.4 Lighting Design

Successful lighting design begins with an assessment of occupants' lighting needs, which depend on the tasks performed in the workspace. The lighting system should be designed to provide the quantity and quality of light responsive to those requirements. Chapter 10 of the *IESNA Lighting Handbook* (9th edition), "Quality of the Visual Environment," identifies several issues that should be considered, including color, daylight availability, glare, and light distribution. Retrofits that skip this assessment may perpetuate designs that have become inadequate because of workspace rearrangements or changing tasks (for example, moving from paper-based to computer-based tasks). The principles and guidance that apply to interior lighting are applicable to exterior lighting as well. Outdoor lighting that is designed and implemented properly should be cost-effective, should control light by directing it where it is needed, should reduce glare and distribute illumination evenly, and should reduce light trespass.

### The Right Quantity of Light

The quantity of light, or foot-candle illuminance level, that makes up an acceptable design depends on the tasks being performed in the space. Chapter 10 of the *IESNA Lighting Handbook* includes a "Lighting Design Guide" that provides recommended illuminances for seven general application categories, divided into three sets of visual tasks (**Table 6.2**). 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.

Keep in mind that the lighting level targets should be considered average maintained levels for the task; they should not necessarily be applied uniformly as the ambient light level for the entire space. Lighting levels should be customized through the use of supplemental task lighting in areas requiring higher localized levels. Target lighting levels should be the sum of the ambient and task lighting levels. This task-ambient lighting design approach creates flexibility to accommodate individual tasks or worker requirements, creates visual interest, and can save considerable energy in comparison to a uniform ambient-level approach.

Room dimensions and finishes also affect the required light output and thus the energy consumption of all interior lighting systems. As much as one-third of the energy used by a lighting system depends on the surrounding interior features, including the ceiling height, number and location of windows, and color and reflectivity of room surfaces and furnishings. Lighting designers can work with architects and interior designers to ensure that features that enhance

**Table 6.2: Recommended light levels**

The 9th edition of the *IESNA Lighting Handbook* 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: *E SOURCE Lighting Technology Atlas* (2005); adapted from *IESNA Lighting Handbook*, 9th edition

lighting levels, such as light-colored finishes, are used wherever possible. This helps minimize the required light output and therefore the energy consumption of the lighting system.

## The Right Quality of Light

Lighting quality is the cornerstone of efficient lighting. The most efficient light sources mounted in the best luminaires may save energy, but they will not produce much value for building owners and occupants if they are applied improperly. Lighting designers can ensure high quality by considering such classic elements of lighting design as luminance ratios and color qualities.

**Luminance ratios and glare.** The eye does not see absolute levels of *illuminance* (the amount of light shining on a surface); it sees differences in *luminance* (the amount of light reflected back from a surface). Eyestrain and fatigue are caused when the eye is forced to adapt continually to different luminances. Therefore, it is important not only to provide the right level of light but also to ensure that light is evenly distributed across the task area. Balancing light levels also ensures that task lighting levels will be adequate throughout the space. Uniformity on vertical surfaces should also be maintained to avoid a gloomy, cave-like atmosphere.

IESNA recommends as good design practice an average luminance ratio of no more than 3 to 1 for close objects and 10 to 1 for distant objects and outdoor applications. In other words, the difference in light level between the task area and the background should be less than a factor of three. Although some designers use variation in illuminance as an organizing theme (for example, to define hallways leading to open offices or as a highlighting strategy in retail areas), large foot-candle variations within a workspace should be avoided.

*Glare* is the most important quality factor. Glare results when luminance levels—or the differences in luminance levels—are too high and objects appear too bright. Because glare creates discomfort, loss of visual performance, and impaired visibility, it should be minimized wherever possible.

*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. A veiling reflection occurs when light strikes a task and produces shiny spots that overwhelm the task. The decrease in contrast reduces visibility and can cause eyestrain. To combat glare from veiling reflections, imagine that the occupant’s visual task is a mirror, and then do not place bright fixtures such that they would appear in that mirror. Because it is 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.

**Color and spectral content of light sources.** There are two common ways to describe the color of light from a source: correlated color temperature (CCT) and color rendering index (CRI). Both metrics should be considered when evaluating light sources.

*Correlated color temperature*, measured in degrees kelvin (K), refers to the temperature of a black-body radiator emitting light of comparable color. The scale may seem intuitively backward: The higher the color temperature, the “cooler” or bluer the light. 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 foot-candles 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 daylit, 5,000 K may be the most appropriate CCT.

*Color rendering index*, measured on a scale of 0 to 100, 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. However, in general, high-CRI light sources render colors better than low-CRI sources (**Table 6.3**). A CRI of 80 or greater is considered by the industry to provide excellent color rendering.

## Outdoor Lighting

Well-designed outdoor lighting is cost-effective, controls light by directing it where it is needed, reduces glare, distributes illumination evenly, and reduces light trespass. The most common lamps used for outdoor lighting are high-intensity discharge (HID) sources—metal halide and high-pressure sodium. In recent years, compact fluorescent lamps (CFLs) and induction lamps have become viable sources for outdoor lighting as well, offering good color quality and better control options than HID sources. As costs come down and performance improves, light-emitting diodes (LEDs) could become a good choice for outdoor lighting as well. Regardless of the light source, however, the following points are important in the design of exterior lighting:

**Table 6.3: Typical CRI values for selected light sources**

Light sources with a color rendering index (CRI) of 80 or higher are considered to provide excellent color rendering.

Light source	CRI range
Incandescent	100
Ceramic metal halide	85 to 94
T5 fluorescents	80s
T8 fluorescents	75 to 98 <sup>a</sup>
Quartz metal halide	65 to 70
T12 fluorescents	58 to 62
High-pressure sodium	22

Note: a. T8 lamps with CRIs in the 90s offer lower efficacy than other T8 lamps.

Courtesy: E SOURCE

- *Pick the appropriate design illumination level.* An average of 1 foot-candle (or less) is usually sufficient. For more information, refer to the *IESNA Lighting Handbook* and several of its recommended practices.
- *Use IESNA-cutoff luminaires or full-cutoff luminaires.* These types of fixtures do not spread light into the sky above the horizontal.
- *Use whiter light sources.* Recent research, although not yet codified, shows that the whiter light produced by metal halide and fluorescent lamps provides better “seeability” than an equivalent amount of yellowish light from sodium lamps.
- *Provide controls.* Use time clocks, photo cells, motion detectors, or pager controls to run the lights only when needed or to dim them as appropriate.

Light pollution is a major concern in designing exterior lighting. Outdoor lighting ordinances and codes encourage better-quality lighting that reduces glare, light trespass, and energy waste. Many codes are now including the concept of e-zones to distinguish between different types of lighting areas. For example, near national or state parks, wildlife refuges, or astronomical observatories, lighting levels should be much lower than in city centers. The ordinances and community standards vary, and local zoning departments should be contacted before implementing an outdoor lighting project. (For more information, visit the web site of the International Dark Sky Association, [www.darksky.org](http://www.darksky.org).)

## 6.5 Use Efficient Light Sources

Efficient lighting begins with the use of as much daylight as possible. After that, choose the lamp/ballast/fixture combination that will maximize efficiency while balancing the considerations of lighting quality and quantity described above. There is a wide variety of light sources to choose from including fluorescent (linear and compact), high-intensity discharge (HID), and newer sources such as induction lamps and light-emitting diodes (LEDs). These sources vary widely in their efficacy, color quality, service life, and the applications for which they are best suited (**Table 6.4**). Historically, fluorescent lighting has been used for high-quality, general-purpose indoor diffuse lighting. HID lighting has been used for industrial and outside lighting. However, technical advances and a flood of new products have led to some crossover in the way

**Table 6.4: Typical properties of light-source upgrade alternatives**

A variety of lamps are available for energy-efficient upgrades. Linear fluorescent lamps are the most widely used, but each type has applications in which it can be an effective choice. The data listed do not represent the full range of variations for each lamp type, but only the ranges for the most effective choices.

