energydesignresources

# design brief

## LIGHTING CONTROLS

**HOW TO GET THE RIGHT AMOUNT OF LIGHT WHERE IT'S NEEDED, ONLY WHEN IT'S NEEDED.**


## Summary

Lighting controls can increase the value of commercial buildings by making them more comfortable, productive, and energy efficient. These controls work either by turning lights off when they are not needed or by dimming light output so that no more light is produced than necessary. By creatively combining these two functions, designers can achieve even greater benefits. Here are some examples of the value that lighting controls can add to a building:

- An office building that installed daylight dimming controls and experienced a 15 percent decline in absenteeism.
- A campus where occupancy sensors positioned in 8,000 rooms have saved the school $1.3 million a year, with a payback of about one year.
- An electronics manufacturer that used an energy management system to control lights and saved more than $68,000 annually, with a payback of less than one year.
- A government laboratory that discovered when it gave workers control over lighting levels that they used the controls to improve their visual comfort as well as to save energy.

Lighting controls present an additional benefit to designers. Adding them to a design can make it easier to meet California's stringent lighting energy-efficiency requirements.


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## Introduction

By incorporating controls that vary the time of operation and the intensity of electric lighting systems, designers and owners can significantly improve the value of commercial buildings. These controls may be used to make buildings more:

Better lighting controls may reduce eye-strain and fatigue, making it possible for workers to concentrate most effectively for longer periods of time.

- *Comfortable,* by allowing users to tailor lighting levels to their personal tastes.
- *Productive,* by optimizing the work environment for whatever tasks are at hand. Eyestrain and fatigue may be reduced, which allows workers to concentrate better and for longer periods of time.
- *Energy efficient,* by keeping lights off when they are not needed or by reducing lighting levels to match the task at hand.

One prominent example of a building that used state-of-the-art (at least at the time it was built) lighting controls to obtain all these benefits is Lockheed-Martin's Building 157 in Sunnyvale, California. This advanced building features abundant daylighting along with dimmable fluorescent lights that automatically maintain a constant lighting level. The lighting design itself saves about 75 percent of the energy that designers estimate would have been consumed by a conventional lighting system. Overall, including improvements to the HVAC system, the building consumes about half the energy of a typical building of the same size.

Although these efficiency upgrades paid for themselves in about four years, that was not their most significant consequence. The building's excellent daylighting, lighting, and HVAC design made it so comfortable for workers that absenteeism among those who moved into the building dropped by 15 percent. Certainly, the advanced lighting controls contributed to that improvement. According to one researcher, the value of the reduced absenteeism paid for the cost of the efficiency upgrades in just a single year.[1]

The lighting controls that make such benefits possible involve developing a set of strategies and applying the systems that will implement those strategies. The general 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 off according to a schedule;
- *Tuning,* in which power to electric lights 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 1**).[2] 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

**Table 1: 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 (EMSs) |
| Tuning | Continuous dimming, bi-level switching |
| Daylighting harvesting | Continuous dimming, bi-level switching, photosensors |
| Demand response | Voluntary or automatic curtailment via utility signals, dimmers, switches, EMS |
| Adaptive compensation | Dimming, switching, timers, photocells |

Courtesy: Platts; data from James Benya et al. [2]

There is no simpler way to reduce the amount of energy consumed by lighting systems than to turn lights off whenever no eyes are present to benefit from the illumination.

functions varies in complexity from simple timers to intricate electronic dimming circuits. Each of these technologies can be applied individually with much benefit, but by creatively combining them, designers can deliver even greater value to their clients.

## On-Off Controls

There is no simpler way to reduce the amount of energy consumed by lighting systems than to turn lights off whenever no eyes are present to benefit from the illumination. All electric lights are equipped with a manual switch that is well suited for this purpose, but these switches are not used as often as they could be. In response to that problem, the lighting industry provides several automatic switches that either mark time or sense the presence of occupants.

The most effective variety of automatic switches bases its operation on whether anyone is present to make use of the light. Known as occupancy sensors, these switches often reduce lighting energy consumption by half or more. They are not appropriate for every application, however. Sometimes they are too expensive, or they may be unable to provide proper control because of the way space is configured or used. They also may not be appropriate when safety is an issue—such as in mechanical and electrical rooms, where injuries can occur if lights go off at the wrong time. In these cases, manual controls are the safest option.