Lamp type	Lamp property					Typical applications
	Mean efficacy, including ballast (mean lm/W)	Lumen maintenance (%)	Rated life (hours)	Color rendering index	Correlated color temperature (K)	
Full-size fluorescent (T5, high-performance T8)	80 to 97	92 to 93	20,000 to 30,000	80 to 85	2,700 to 6,500	General area lighting of all kinds, including open and closed offices, classrooms, and high-bay areas
Compact fluorescent	43 to 71 <sup>a</sup>	86	6,000 to 12,000	80 to 85	2,700 to 6,500	Incandescent replacements in table and floor lamps, cans, wall washers, and sconces
Quartz pulse-start metal halide	60 to 80 <sup>a</sup>	65 to 75	20,000	65 to 70	2,900 to 4,200	Outdoor lighting, high-bay lighting, and remote-source lighting
Ceramic pulse-start metal halide	60 to 80 <sup>a</sup>	80	20,000	85 to 94	2,900 to 4,200	Where color is critical, including high-bay and retail applications
High-pressure sodium	60 to 110 <sup>a</sup>	85 to 90	24,000	22	1,900 to 2,200	Outdoor lighting and in high-bay applications where color is not critical
Induction	50 to 60 <sup>a</sup>	70 at 60,000 hours; 55 at 100,000 hours	100,000	80	2,700 to 4,100	Where maintenance costs are high, including roadways and tunnels, parking garages, escalator wells, warehouses, and malls
LED	15 to 30	70	50,000 <sup>b</sup>	80 to 90	2,700 to 10,000	In color-based applications such as exit signs, niche applications such as outdoor signage, task lamps, and accent lighting

Notes: K = kelvin; LED = light-emitting diode; lm/W = lumen per watt.

a. Higher efficacies for higher-wattage lamps.

b. Time at which output has degraded to 70 percent of initial output.

Courtesy: E SOURCE

these lamps are applied—fluorescent lighting is now the most effective choice for many industrial and exterior lighting applications, while HID lighting (specifically metal halide) is now a good choice for some interior uses.

## Make Use of Daylight

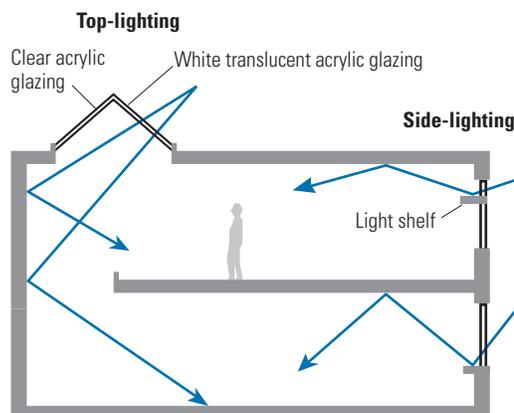
The most efficient source of light is the sun, effectively providing up to 140 lumens (lm) of light for each watt (W) of heat energy, which compares favorably with the 90 lm/W from an efficient electric lighting system. Systems that use daylight to supplement electric lighting offer the potential to cut energy use, reduce peak demand, and create a more desirable indoor environment. However, it takes careful planning to achieve all the possible benefits from a daylighting system, and a number of resources are available on the web to help in the effort (see sidebar). As an overall guide, follow these four basic principles to produce an effective daylighting system:

- *Bring in the light.* Light can be brought into a building via conventional glazing, light shelves, skylights, and clerestory windows (**Figure 6.5**) or with more advanced approaches such as light pipes or specialized reflective materials.

- *Eliminate glare.* Glare is the number-one killer of daylighting systems—direct sunlight can cause very uneven luminance ratios that are distracting or even painful to occupants. Means for combating glare include using translucent materials and bouncing direct light off surfaces such as painted walls, perforated metal, or fabrics.
- *Adjust electric lights as appropriate.* Without lighting controls, daylighting will not 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 6.6** shows how an automatic daylight control system installed at a grocery store cut energy use by 30 percent and decreased demand during peak hours.
- *Commission the system.* Many daylighting systems fail to deliver the expected benefit because they are not commissioned. Commissioning consists of adjusting photosensors and ensuring proper sensor placement so that the electric lighting system responds properly to the presence of daylight.

### Figure 6.5: Simple daylighting techniques

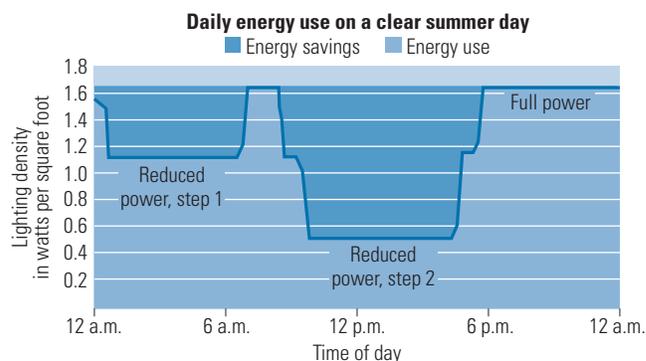
A mix of top- and side-lighting, light shelves, high-reflectance ceilings, and wall diffusion provides fairly uniform deep-plan daylighting without the glare of direct sun.



Courtesy: E SOURCE Lighting Technology Atlas (2005)

### Figure 6.6: Skylights cut lighting energy use

A grocery store in Valencia, California, used skylights and photocells to reduce lighting energy use by 30 percent during a monitored two-week period.



Source: California Energy Commission, PIER program

Properly planning and implementing a lighting control system will reduce the chances of over-dimming, under-dimming, and rapid cycling—problems that frequently occur in daylighting systems. These problems can often lead to users overriding the control system and eliminating any savings that may have accrued.

## Linear Fluorescent Lamps

Fluorescent lighting systems offer high efficacy, long life, and good light quality, and they generally have few operational limitations for most indoor lighting applications. They are the best choice for general lighting in commercial, institutional, and industrial spaces with low to medium ceiling height. In addition, the introduction of high-intensity fluorescent lamps and fixtures makes fluorescent systems a leading choice for areas with high ceilings (more than 15

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### RESOURCES: Daylighting

A number of daylighting resources, including reference guides, case histories, and software, are available free of charge on the web:

#### *Daylight in Buildings: Source Book on Daylighting Systems and Components*

<http://gaia.lbl.gov/iea21>

This comprehensive reference book, published by Lawrence Berkeley National Laboratory's Building Technologies Department, describes and evaluates new and innovative technologies for using daylight in buildings.

#### **Daylight Dividends** [www.daylightdividends.org](http://www.daylightdividends.org)

The Lighting Research Center maintains a web site that provides information, including case studies, aimed at building owners, architects, and engineers interested in the benefits of natural light.

#### **BetterBricks** [www.betterbricks.com/default.aspx?pid=lightinglabs](http://www.betterbricks.com/default.aspx?pid=lightinglabs)

This organization sponsors a network of university-associated laboratories throughout the northwest region of the United States. Its labs offer free analysis and consultation.

#### **DesignLights Consortium** [www.designlights.org](http://www.designlights.org)

This group offers guidelines on skylighting for warehouses and retail outlets and also provides case studies and software for skylight system design.

#### **Wisconsin Daylighting Collaborative/Energy Center of Wisconsin** [www.daylighting.org](http://www.daylighting.org)

The collaborative provides case studies, training programs, demonstrations, and design assistance.

#### **Skycalc** [www.energydesignresources.com/resource/129](http://www.energydesignresources.com/resource/129)

Skycalc is a Microsoft Excel-based software tool that assists designers in developing daylighting strategies that use skylights.

#### **SPOT** [www.archenergy.com/SPOT/index.html](http://www.archenergy.com/SPOT/index.html)

The Sensor Placement and Orientation Tool (SPOT) helps designers establish correct photosensor placement relative to a proposed daylighting electric lighting design. It also analyzes and predicts overall system performance prior to field installation and commissioning.

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feet)—the type of application that used to be the exclusive domain of HID light sources (see sidebar). A successful upgrade using fluorescent lamps requires careful consideration of options for lamps (diameter, length, intensity, and phosphor blend) and ballasts (electronic versus magnetic, rapid-start or programmed rapid-start versus instant-start).

**Picking the right fluorescent lamp.** Manufacturers have introduced a wide array of linear fluorescent lamp choices, including reduced-wattage, premium, and high-performance versions. There are also choices of CCT, CRI, lamp diameter, light output level (standard, high-output, or very high output), and starting method (rapid-start, programmed rapid-start, or instant-start). For most general lighting upgrades, the best choices are:

- *T8 (eight-eighths of an inch in diameter) or T5 (five-eighths of an inch in diameter) lamps.* The most efficient T8s are the high-performance type, also commonly called “super T8s” (Table 6.5). High-performance T8 lamps can be installed to replace T12 lamps and even cost-effectively upgrade lower-quality T8s. An office building in Minneapolis owned and managed by Hines upgraded more than 15,000 fixtures from T12 to T8 technology on its way to achieving and maintaining ENERGY STAR status. A retrofit from standard T8 lamps to high-performance T8s in modular classrooms in California cut lighting power from 116 W to 74 W and decreased air-conditioning loads in the confined classroom spaces. High-performance T8 lamps provide their biggest boost in efficiency when they are combined with high-performance ballasts. Reduced-wattage T8s, sometimes called “energy-saver” lamps, 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), they produce less light than full-wattage lamps, and they are not dimmable with current ballast technology.