### Occupancy Sensors

Occupancy sensors are used most effectively in spaces that people pass in and out of often, such as private offices, secondary school or college classrooms, lecture halls, auditoriums, warehouses, storerooms, restrooms, loading docks, basements, corridors, stairwells, office lounges, lunchrooms, conference rooms, and library book stacks. Spaces such as open-plan offices, where one or more people may be present throughout the course of the workday, are usually not good candidates for occupancy sensors. Other spaces where occupancy sensors may yield little or no savings include primary school classrooms, reception areas, lobbies, retail spaces, and dormitory or hospital rooms.

Even where they are appropriate, occupancy sensors may produce widely varying savings, depending on local conditions. One study found that savings ranged from 15 to 90 percent (**Table 2**).[3] As a result, we strongly recommend that designers who use these sensors exercise caution in three areas:

- Estimating savings as well as the cost-effectiveness of performance,
- Selecting the best sensor type for a given room configuration, and
- Identifying the best mounting location.

To estimate savings in new buildings, designers frequently rely on operating schedules provided by their clients. For example, school schedules may indicate when classrooms and lecture halls will be in use, and office occupancy and cleaning hours are well defined for open-plan offices, lunchrooms, restrooms, and the corridors that serve them. But sometimes these schedules are less than accurate. A study of commercial buildings carried out by San Diego Gas & Electric found that measured "burn hours" in halls and lobbies were 50 to 72 percent greater, respectively, than estimates based on operating schedules. In private areas and conference rooms, however, burn hours were 29 to 46 percent less than estimates.[4]

Designers can sometimes produce better estimates by observing the future occupants of a building in their current work spaces. Tools and techniques for making such observations include:

- *Lighting loggers,* which count lighting hours, record the time of use or duration, and sometimes correlate duration with sensed occupancy. Battery-operated loggers can be placed inconspicuously in rooms and retrieved for later analysis in

**Table 2: Typical range of savings from occupancy sensors**

Savings vary by a factor of two or three in most applications, with the exception of open-plan offices and classrooms. Actual savings may differ.

| Space type | Savings potential (%) |
|---|---|
| Restroom | 60 |
| Conference room | 50 |
| Private office | 38 |
| Break room | 29 |
| Classroom | 58 |

Courtesy: Platts; data from D. Maniccia et al. [3]

relation to room schedules or measured occupancy to estimate the savings potential. If the goal is to reduce peak demand, the more sophisticated loggers will be most useful because they will report when lights are on during the peak demand period.

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- *Recording ammeters,* which can be connected at lighting breaker panels to determine when lights are in use in banks of rooms on a common electric feeder. Savings can be determined by comparing the ammeter's data to work and cleaning schedules.
- *Random surveys,* such as observing a building's exterior at night to discover rooms in which lights have been inadvertently left on. Also, interviewing custodial and security personnel may be effective.
- *Existing timers, scheduling controllers,* and *energy management system (EMS) operating plans* will indicate current usage.

Whenever any of these techniques is employed, it is important to account for seasonal variations in operation in order to avoid incorrectly extrapolating short-duration data to a full year.

Once cost-effective applications have been identified, the next task is to select the best type of sensor. The two most common types are passive infrared sensors, which require a direct line of sight to the moving heat source, and ultrasonic sensors, which detect any movement, human or otherwise (for example, curtains).

Passive infrared (PIR) sensors, the least expensive and most commonly used type, are able to "see" heat emitted by occupants. Triggering occurs when a change in infrared levels is detected, such as when a warm object moves in or out of view of one of the sensor's "eyes." PIR sensors are quite resistant to false triggering. PIR sensors may have an operating range of up to 35 feet, but they are best used within a 15-foot range for two reasons: First, there are potential "dead" spots between their wedge-shaped sensory patterns that get wider with distance (see **Figure 1**), and second, being passive, they do not send out any signal. Instead, PIR sensors depend on the intensity of the heat output of the moving subject.

Ultrasonic (US) sensors emit a high-frequency (more than 20,000 cycles per second) sound above the human audible range (although some animals, such as seeing-eye dogs, might be affected) and listen for a change in the frequency of the reflected sound. Because they emit a signal instead of receiving it, they are able to cover larger areas than PIR sensors and are more sensitive. US sensors are prone to false triggering and can be set off by air movement, such as that produced by a person running by a door, moving curtains, or even the on-off cycling of an HVAC system.

Hybrid or dual-technology sensors incorporate features of two or more other types of sensors in one device. The most common combination incorporates PIR and US sensors, taking advantage of the PIR units' resistance to false triggering and the sensitivity of the US sensors.

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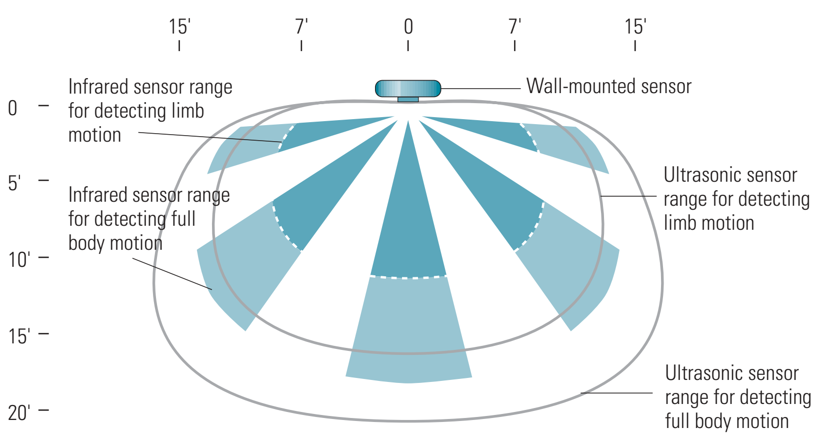
**Figure 1: Sensor coverage diagram**

Ultrasonic sensors can detect motion at any point within the contour lines. Infrared sensors "see" only in the wedge-shaped zones, and they don't 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: Platts

For continued energy savings, users should take precautions in positioning sensors and educate building occupants about the purpose of the devices.

Sensors are also available that detect noise made by people or mechanical activity, such as keyboard tapping. Unfortunately, these sensors also respond to sounds unrelated to the occupancy of a space, such as a slammed door or street noise, and they require relatively high sound levels (higher than a typical quiet office). No occupancy sensors using only audible technology are offered, but some use audible sensors in combination with PIR sensors to increase the overall reliability of the occupancy sensor. They have 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 problem.

Having selected the right type of sensors, designers then need to determine where to place them. 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.

Even after determining mounting positions, the designer's job is not done. Occupancy sensors are highly visible and can be improperly adjusted, stolen, vandalized, or fooled into incorrectly perceiving an occupied or unoccupied condition. For PIR sensors, care should be taken to locate sensors so that people in the space will always be "visible" to the sensor. Beware of partitions or corners in rooms that may hide the occupants from the sensors.

For continued energy savings, users should take precautions in positioning sensors and educate building occupants about the purpose of the devices. The following steps have proven effective for deploying sensors:

- Involve building personnel in planning for the sensors.

- Train maintenance personnel and office occupants to keep sensors operational, and follow up to make sure settings are correct.

- Position sensors carefully so that they truly "see" the area intended to be observed—the most common cause of false triggering is incorrect positioning.

Although occupancy sensors may be challenging to implement, keep in mind that the payoff can be big. For example, at the TRW Space and Defense Park in Redondo Beach, California, the company's energy manager conducted a painstaking 18-month evaluation of that three-million-square-foot campus. He first tried out several sensors in six offices. Based on those results, he installed 550 sensors in two buildings. Finally, he installed sensors in 8,000 offices, labs, conference rooms, and work areas. Those sensors reduced lighting energy consumption by 50 percent, saving more than $1.3 million per year. On average, each sensor saves about $169 per year, yielding a 1.1-year payback period.[5]

### Timed Switches

Timed switches may operate either according to the time that elapses after they are triggered or on programmed schedules based on clock time or astronomic time. Some projects may benefit from an energy management system that can automate the switching.

**Elapsed time switches.** These 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 period unless the time cycle has been restarted by the occupant (or manually turned off sooner). Time intervals may range from 10 minutes to 12 hours. Because they require no consideration of a room's shape, its size, or the tasks being done there, elapsed-time switches are much simpler to specify than

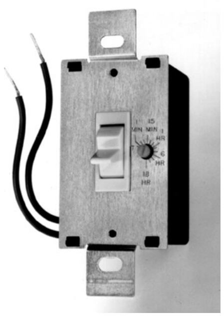
Because elapsed time switches don't require consideration of a room's shape, size, or use, they are much simpler to specify than occupancy sensors and are less prone to user maladjustment.

occupancy sensors, and they are less prone to user maladjustment. Due to their low cost ($15 to $55 plus installation), these switches offer an economical way to cut unnecessary lighting use, especially when fixed-duration events occur within a space.