T5 lamps, on the other hand, come only in metric lengths, which means that they are not a good retrofit option, unless fixtures are being replaced as well as lamps and ballasts. The efficacy of T5s is similar to that of T8 lamps, but because they are smaller they provide better optical control. 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 also offer better performance than T8s in enclosed fixtures and warm spaces because they are designed for a higher operating temperature.

- *Four-foot lamps.* The most common length for T8 lamps is four feet, which makes it the cheapest and easiest length to buy and stock. Eight-foot lamps are slightly more efficient, but they break more easily and can be difficult to transport.

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### **CASE STUDY: Upgrade to Fluorescents Improves Distribution Center Lighting**

Demoula’s Market Basket supermarket chain converted the lighting in its main warehouse distribution center in New England from high-intensity discharge to fluorescent equipment. The new fixtures, each of which houses six high-output T5 lamps, replaced 400-watt mercury vapor or high-pressure sodium fixtures on a one-for-one basis. The connected load was reduced from 460 to 351 watts per fixture. When aisles are vacant, occupancy sensors now turn off four of the lamps to drop the lighting energy by two-thirds (to 117 watts per fixture). In addition to achieving over 50 percent energy savings, the new lighting is much brighter, has better color, and offers instant-on and instant-restrike capabilities.

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**Table 6.5: The T8 family tree**

Linear T8 fluorescent lamps are available with a wide variety of characteristics. The high-performance T8 lamps offer the highest output and the best color quality.

Lamp type	Nominal power (W)	CRI	Efficacy (lm/W)
700 series	32	70s	<85
800 series	32	Low 80s	87 to 94
High performance (super T8)	32	High 80s	94 to 100
Energy saver	30	High 80s	94 to 100
Reduced wattage	28	High 80s	94 to 100
Reduced wattage	25	High 80s	94 to 100

Notes: CRI = color rendering index; lm/W = lumens per watt; W = watt.

Courtesy: E SOURCE; data from Consortium for Energy Efficiency

- *Standard light output.* Standard-output lamps are more efficient and less costly than high-output (HO) and very high output (VHO) systems, and they are available with a wider range of color temperatures. T5HO lamps are often used for high-bay applications because their high-intensity light is useful in large spaces.
- *CRI in the 80s.* Light sources with a CRI in the 80s provide good color rendering—far better than the old “cool-white” T12 lamps that provided a CRI in the 60s. Fluorescent lamps with CRIs in the 90s are available, but they carry a substantial penalty in efficacy.
- *CCT 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 incandescent lights or earth-tone color schemes; 4,100-K lamps may blend better with cooler daylight, HID sources, or blue-gray color schemes.

**Picking the right fluorescent ballast.** Ballast choices can be equally bewildering. The best choices for ballasts are:

- *Electronic (high-frequency).* Electronic ballasts are about 12 percent more efficient than conventional magnetic ballasts. They eliminate flicker and hum and are extremely cost-effective. The most efficient units are high-performance ballasts as defined by the Consortium for Energy Efficiency ([www.cee1.org/com-lt/com-lt-specs.pdf](http://www.cee1.org/com-lt/com-lt-specs.pdf)).
- *Instant-start.* This is the most efficient type of ballast, but it yields the shortest lamp life in applications with frequent on/off cycling. Instant-start ballasts are a good choice for lamps that burn six hours or more per start.
- *Programmed-start.* Programmed-start ballasts, also called programmed rapid-start ballasts, represent the next step in the evolution of rapid-start technology. Their use increases lamp life but carries some penalty in efficiency. They are the best choice in applications where lights will frequently be turned on and off, as often happens when occupancy sensors are used.
- *Universal-input.* Universal-input ballasts typically accept any input voltage between 120 and 277 volts. They make retrofitting easier and reduce stocking requirements, but provide slightly lower efficiency than dedicated-voltage ballasts.

Finally, make sure that lamps and ballasts are compatible. Most lamps are only compatible with one starting method; the major exception is high-performance T8s, which can use either rapid- or instant-start ballasts.

## Compact Fluorescent Lamps

Use compact fluorescent lamps (CFLs) to replace incandescent lamps in downlights, sconces, table lamps, task lights, and wall washers. They cost more initially than incandescent lamps do, but quickly pay for themselves through energy and maintenance savings. The longer the annual operating hours, the more attractive the economics of CFLs become, because more incandescent relamping costs are being avoided per year.

CFLs come in two general forms—self-ballasted or pin-base. Self-ballasted CFLs—also known as screw-base, screw-in, or integrally ballasted CFLs—can replace incandescent lamps without modifications to the existing fixtures. They combine a lamp, ballast, and base in a single sealed assembly that is discarded when the lamp or ballast burns out.

Pin-base CFLs, the type most commonly employed in commercial buildings, are used with a separate ballast. They are available in lower-power versions, which can replace incandescent lamps, and in higher-power versions, which can replace linear fluorescent lamps or HID lamps. Pin-base systems feature a ballast and pin-base fluorescent lamp socket that is wired into a fixture by the fixture manufacturer or as part of a retrofit kit. Because they are hardwired, dedicated systems, they eliminate the possibility that a user will return to using an inefficient incandescent bulb.

One of the most common uses of CFLs in commercial buildings is in recessed downlight cans. A wide range of fixtures is now available for this fixture class, some with very good reflector designs, good optical control, and dimming capabilities. Care must be taken in this application to ensure that excess heat buildup does not shorten the lamp life.

When using CFLs, remember these key points:

- *Go for a 3:1 ratio.* Lamp manufacturers often publish a 4:1 ratio for replacing incandescent bulbs with CFLs (that is, a 25-W CFL can replace a 100-W incandescent lamp). A 3:1 ratio is more appropriate (a 25-W CFL can replace a 75-W incandescent lamp)—in practice, CFL output is lower than the nominal rating because of lumen degradation and the effects of temperature and position on lamp output.
- *Limit the number of CFL types.* CFLs are available in a wide variety of sizes and shapes—it is useful to standardize on just a few types to reduce stocking requirements and confusion at relamping time.
- *Use dedicated fixtures.* To prevent the replacement of CFLs with incandescent bulbs when it is time to relamp, use dedicated fixtures that will only accept pin-based CFLs.
- *Choose CFLs that have earned the ENERGY STAR.* This rating from the EPA ensures reliability as well as efficiency in self-ballasted CFLs (visit [www.energystar.gov/index.cfm?c=cfls.pr\\_cfls](http://www.energystar.gov/index.cfm?c=cfls.pr_cfls) for more information).

## High-Intensity Discharge Lamps

Wherever an intense point source of light is required, HID light sources are the primary alternative to high-wattage incandescent lamps. Although HID lamps can provide high efficacy in a wide range of sizes, they have special requirements for start-up time, restrike time, safety, and mounting position. The basic types of HID lamps include mercury vapor, metal halide, and sodium, but mercury vapor lamps are an old, inefficient technology and should not be part of any upgrade plans. The primary uses for HID lighting are outdoor lighting, high-bay lighting, retail lighting, and remote-source lighting (**Table 6.6**).

**Metal halide lamps.** Metal halide lamps offer good color quality and efficacies of up to 100 lm/W. Were it not for several limitations, metal halide lamps might be considered the ideal light source. The limitations include:

- *Long start-up times.* Starting the lamps initially takes three to five minutes, and restarting after a shutdown or power outage takes 10 to 20 minutes. The introduction of electronic ballasts has reduced but not eliminated these delays (**Table 6.7**).
- *High UV output.* 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.
- *Color shifting.* The color of the light output from a metal halide lamp can shift, sometimes dramatically and randomly. The use of electronic ballasts and ceramic metal halide lamps reduces this effect.
- *Lamp position.* The light output of metal halide lamps is sensitive to the position of the lamp. (Sodium lamps are not position-sensitive.)

**Table 6.6: Applications for HID light sources**

Good 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	x	x		
Downlights	x	x		
Parking areas	x		x	x
General outdoor	x		x	x
Roadways or tunnels	x		x	x
Sports arenas	x	x		
High-bay spaces (including hangars and warehouses)	x	x	x	
Low-bay spaces (including supermarkets, light industrial, or retail shops)	x	x	x	
Outdoor signage	x			

Courtesy: E SOURCE

**Table 6.7: Metal halide warm-up and restrike times**

Electronic ballasts have shortened warm-up and restrike times for pulse-start metal halide lamps but have not eliminated them entirely.