There are two basic types of elapsed time switches: mechanical and electronic. The mechanical units are little more than spring-wound kitchen timers connected to a small relay. Maximum time settings of 20 minutes are common, although timers capable of handling periods of up to 12 hours or more are available. These simple devices can suffer mechanical failures relatively quickly if used in high-traffic areas such as school libraries or public spaces.[6]

**Figure 2: An electronic elapsed time switch**

Just out of the box, this electronic switch looks much like a conventional toggle switch except for the adjustment screw that allows installers to vary the on-time interval.



Courtesy: Invensys [7]

Like the spring-wound type, electronic elapsed time switches provide a defined maximum "on" time, after which lights are turned off automatically. The user does not, however, set the interval; this is done by the installer, using a hidden adjustment screw. Because they look like conventional toggle switches (**Figure 2**),[7] occupants are usually unaware of the electronic device's existence (when set properly), which greatly reduces vandalism and theft. These timers also provide an easy and economical way to comply with energy codes that call for automatic lighting controls.

Earlier generations of electronic timer switches could only control up to 300 watts, and some did not work well with electronic ballasts because the switches had problems handling ballast inrush current. New designs have overcome those problems so that timer switches can control 800 watts or more of incandescent or electronically ballasted fluorescent lamps. However, the load ratings of electronic timer switches vary by manufacturer and model number, and they are typically lower for incandescent lamp loads than for fluorescent lamp loads, so it is important to check the data sheets for any timers you plan to use. A relay can be added between the switch and the lights to increase the wattage capacity of the unit.

It is tempting to choose a short time interval so as to increase energy savings, but that can lead to problems. Librarians returning books to shelves, for example, may need to remain in an aisle longer than the 10 to 20 minutes that browsers typically require. In one application (Columbia University's Uris Business School), short intervals resulted in so much user frustration that the switches were disconnected and the stacks returned to 24-hour lighting operation.

**Clock switches.** Where occupancy follows a well-defined pattern (as in merchandising), clock switches may be the most cost-effective option. Clock switches control lights by turning them on and off at prearranged times, regardless of occupancy. They are typically located in electric closets that house lighting power panels. These devices cost relatively little to install, are generally invulnerable to vandalism or user maladjustment, and can control large loads with single sets of contactors. Clock switch equipment can be mechanical devices employing motors, springs, and relays or sophisticated electronic systems that handle several time schedules simultaneously. Typical unit prices are shown in **Table 3**.

Mechanical clock switches may require manual correction for daylight saving time or after a power failure (unless equipped with battery backup, which can triple their price). Spring-wound mechanical backup is also available for maintaining operation during power outages.

**Table 3: Typical prices of clock switches for lighting control**

| Type of switch | Typical price |
|---|---|
| 24-hour mechanical | $35–$70 |
| 7-day mechanical | $55 |
| 7-day electronic | $160 |
| 7-day electronic with battery backup | $215 |
| 1-channel 365-day electronic | $250–$300 |
| 4-channel 365-day electronic | $570 |

Courtesy: Platts; data from manufacturers

Electronic clock switches, on the other hand, routinely include battery backup and can be easily programmed to adjust for the shift to daylight saving time or for holiday schedules.

At least one manufacturer makes a line of clock switches that can be synchronized and programmed via radio signals using existing pager and/or cellular networks. The system's wireless controllers contain an electronic quartz-crystal clock with battery backup, a control computer, and a power control relay. Control settings are stored in nonvolatile memory so they will not be lost in the event of an extended power failure. In addition, the computer system can calculate the time of sunset and sunrise for any preset location. These systems can be used as multiple-event, fixed-time clock switches for indoor lighting applications or as astronomical clock switches for outdoor applications, replacing the need for photocells. When used as astronomical clock switches, the systems can be programmed to turn lights on and off for a fixed number of minutes before or after sunset or sunrise.

A common EMS function 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.

**Energy management systems.** An energy management system (EMS) performs the same function as a clock switch but with greater sophistication and additional features. A common EMS function 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. With this type of system, occupants can override the shutdown in their area by touching a local switch or by phoning in a code to the EMS.

For example, when Bernie Meyers, energy manager for the Westinghouse Process Control Division, installed simple lighting monitoring equipment, he found that manual light switching was costing his facility over $68,000 per year in wasted energy. It turned out that lights were being operated an average of 22 hours a day, every day of the year, even though the building was occupied only 16 hours a day, five days a week.

Meyers upgraded the building's EMS so that on weekdays it automatically turned lights on at 6:00 a.m. in manufacturing areas and at 7:00 a.m. in office areas. In the evening, the lights are programmed to switch off in accordance with the cleaning crew's schedule, so that all the lights are off by 10:00 p.m. The system does not turn lights on during the weekends, although there are about 90 local override switches that allow workers to turn on lights during nonscheduled periods.

This lighting control system cost only about 16¢ per square foot, yet it saved nearly half the energy that had previously been consumed by the building's lighting system. Meyers estimates that it paid for itself in less than nine months of operation.[8]

Remote relays are typically used with an EMS to control entire circuits at the breaker panel. Such systems are designed to work with magnetic ballasts, which—unlike some electronic ballasts—do not create a large inrush current during start-up. Caution is advised when retrofitting an older EMS system with electronic ballasts. These older units may open circuit breakers when they are confronted by the large inrush current from many electronic ballasts turning on simultaneously. Ballast inrush current is less of a problem with newer EMS systems that have control relays designed to switch on when the power line voltage is crossing 0 volts (V), which helps to avoid problems caused by ballast inrush current.

Four factors are key in determining whether an EMS will be more cost-effective than simple local controls for time scheduling:

- The typical per-point cost for the EMS. The per-point cost may range from $175 to $400, depending on the type of system, its expandability, and the cost of installation labor.
- The maximum average lighting wattage that can be controlled by a point.

In one case, a lighting control system that cost only about 16¢ per square foot saved nearly half the energy that had previously been consumed by the buildings lighting system.

- Whether or not the space has the same use pattern every day of the week.

- The degree to which manual switching is tied in to the EMS to provide local switching and override capability.

Here's an example of determining an EMS's cost-effectiveness. An in-wall, or wall-box, timer control that would replace a standard wall switch would cost about $100, including installation. Such a unit could handle a ballast load of about 960 watts of fluorescent lighting for about 11¢ per watt. To yield comparable economics, a $220 per control-point EMS would need to control at least 2,000 watts of lighting at each point ($220 ÷ 11¢ = 2,000). If it handles more wattage per point, then it is more cost-effective than local controls.

However, an EMS provides more flexibility than simple local controls. It can be programmed to turn on the lights only on those days when the space will be used, whereas the $100 wall-box timer control will turn the lights on and off the same time every day of the week, including days such as weekends when the space may not be in use. "Double-duty" timers, which can be programmed for a different cycle each day of the week, are available. However, they cost about twice as much as basic wall-box timers and are typically too large for in-wall mounting.

Open communications protocols, such as BACnet and LonWorks, also make it easier than it used to be for an EMS to communicate with dedicated lighting control systems, providing even more flexibility. For example, gateways are available that enable an EMS to interface with lighting control systems based on various communications protocols, including DALI (digitally addressable lighting interface), a protocol that enables a computer to communicate with individual lighting fixtures equipped with DALI-compatible ballasts.

## Dimming Controls

Dimming controls reduce the output of lighting systems. They are usually employed to align lighting levels with human needs and to save energy. When combined with light sensors, dimming control can automatically correct for fixture dirt buildup and lamp lumen depreciation or modulate lamp output to account for incoming daylight. Advanced controls that allow workers to adjust lighting levels from their computer desktops promise to make dimming controls more effective and increasingly commonplace.[9]

If a building has spaces of 2,000 square feet or more that can be remotely controlled with one point without compromising the flexible use of the area, consider EMS controls. If not, use local controls instead.

There are two ways to modulate the output of lighting systems. The most basic, step-control, offers several distinct levels to which lights may be set. This may be accomplished by putting banks of lamps on different switching circuits, or by using ballasts, known as step-dimming ballasts, that dim lights to specific levels. For example, in a three-lamp fluorescent fixture, two of the lamps may be switched separately from the third, which allows the user to select three different levels of light output. In the more sophisticated dimming arrangement, known as continuous dimming, lamp output can be varied over a continuum to achieve the desired light output.

### Step-Control

Step-control systems provide discrete reductions in light output at a lower cost than continuous dimming systems. The familiar three-way incandescent lamp is perhaps the most popular step-control product currently available. For nonincandescent lighting systems, there are two different ways to step-dim: put banks of lamps on different switching circuits or use ballasts, known as step-dimming ballasts, designed for this purpose.