Lamp/ballast type	Warm-up time (minutes)	Restrike time (minutes)
Probe-start/magnetic	4 to 5	10 to 20
Pulse-start/magnetic	2 to 3	3 to 5
Ceramic/magnetic	2 to 3	10 to 20+
Quartz pulse-start/electronic	1 to 3	2 to 4
Ceramic/electronic	1 to 3	10 to 20+

Courtesy: E SOURCE; data from Stan Walerczyk

Several developments in technology have made metal halide systems more effective. Manufacturers introduced pulse-start technology in the late 1980s and early 1990s to improve on the performance of older probe-start technology. More recently, electronic ballasts and ceramic metal halide lamps have improved performance even further. Ceramic metal halide lamps offer better CRI and lower lumen depreciation rates than the conventional quartz version. Electronic ballasts improve efficiency and color stability, reduce lumen depreciation rates, and cut warm-up and restrike times (**Table 6.8**). Many electronic ballasts are also dimmable.

Despite their limitations, metal halide lamps can be a good option in a number of applications, including outdoor and high-bay lighting. Ceramic metal halide lamps are also a good choice wherever color quality is critical, including retail lighting and some manufacturing operations. For example, a retrofit of ceramic metal halide lamps with a CRI of 92 is helping maintenance workers do their jobs better in the Alaska Airlines maintenance hangar at Seattle-Tacoma airport.

**Sodium lamps.** There are two types of sodium lamps: high-pressure sodium (HPS) and low-pressure sodium (LPS). HPS lamps, which produce a yellowish light, vary widely in their efficacy and color quality. Three basic grades are available, based on CRI: The lowest, with a CRI of about 21, is 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. For this last type of lamp, better color comes at the cost 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.

## Other Light Sources

Two other light sources bear consideration for some lighting upgrade applications: LEDs and induction lamps.

**LEDs.** light-emitting diodes are solid-state electronic devices that create light. They offer several advantages over conventional light sources, including long life and vibration resistance. Their small size and the directional nature of their light output are also beneficial 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.

**Table 6.8: 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 to 70	90 to 95
End-of-life lumen maintenance with electronic ballast (%)	70	80

Notes: CRI = color rendering index.  
Data are for 250- to 400-watt lamps.

Courtesy: E SOURCE

The most successful early applications for LEDs have been those where they replace filtered incandescent bulbs, such as in traffic signals and exit signs, because the filtering of the emitted incandescent light 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, an exit sign, this absorptive filter reduces the efficacy of the incandescent lamp-plus-filter combination to less than 5 lm/W. With LEDs, the color of the light they generate depends on the materials used to construct the LED, not on a filter. Modern, high-brightness red LEDs operate with an efficacy of 20 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. Many facilities have already replaced incandescent exit signs with LED signs, cutting the energy used by the signs by 80 percent or more in the process. For information on ENERGY STAR-qualified exit signs, most of which use LEDs, visit [www.energystar.gov/index.cfm?c=exit\\_signs.pr\\_exit\\_signs](http://www.energystar.gov/index.cfm?c=exit_signs.pr_exit_signs).

For general illumination, LEDs have great potential but are still under development. As of 2006 the most efficient white LEDs available offered an efficacy of about 30 lumens per watt in real-world conditions—and producing white light with LEDs still costs far more than it does with other light sources. (For updates on the status of LED lighting, visit the U.S. Department of Energy’s “Solid State Lighting” web site, [www.netl.doe.gov/ssl](http://www.netl.doe.gov/ssl).)

**Induction lamps.** Induction lamps, also called electrodeless lamps, consist 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—no electrodes required. The main advantages of induction lighting are the ability to produce a substantial amount of light in a relatively compact package and a long lamp life due to the elimination of the electrodes. The major drawback of induction lighting is high installed cost. In applications where maintenance costs are high, though, induction lighting systems can be cost-effective.

Existing induction-lamp products are aimed at two distinct market niches. The higher-wattage versions available (55 to 165 W) 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, including atriums (such as 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.

## 6.6 Use Efficient Luminaires

Many lighting projects use efficient lighting sources but fail to deliver the light in an efficient manner. To make the best use of an efficient source, it is essential to consider the efficiency and light distribution of the fixture that will deliver the light from the source. The fixture efficiency is a measure of how much of the light produced by the light source actually gets out of the fixture. It can vary from a low of about 50 percent to a high near 100 percent. In practice, fixture efficiency can make a big difference in a lighting system's overall efficiency—a fixture with an efficiency of 90 percent will deliver 50 percent more of its light than one with an efficiency of only 60 percent. To illustrate the impact improved efficiency can have, a designer who uses a fixture with a 90 percent efficiency and needs 100 fixtures to provide adequate lighting would have needed 150 fixtures to provide the same amount of light with the less-efficient fixture, all else being equal. Lighting fixtures for commercial installations are classified as direct, indirect, or indirect/direct (Figure 6.7).

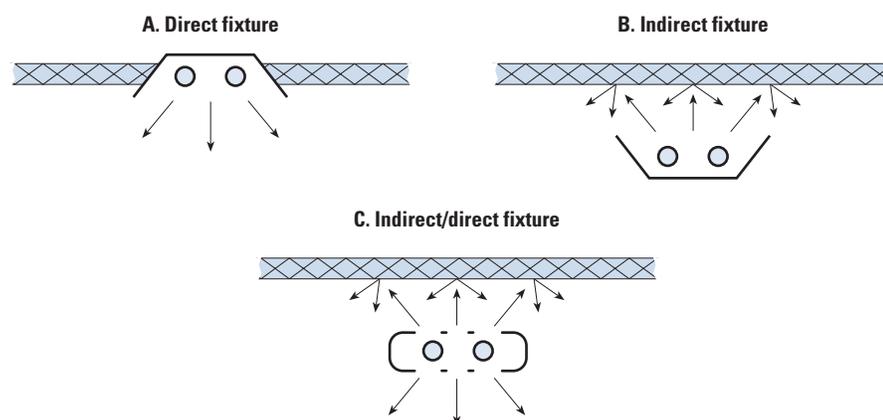
### Direct Lighting

The most common and lowest first-cost approach for general commercial lighting is direct downlighting with 2-by-4 or 2-by-2 fluorescent fixtures. This design provides good illumination for horizontal tasks, but it leaves ceilings and wall surfaces dark, creating a cave effect. It also may cause glare for computer-based work, because the fixtures may use bright lamps or lenses that can be reflected in computer screens. These fixtures may also be a source of direct glare into an occupant's eyes. The pattern of light distribution from a direct fixture is determined by the reflectors and lenses or diffusers it uses.

**Reflectors.** Reflectors are inserts designed to reduce the internal light loss in fixtures by using highly reflective surfaces to redirect light out of the fixture. They can be used in new fixtures or installed in existing fixtures as part of an energy-savings retrofit strategy.

**Figure 6.7: Fixtures have their ups and downs**

Lighting fixtures may send all or most of their light downward (A), upward (B), or a mixture of the two (C).



Courtesy: *E SOURCE Lighting Technology Atlas* (2005)

Most high-efficiency fixtures use specular reflectors, which perform like mirrors to aim light in particular directions. The same fixture with a different reflector design can produce a very different distribution pattern. Light distribution also varies according to the horizontal orientation of the fixture. Although a spherical HID fixture usually distributes its light in a uniform, circular pattern, many of the more efficient fluorescent fixtures emit light differently along their length than they do at the ends. This pattern can be used to improve system efficiency in applications such as narrow warehouse aisles.

Specular reflectors can also be retrofitted into existing fixtures, providing a 12 to 16 percent efficacy improvement over new white-enamel diffuse reflectors. These retrofitted reflectors provide more directional control than the white paint that is often employed, and they can be used to widen or narrow the light distribution from the fixtures. In some cases, the use of reflectors and high-efficiency sources enables delamping.

**Lenses and diffusers.** Most indoor commercial fixtures use some type of diffuser, lens, or louver over the face of the fixture to block direct view of the lamp or to diffuse or redirect light. Diffusers are simply semitranslucent plastic sheets that hide lamp images and diffuse light evenly across the face of the fixture. Because they spread light in all directions and absorb a large amount of light, diffusers are not only inefficient but also ineffective at controlling glare. Using clear plastic lenses with small prismatic surface patterns instead of diffusers improves efficiency and the distribution of light.

**Louvers.** Specular parabolic cube (or “paracube”) louvers can reduce the light loss that occurs with translucent lenses. By employing highly reflective surfaces shaped to send light down to a task (instead of bouncing it back and forth between parallel surfaces, as occurs with “eggcrate”-style louvers), these devices block lamp images, reducing the potential for reflected glare in computer screens or other shiny materials. Paracube louvers with openings smaller than 1 inch are effective at reducing glare, but they absorb a great deal of light and dramatically reduce fixture efficiency. Appropriate louver cube sizing (over 1.5 inches) typically requires a deeper fixture and a different method of attachment than conventional shallow fixtures can provide. Large-cell parabolic louvers can create an acceptable appearance and distribution, adding value to a lighting upgrade.

## Indirect Lighting

The best type of lighting system for glare control and visual comfort is an indirect or indirect/direct system. Indirect lighting can make a space feel brighter with less light because it illuminates the ceiling and top portions of walls. 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 computer terminals. Indirect lighting is most useful in rooms with 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, or indirect fixtures can be integrated into or mounted onto office furniture.

The introduction of T5 fluorescent lamps, which are thinner and provide a higher intensity of light output than T8 lamps, 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.

Indirect lighting can also provide another benefit: The even illumination that it provides means that a lower ambient lighting level may work for a given space. For example, 30 foot-candles of indirect illumination may be sufficient in a location where 40 or 50 foot-candles of direct lighting would be required to provide a similar work environment.

## 6.7 Automatically Control Lighting

Reducing the connected load of the lighting system represents only one part of the potential for maximizing energy savings. The other part is minimizing the use of that load through automatic controls. Automatic controls switch or dim lighting based on time, occupancy, lighting-level strategies, or a combination of all three. In situations where lighting may be on longer than needed, left on in unoccupied areas, or used when sufficient daylight exists, consider installing automatic controls as a supplement or replacement for manual controls.

The general control strategies used by lighting designers include:

- *Occupancy sensing*, in which lights are turned on and off or dimmed according to occupancy;
- *Scheduling*, in which lights are turned on and off according to a schedule;
- *Tuning*, in which light output is reduced to meet current user needs;
- *Daylight harvesting*, in which electric lights are dimmed or turned off in response to the presence of daylight;
- *Demand response*, in which power to electric lights is reduced in response to utility curtailment signals or to reduce peak power charges at a facility; and
- *Adaptive compensation*, in which light levels are lowered at night to take advantage of the fact that people need and prefer less light at night than they do during the day.

These strategies can be accomplished by means of various control devices, including on-off controls, dimming controls, and systems that combine the use of both types of equipment (**Table 6.9**). These controls can be quite sophisticated, but in general they perform two basic functions: They turn lights off when not needed, and they modulate light output so that no more light than necessary is produced. The equipment required to achieve these functions varies in complexity from simple timers to intricate electronic dimming circuits. Each of these technologies can be applied individually to great effect or combined for even greater benefit. Whatever control strategy is employed, steps must also be taken to commission the system to make sure that it performs as expected, and plans must be made for retrocommissioning the system over time so that it continues to perform that way.

### On-Off Controls

The simplest way to reduce the amount of energy consumed by lighting systems is to turn lights off when they are not needed. All electric lights come with a manual switch for that purpose, but these switches are not used as often as they could be. As a result, the lighting industry offers several automatic switches that either mark time or sense the presence of occupants.

**Occupancy sensors.** Occupancy sensors are most effective in spaces where people move in and out frequently in unpredictable patterns: for example, private offices, lecture halls, auditoriums, warehouses, restrooms, and conference rooms. Occupancy sensors are less likely to be effective in open-plan offices, where one or more people may be present throughout the day, or

in reception areas, lobbies, retail spaces, or hospital rooms. The savings achievable with occupancy sensors, even in the most appropriate spaces, varies widely, depending on local conditions.

The three most common types of occupancy sensors are passive infrared (PIR), ultrasonic, and those that combine the two technologies. PIR devices are the least expensive and most commonly used type of occupancy sensor. They detect the heat emitted by occupants and are triggered by changes in infrared signals when, for example, a person moves in or out of the sensor’s field of view. PIR sensors are quite resistant to false triggering and are best used within a 15-foot radius (**Figure 6.8**).

Ultrasonic devices emit a sound at high frequency—above the levels audible to humans and animals. The sensors are programmed to detect a change in the frequency of the reflected sound. They cover a larger area than PIR sensors and are more sensitive. They are also more prone to

**Table 6.9: Lighting control strategies and equipment**

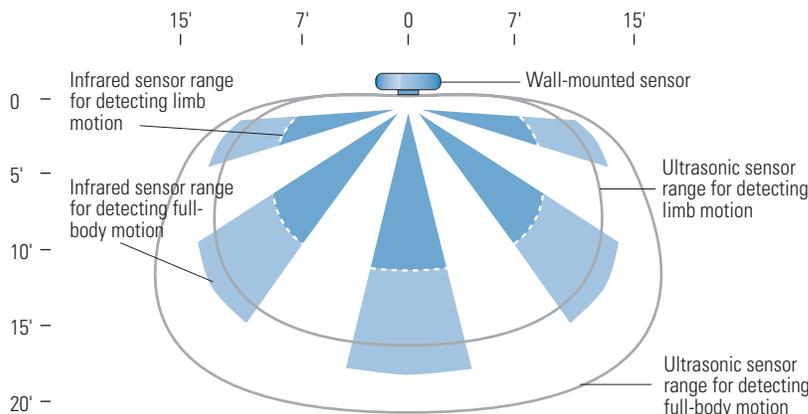
A number of different control strategies and a variety of equipment options are available to the lighting designer.

Strategy	Equipment
Occupancy sensing	Occupancy sensors—infrared, ultrasonic, dual technology
Scheduling	Timed switches, energy management systems
Tuning	Continuous dimming, bilevel switching
Daylight harvesting	Continuous dimming, bilevel switching, photosensors
Demand response	Voluntary or automatic curtailment via utility signals, dimmers, switches, energy management systems
Adaptive compensation	Dimming, switching, timers, photocells

Courtesy: E SOURCE; data from *Advanced Lighting Guidelines*

**Figure 6.8: Occupancy sensor coverage patterns**

Ultrasonic sensors can detect motion at any point within the contour lines. Infrared sensors “see” only in the wedge-shaped zones, and they do not generally see as far as ultrasonic units. Some sensors see farther straight ahead than to the side. The ranges shown here are representative; some sensors may be more or less sensitive.



Courtesy: E SOURCE *Lighting Technology Atlas* (2005)

false triggering. For example, ultrasonic sensors can be fooled by the air currents produced by a person running past a door, moving curtains, or the on-off cycling of an HVAC system.

Hybrid devices that incorporate both PIR and ultrasonic sensors are also available. These take advantage of the PIR device's resistance to false triggering and the higher sensitivity of the ultrasonic sensor. Some hybrid sensors combine PIR with sensors for audible sound. That design has proved useful in cases where the frequencies used in ultrasonic sensors interfere with equipment such as hearing aids—a problem that is less frequent than it used to be because sensor manufacturers have learned to use frequencies that minimize the issue.

Evaluating the economic feasibility of an installation is best done by monitoring lighting and occupancy patterns. The use of inexpensive automatic datalogging systems will indicate the total amount of time the lights are on when the space is vacant, the time of day the savings take place, and the frequency of lamp cycling. Data can also be gathered through the use of recording ammeters connected at lighting breaker panels; through random surveys, such as observing a building's exterior at night or interviewing custodial and security personnel; and through existing timers, scheduling controllers, and energy management systems. Whatever way the data is gathered, it is important to account for seasonal variations in operation in order to avoid incorrectly extrapolating short-duration data to a full year. This information will help lead to an informed decision on the economic feasibility of potential occupancy-control opportunities.

Sensor placement is also crucial to success (see sidebar). Wall-mounted sensors are suitable in smaller rooms—offices, bathrooms, and equipment rooms that are only intermittently occupied. In larger spaces or wherever the lighting load is higher, it is better to mount the sensor in the ceiling. Some units can be mounted in the corner or on the wall near the ceiling (**Table 6.10**).

**Timed switches.** Timed switches operate based on either elapsed time after triggering or on programmed schedules using clock time. Elapsed-time switches, also called timer switches, typically fit into or over a standard wall-switch box and allow occupants to turn lights on for a period that is determined either by the occupant or by the installer. Lights go off at the end of that interval unless the cycle has been restarted by the occupant or manually turned off sooner. Time intervals typically range from 10 minutes to 12 hours. Elapsed-time switches are much simpler to specify than occupancy sensors, are less prone to faulty user adjustment, and cost less.

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### **CASE STUDY: Saving Energy with Occupancy Sensors**

As part of a lighting upgrade at one of its facilities in Beverly Hills, California, Arden Realty installed a variety of occupancy sensors. These included ceiling sensors in larger areas and wall sensors in smaller offices. The wall sensors used infrared technology and the ceiling sensors used the ultrasonic approach. Savings amounted to an estimated 3,920 kWh/year in lighting electricity use and another 1,253 kWh/year in reduced cooling energy. Energy use at the facility was also cut by more than 140,000 kWh/year by replacing T12 lamps with T8 lamps, retrofitting reflectors in some fixtures, and replacing incandescent bulbs with compact fluorescents. These lighting measures are part of a building upgrade that includes a new energy management system and the use of variable-frequency drives on various pumps and fans. Overall, Arden, the largest landlord of office buildings in Southern California, has performed more than 100 lighting retrofits, covering over 12 million square feet. The efficiency improvements of these lighting upgrades have been a key element for many Arden properties in earning the ENERGY STAR.

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**Table 6.10: Occupancy sensor applications**

When using occupancy sensors, it is essential to place them correctly.

Type of sensor	Applications
Ceiling mount	Open partitioned areas, small open offices, file rooms, copy rooms, conference rooms, restrooms, garages
Corner mount/wide view	Large office spaces, conference rooms
Wall switch	Private offices, copy rooms, closets
Narrow view	Hallways, corridors, aisles
High mount/narrow view	Warehouse aisles

Courtesy: E SOURCE

Elapsed-time switches may be mechanical or electronic. Mechanical units, typically set by the user, are basically spring-wound kitchen timers connected to a relay, and so are subject to mechanical failures if used in high-traffic areas. Time intervals on electronic switches are typically set by the installer using a hidden setscrew. These electronic devices look like conventional toggle switches, so occupants are usually unaware of the presence of the device, which reduces vandalism and theft. Elapsed-time switches are also an easy, economical means of complying with energy codes that call for automatic lighting controls.

Clock switches control lights by turning them on and off at prearranged times, regardless of occupancy. They are most useful in locations where occupancy follows a well-defined pattern, such as a retail outlet. They are typically placed in electric closets that house lighting power panels. These devices cost relatively little to install and can control large loads with a single set of contactors. Equipment may consist of mechanical devices—motors, springs, and relays—or sophisticated electronic systems that handle several schedules simultaneously. Mechanical switches may require correction for daylight savings time or after a power failure unless battery backup is available, but battery backup can triple the device's price. Electronic devices routinely include battery backup and can be easily programmed to adjust for shifts to and from daylight savings time or for holiday schedules.

One thing to note: If a space has fluorescent lighting, make sure that electronic switches do not use a triac relay. Triacs may trickle a small amount of current to ballasts and lamps, even when they are off, which may damage the lamps as well as waste energy.

**Energy management systems (EMSs).** An EMS performs the same function for lighting as a clock switch, but with more sophistication and additional features. A typical EMS is designed to handle a variety of loads, including HVAC, but pure lighting-management systems are also available. Systems are now becoming available that combine on-off and dimming capabilities in an EMS. A common EMS feature is a sweep mode that automatically cycles lights on or off, one section or floor at a time, signaling occupants that lights will soon be shut off. Occupants can then override the shutdown in their area by pressing a local switch or by phoning in a code to the EMS (see sidebar).

## Dimming Controls

Dimming controls are usually used to match lighting levels with human needs and to save energy. When combined with photosensors that measure local light levels, dimming controls can correct for dirt buildup in fixtures and lamp lumen depreciation. Dimming controls are also used to modulate lamp output to account for incoming daylight. Dimming may be accomplished in either a

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## CASE STUDY: Turning Off Lights with an EMS

A lighting control system linked to an energy management system at a 250,000-square-foot office building in Boston, Massachusetts, produced 112,500 kWh/year in energy savings. Most of the work at the site is done in a single shift, Monday through Friday. An audit at the start of an energy-efficiency upgrade found that the lights were frequently left on in some areas during times when the spaces were unoccupied. Cleaning crews and security guards were supposed to turn off the lights in unoccupied areas, but for various reasons that was often overlooked. Sometimes after-hours or weekend workers would turn on the lights but forget to turn them off when they left. The audit identified the general lighting in the facility as an opportunity for energy savings, but the layout of the facility was not deemed to be conducive to the use of occupancy sensors in all areas. Occupancy sensors were installed in private offices and restrooms, but high partitions and frequent rearranging of the space made them impractical for the large open areas. Instead, an automatic lighting control system was installed as part of a comprehensive EMS being installed at the site.

The building was divided into 47 lighting “zones,” and a time schedule was assigned to each zone. New electronic relays were installed on the lighting circuits and tied into the EMS. The system turns the lights on and off at the designated times and allows for overrides when necessary, ensuring that occupants are still in control when they need to be.

At each zone’s designated time, all the lights in that zone blink to alert any remaining occupants that all lights will go off in a few minutes. Anyone still working uses a phone to call a designated number (to the EMS computer) to get an additional hour of light. When that hour is up, if no further overrides are requested, the lights go out and stay out until the designated morning “lights on” time. Schedules for each zone can be changed easily if necessary. The system can also be accessed by facility managers from remote locations.

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stepped or continuous fashion. Advanced dimming technologies, using individually addressable ballasts and wireless technology, are also available.

**Step dimming.** Two means of step dimming are available: banks of lamps may be put on different switching circuits or ballasts designed specifically for step dimming may be applied. The first method is often referred to as bilevel switching, even though more than two levels may actually be available. For example, in a system with three-lamp fluorescent fixtures, one switch may operate the center lamp in each fixture, while another operates the outer lamps. This arrangement makes three lighting levels possible (one lamp, two lamps, or three lamps lit), yet the term “bilevel” is still used to describe it.

Step-dimming ballasts offer more light control and energy savings than nondimming ballasts but cost less than the more versatile continuous-dimming ballasts. Step-dimming ballasts typically offer two or three lighting levels, and they can be used with occupancy sensors so that the sensors are able to dim the lamps rather than turn them off, which can reduce on-off cycling and extend lamp life. These units also offer a viable way to reduce lighting levels during non-critical hours and to shed peak demand in common areas such as corridors.

Step-dimming ballasts are especially useful for HID lamps. These lamps typically require long warm-up times, so they are not suited to being switched on and off by occupancy sensors. Better results can be obtained by switching the lamps between low power and full power.

**Continuous dimming.** Continuous-dimming controls adjust lighting levels over a wide range. They offer more flexibility than step dimming and are used in a wide variety of applications, including mood-setting and daylight dimming.

Fluorescent lamps may be dimmed for two purposes: energy savings and architectural effect. Energy-saving dimmers typically dim down to 20 percent, while architectural dimmers may reduce light levels to 1 percent or less. Dimming ballasts are often used to reduce electric light output whenever daylight is available. Dimming can also be used in load-shedding strategies—better to have employees work briefly under slightly lower light levels than be forced to send them home because of a power failure.

Dimming ballasts use either low-voltage or power-line control. Most ballasts are controlled by a separate, low-voltage circuit. This approach requires additional wiring, but the ballasts are compatible with a wide variety of dimming controls. For example, low-voltage-controlled ballasts can easily be connected to EMSs that offer 0- to 10-volt output channels. Power-line-controlled ballasts can dim fluorescent lamps with standard incandescent wall dimmers installed directly on the line-voltage switch leg—no extra wires necessary. The ballasts are not compatible with all dimmers, however, so ballast and dimmer should be checked for compatibility. Personal dimming controls, which allow individuals to control light levels in their own work areas, are also becoming more widely available. Such dimming controls have been shown to cut energy use and increase worker satisfaction levels.

In recent years, it has become easier to dim compact fluorescent lamps as well as full-size fluorescents. New screw-base, step-dimmable, and continuously dimmable CFLs provide dimming capabilities down to the range of 10 to 20 percent, and these products work well with most existing incandescent dimmers. These lamps cost two to three times more than standard CFLs. New pin-base CFL dimming products are on the market as well, providing opportunities to dim lights to 5 percent of maximum output or even lower levels.

HID dimming is more limited because it is accompanied by color shifting, reduced CRI, increased flicker, adverse impact on lamp life, and inadvertent lamp shutdown during line-voltage variations. New electronic dimming ballasts for metal halide lamps are reducing the severity of some of these effects, making HID dimming more feasible.

Building operators can achieve the highest levels of energy savings through a combination of dimming and on-off strategies. However, the total savings achieved by implementing both strategies will be less than the sum of the savings gained by implementation of each of the strategies alone. The reason for this is simple: Take, for example, a system that combines occupancy sensing and dimming. Dimming cannot save energy when occupancy sensors have already shut off a lamp, and the occupancy sensors save less energy when they turn off lights that otherwise would have been dimmed.

**Addressable ballasts.** Most dimming is accomplished by controlling banks of dimmable ballasts together. Digitally controlled ballasts that use control protocols such as DALI (digitally addressable lighting interface), LonWorks, BACnet, or other proprietary protocols provide more flexibility. Each ballast is assigned an identifier, or “address,” and can be controlled individually or in clusters that can easily be regrouped. With some systems, two-way communications are also possible. This capability not only gives users the ability to tailor local lighting conditions to their individual needs, but may also give energy managers a tool for tracking and controlling energy use and responding to load-shedding signals (see sidebar).

Some protocols, such as DALI, are designed for use over a dedicated low-voltage network, but DALI-to-Ethernet converters are available so that DALI can be used in buildings with existing

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## CASE STUDY: System Controls and Tracks Lighting Use

A lighting control system based on the digitally addressable lighting interface (DALI) allows the energy manager at the Harvard School of Public Health to control any of the lights in the school's refurbished office space using a personal computer and the Internet. He can pinpoint the location of any failed lamps or ballasts and get up-to-the-minute reports on lighting energy consumption. The system has allowed him to better manage energy use and maintenance while keeping building occupants comfortable. All of the ballasts have been set to operate partially dimmed as the default mode, so if occupants say that they need more light, it takes just a few keystrokes to give it to them without having to add new fixtures. The system can also be used to dim lights in response to load-shedding signals from the local utility.

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Ethernet networks without the need to run additional control wires. Some digital ballasts include a built-in DALI interface; others use another proprietary protocol. Conventional low-voltage controlled-dimming ballasts can be added to digital lighting control systems via special interfaces that connect to DALI systems and convert the DALI commands to standard 0- to 10-volt direct-current control signals.

**Wireless lighting controls.** One of the difficulties that comes up when adding controls as part of a lighting upgrade is the expense of running the wires. One promising solution is wireless lighting controls. A typical wireless lighting control system consists of a set of sensors, actuators, and controllers that communicate via radio waves rather than wires. Although wires are still required for the lighting equipment itself, using radio waves instead of wires to transmit control signals offers a number of potential advantages, both in terms of ease of installation and maintenance and in terms of flexibility. Wireless lighting controls have been available for a number of years, but their use has been limited to a few niche markets such as high-end homes, conference rooms, and classrooms that often need a large variety of lighting scenes. These systems are installed to provide amenities they're not aimed at energy savings and they lack the reliability and flexibility that would be needed in a commercial facility. Newer, more-capable wireless systems, some of which are available today, may broaden the wireless lighting controls market considerably if costs can be brought down. One promising technique uses a concept known as a mesh network, which is a decentralized set of wireless nodes that are linked to one another to form a self-organizing, self-healing network. Control is split up among the different nodes so that there are multiple, redundant paths throughout the network. Each device on the network is designed to transmit over short distances, which reduces power requirements and minimizes the potential for interference. Leading players in the mesh network field are the Zigbee Alliance ([www.zigbee.org](http://www.zigbee.org)) and the Z-Wave Alliance ([www.z-wavealliance.org/modules/start/](http://www.z-wavealliance.org/modules/start/)).

## Commissioning Ensures the Benefits of Lighting Controls

Most lighting controls require commissioning to ensure that they operate as intended and are properly adapted to local conditions. Specific steps depend on the types of controls installed:

- For all systems, verify that sensors are placed according to construction drawings and make adjustments for any unexpected obstructions.
- For daylighting systems, calibrate the system after all furnishings and interior surface finishes are in place. For help in commissioning daylighting systems, Architectural Energy Corp. has

created the Sensor Placement and Orientation Tool. This tool is available free of charge at [www.archenergy.com/SPOT/index.html](http://www.archenergy.com/SPOT/index.html).

- For systems with occupancy sensors, check placement and orientation against construction drawings and adjust the sensitivity and time delay of the sensor.
- For scheduling systems, put in appropriate start and stop times for weekday, weekend, and holiday operation and verify correct operation of overrides.
- For manual dimming, check that the dimmer is installed as specified and that the upper limits set are appropriate for the tasks being performed and the lower limits set do not cause the lamps to flicker.

In addition, to decrease the chances that occupants will sabotage the controls, occupants and maintenance personnel should be informed about the benefits of the systems and, where possible, involved in the design process. They should also be informed about how the controls work and trained in the use of the override controls so that they can use them when needed and not be tempted to override permanently. All control systems also need periodic maintenance to ensure that they continue to work properly.

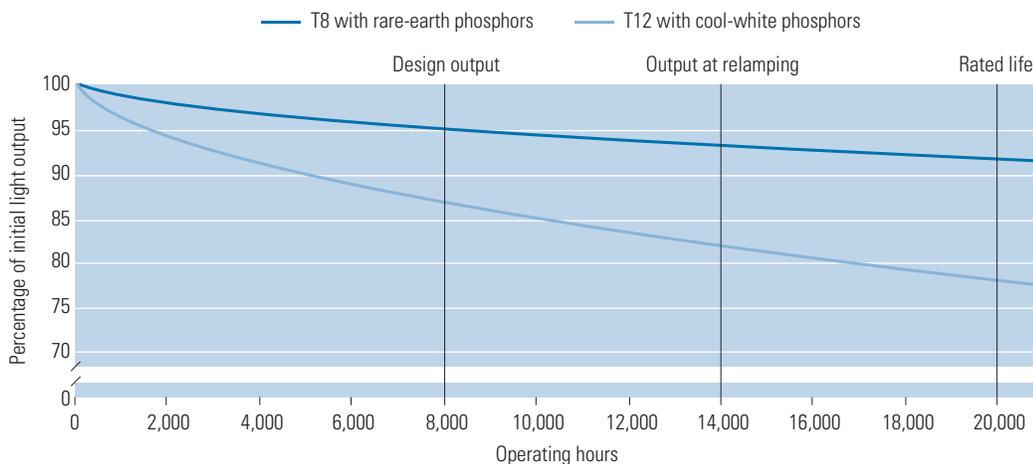
## 6.8 Build In an Operations and Maintenance Plan

A lighting upgrade can cut energy bills, improve the look of a facility, and boost employee morale, but all those benefits can fade away if the new lighting systems are not well maintained. All lighting systems experience a decrease in light output and efficiency over time, because:

- Lamp light output decreases (lamp lumen depreciation) (**Figure 6.9**).
- Dirt accumulates on fixtures (luminaire dirt depreciation). The IESNA issued new guidelines in late 2003 for estimating the effect of dirt accumulation on luminaires. The document,

**Figure 6.9: Typical lamp lumen depreciation curves**

The slower rate of lumen depreciation of some lamps compared to others can translate to lower installed wattage for an equal amount of maintained foot-candles.



Courtesy: *E SOURCE Lighting Technology Atlas* (2005); data from Philips Lighting Co.

“IESNA/NALMCO RP-36-03,” may be purchased from <http://webstore.ansi.org/ansidocstore/product.asp?sku=IESNA%2FNALMCO+RP-36-03>.

- Lamps burn out.
- Control systems drift out of spec or are overridden by occupants.

For maximum effectiveness, maintenance should be addressed right from the start of the design process in the following ways.

- *Design lighting systems with components that minimize light loss over time, are easy to maintain, and use the fewest types of lamps.* The process begins with the choice of lamp. To account for lighting-system degradation, designers typically oversize initial light output by 35 percent or more to “maintain” minimum target illumination levels when lamps are changed and fixtures cleaned. Proper design and maintenance—using high-quality lighting components that suffer less degradation or degrade more slowly—can cut that excess nearly in half, saving almost 15 percent in connected load. Minimizing that 35 percent safety factor involves choosing lamps with minimum lumen depreciation. Maintenance costs can be further minimized by limiting the number of different types of lamps that must be stocked and by choosing lamps with maximum rated life to reduce burnout rate.
- *Train personnel in proper maintenance techniques, including cleaning and relamping.* Knowledge of the equipment; an understanding of the procedures; and an appreciation for the relative costs of energy, labor, and lamps are essential parts of instruction. Annual retraining is also necessary to remind staff of proper procedure and to account for changes in equipment and staff turnover. Retraining is especially important immediately after a lighting upgrade. Such training should include hands-on work with new devices and a quiz to indicate which employees may need further technical education. A variety of training and certification programs are offered by national organizations for the design and maintenance of efficient lighting systems (see sidebar). Many utilities also sponsor local training programs. Hiring a lighting-management company may simplify maintenance. Using an outside firm can eliminate the need to train employees in lamp maintenance practices and cut the necessity of maintaining large stocks of extra lamps. In addition, a firm familiar with new technologies can help a facility take advantage of the latest lighting-system improvements.
- *Control purchasing and inventory to ensure that only the right replacement components are available.* If the right ballast or lamp is not immediately available when an occupant complains about a burnout, the need to provide a quick replacement will almost guarantee that the wrong type is installed instead. Maintaining proper purchasing specifications and inventory eliminates the possibility of using the wrong equipment.

### Plan for Group Relamping

In many cases, the most cost-effective way to maintain a lighting system is a planned program of group relamping, in which all lamps are replaced in the same operation. This practice is in contrast to spot relamping, in which lamps are replaced only when they burn out.

- On a per-lamp basis, group relamping requires much less labor than spot relamping because the maintenance workers have all the required materials on hand and can move systematically from one fixture to the next. In addition, group relamping is normally done outside working hours, which reduces disruption of normal activities.
- It is an easy task to schedule and to delegate to outside contractors who have special equipment and training.

- Group relamping provides brighter and more-uniform lighting because it gets rid of lamps before they are at the end of their lumen depreciation curve.
- It offers increased control over the replacement lamps, reducing the probability of mixing incompatible lamps, such as those with different color temperatures.
- Other maintenance activities can be combined with group relamping, such as ballast and reflector inspection and lens cleaning. It also provides an opportunity for retrofitting reflectors, lamps, ballasts, or lenses as necessary.

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## RESOURCES: Training and Certification Programs

A number of organizations offer training and certification programs for the design and maintenance of energy-efficient lighting systems.

### Association of Energy Engineers (AEE)

Contact Leslie Walcker, CLEP Certification Administrator

Atlanta, Georgia

Tel 770-447-5093 ext 223

E-mail [leslie@aeecenter.org](mailto:leslie@aeecenter.org)

Web [www.aeecenter.org/certification/clep](http://www.aeecenter.org/certification/clep)

The AEE Certified Lighting Efficiency Professional (CLEP) program includes a two-day seminar and a four-hour exam oriented toward design and specification of energy-efficient lighting systems.

### The interNational Association of Lighting Management Companies (NALMCO)

Des Moines, Iowa

Tel 515-243-2360

Fax 515-243-2049

E-mail [director@nalmco.org](mailto:director@nalmco.org)

Web [www.nalmco.org/](http://www.nalmco.org/)

The NALMCO Certified Lighting Management Consultant program is a preparatory course and one-day test focusing on lighting systems specification and management.

### National Council on Qualifications for the Lighting Professions (NCQLP)

Alexandria, Virginia

Tel 703-518-4370

Fax 703-706-9583

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

The NCQLP Lighting Certification program consists of a four-hour exam that focuses on overall lighting knowledge as well as information-gathering and decision-making skills.

### Other Certifying Agencies

Contact information by state can be found at [www.boccentral.org](http://www.boccentral.org).

Various energy-efficiency groups around the country, such as the Midwest Energy Efficiency Alliance (MEEA) and Northeast Energy Efficiency Partnerships (NEEP), offer Building Operator Certification programs. Certification requires 56 hours of classroom training and approximately 16 hours of projects that encompass a wide variety of building elements, including energy-efficient lighting practices.

Group relamping is normally done at about 60 to 80 percent of rated lamp life, depending on variables such as labor costs, requirements for fixture cleaning, and the cost and mortality curves of the lamps.

Economic comparisons typically show that group relamping has higher lamp costs but lower labor costs than spot relamping. One such comparison shows a substantial overall savings from group relamping (**Table 6.11**).

## Retrocommission Lighting Controls

All lighting control systems need to go through periodic retrocommissioning where they are checked to ensure that they continue to work as expected—occupancy sensors may become obstructed by a new furniture arrangement, light sensors may require adjustment if interior surfaces are changed to materials with new reflectance values, or a new building may go up next door that changes incoming daylight patterns. Maintenance personnel should inspect the lighting controls at least annually to verify proper operation. Photoelectric controls need occasional cleaning of the photosensitive surface.

Scheduling controls that use relays need to be checked periodically to ensure that they are not permanently overridden. In cases where an override is found, determine the cause before simply clearing the override setting—the override may have been an attempt to solve a problem that has not yet been fixed.

## Develop an O&M Manual

To deal with these factors and sustain an efficient, high-performance lighting upgrade, assemble an operations and maintenance (O&M) manual. Use it as both the lighting-management policy and a central operating reference for building-management and maintenance staff. This manual should include the following information:

- Facility blueprints.
- Fixture and controls schedule.
- Equipment specifications, including product cut sheets.
- Equipment and service provider sources and contacts (include utility contacts).

**Table 6.11: Economics of group versus spot relamping**

Group relamping has higher lamp costs but much lower labor costs, providing, in this case, a 43 percent overall savings. Group relamping also provides additional benefits in lighting quality and facility management.

	Relamp cycle (hours)	Average lamps replaced per year	Average material cost per year	Average labor cost per year	Total average cost per year
Spot relamping on burnout <sup>a</sup>	20,000	525	\$945	\$3,938	\$4,883
Group relamping at 70 percent of rated life <sup>b</sup>	14,000	750	\$1,350	\$1,425	\$2,775
Difference	6,000	225	\$405	-\$2,513	-\$2,108

Notes: a. Assumes labor costs of \$7.50 for relamping and cleaning, material cost of \$1.80 per lamp, and 3,500 hours per year operation.

b. Assumes labor costs of \$1.90 for relamping and cleaning, material cost of \$1.80 per lamp, and 3,500 hours per year operation.

Courtesy: *E SOURCE Lighting Technology Atlas* (2005)

- Fixture cleaning and relamping schedule with service tracking log.
- Procedures for relamping, reballasting, and cleaning fixtures.
- Procedures for the adjustment of photosensors and occupancy sensors.
- Procedures for proper lamp and ballast disposal.

Review the O&M manual with the staff responsible for lighting maintenance. Make training mandatory for all new maintenance personnel. Correct operation and maintenance should be built into job descriptions and should become part of all annual performance reviews.

## Dispose of Lamps Properly

A lighting upgrade will most likely require the removal and disposal of lamps and ballasts. Group relamping every several years and occasional spot relamping as necessary will also create additional lamp waste. Some of this waste may be hazardous and must be managed according to applicable federal, state, and local requirements (see sidebar).

Many lamps contain mercury and are therefore considered hazardous waste under the Resource Conservation and Recovery Act (RCRA), including fluorescent, HID, neon, mercury vapor, HPS, and metal halide lamps. Visit the EPA's RCRA web site at [www.epa.gov/rcraonline](http://www.epa.gov/rcraonline) for more details. To help deal with the problem of lamp disposal, the EPA initiated an outreach program in 2002 to promote the recycling of mercury lamps by commercial and industrial end users. The outreach program aims to increase awareness of the proper disposal methods of these lamps in compliance with federal and state universal waste rules. The National Electrical Manufacturers Association (NEMA) supports the program and offers information on a web site designed specifically to address lamp recycling issues ([www.lamprecycle.org](http://www.lamprecycle.org)).

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## RESOURCES: Disposal Contact and Resource Information

Lighting upgrades and ongoing maintenance will require the disposal of lamps and ballasts. Here are some sources of information on the proper disposal of these items, which may contain hazardous materials.

### Resource Conservation and Recovery Act (RCRA)

Hotline 800-424-9346 (Washington, D.C., metro area: 703-412-9810)

Web [www.epa.gov/rcraonline](http://www.epa.gov/rcraonline)

RCRA provides information on disposal of lamps that contain hazardous materials.

### National Electrical Manufacturers Association (NEMA)

Web [www.lamprecycle.org](http://www.lamprecycle.org)

NEMA maintains a web site with guidelines and detailed information on lamp recycling.

### Toxic Substances Control Act (TSCA)

Hotline 202-554-1401

E-mail [tsc-hotline@epa.gov](mailto:tsc-hotline@epa.gov)

Web [www.epa.gov/pcb](http://www.epa.gov/pcb)

The TSCA provides regulations and guidelines for disposal of ballasts that contain polychlorinated biphenyls (PCBs).

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For ballasts, the proper method of disposal depends on the type and condition of the ballasts. Generally, ballasts manufactured after 1978 contain the statement “No PCBs,” meaning they have not been found to contain polychlorinated biphenyls (PCBs). The disposal of PCBs is regulated under the Toxic Substances Control Act (TSCA). Other factors controlling the disposal of ballasts will depend on the regulations and recommendations in effect in the state in which they are removed or discarded. Because disposal requirements vary from state to state, check with regional, state, or local authorities for all applicable regulations.

The costs of handling and disposal of lamps and ballasts vary, but the expense is rarely a deal-breaker in a lighting upgrade. Typically, disposal costs constitute a very small percentage of the overall life-cycle costs of operating a lighting system. Investigate and budget for these disposal costs, both as a first cost during the upgrade and as an ongoing O&M expense.

## 6.9 Summary

This chapter on the lighting stage of a building system upgrade has described opportunities for improving a building’s lighting system in a cost-effective manner. To ensure a successful upgrade, keep the following strategies in mind:

- Design light (quantity and quality) that is tailored to task and occupant needs.
- Specify equipment that maximizes system efficiency, not just component efficiency.
- Use automatic controls to turn lights off or down when not needed.
- Establish ongoing monitoring, maintenance, and disposal practices.

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