When step-control is achieved by the first of these two methods, it is often referred to as bi-level switching; however, that term is a misnomer and is falling out of favor. For example, for a system with three-lamp fluorescent fixtures, one switch

One of the main applications for step dimming is to meet the requirements of California's Title 24 Energy Efficiency Standards.

may operate the center lamp in each fixture while another operates the outer lamps. This arrangement makes possible three lighting levels (with one lamp, two lamps, or three lamps lit), yet the name "bi-level" is often used to describe it. For high-intensity discharge (HID) lighting, patterns of fixtures can be wired together and switched separately, either manually or in response to occupancy sensors.

One of the main applications for step dimming is to meet the requirements of California's Title 24 Energy Efficiency Standards (2005), Section 131(b), which states that "the general lighting of any enclosed space 100 square feet or larger in which the connected lighting load exceeds 0.8 watts per square foot, and that has more than one light source (luminaire), shall have multi-level lighting controls. A multi-level lighting control is a lighting control that reduces lighting power by either continuous dimming, stepped dimming, or stepped switching while maintaining a reasonably uniform level of illuminance throughout the area controlled. Multilevel controls shall have at least one control step that is between 50% and 70% of design lighting power and at least one step of minimum light output operating at less than 35% of full rated lighting system power (this control step could be completely off, creating a bi-level control). A reasonably uniform level of illuminance in an area shall be achieved by any of the following:

1. Dimming all lamps or luminaires; or
2. Switching alternate lamps in luminaires, alternate luminaires, and alternate rows of luminaires."[10]

Step-dimming ballasts occupy an intermediate position in the array of energy-saving ballast options. They offer more light control and energy savings than nondimming ballasts but cost less than the more versatile continuous-dimming ballasts. They typically offer two or three discrete lighting levels. One of the advantages of step-dimming products is that occupancy sensors can dim the lamps rather than turn them off, which can reduce cycling and extend lamp life. These units also offer a viable way to reduce lighting levels during noncritical hours (such as cleaning times) and to shed peak demand in common areas such as corridors.

Step-dimming ballasts are especially useful for HID fixtures with either metal halide or high-pressure sodium lamps. Because these lamps typically require several minutes to warm up, during which time they provide little light, and even longer (3 to 5 minutes for quartz pulse-start lamps, longer for ceramic metal halide lamps) to restrike after being shut off, they are not well suited to being switched by occupancy sensors. Better results can be obtained by controlling the lamps to switch between low power and full power based on occupancy or other switching methods. HID lamps also shift their color noticeably as they are dimmed, but this shifting is acceptable in many industrial applications, where bi-level lighting could save energy. However, dimming below about 50 percent of initial power can lead to operational problems with HID lamps, and most manufacturers will void their warranties if lamps are operated at less than 50 percent.

A good example of the usefulness of step-dimming with HID lamps is the L.L. Bean Reserve Warehouse Building in Freeport, Maine. Here, Ron Jacques, energy manager, applied step-dimming to high-pressure sodium lights in a building that stored seasonal goods. The building was in use only about 30 percent of the time, and some aisles did not have people in them for days. In order to avoid the problem of long restrike times after the high-pressure sodium lights were turned off, Jacques used step-dimming ballasts controlled by occupancy sensors. Each aisle's lighting is controlled in two zones, and each zone is controlled by two high-mount infrared occupancy sensors. Only when a zone is occupied are the lamps energized at full power. This arrangement saves about 70 percent of the lighting energy, and it paid for itself in less than three years.[11]

## Continuous Dimming

Continuous dimming controls allow users to adjust lighting levels over a wide range of lighting output. They offer far more flexibility than step-dimming controls and are used in a wide variety of applications, including mood-setting and daylight dimming. All the major commercially available light sources used in commercial buildings can be dimmed, including incandescent, fluorescent, and HID lamps.

**Incandescent lamps.** Of all the commonly available lamp types, incandescents are the easiest to dim. For many years, these lamps were dimmed using resistors, which reduced light output but cut energy consumption to a much smaller degree. That problem was solved with the development of modern semiconductor-based dimming controls. With these dimmers, however, the filament runs cooler, reducing color temperature and making lamps (and spaces) appear more yellow. Although these dimmers are inherently much more efficient than resistor dimmers, they cannot compensate for the fact that incandescent lamps run at lower efficacy when operated at less than rated voltage and power. Because of the reduction in voltage, however, lamp life is usually increased greatly in standard lamps. In halogen lamps, lamp life can increase as well, as long as the lamps are periodically run at full power to clean deposited tungsten off the lamp walls. The rapid cycling of dimmed incandescent lamps may create an audible noise, heard as a slight high-pitched hiss in quiet locations. Increased flicker may become obvious on low-voltage incandescent systems using electronic transformers when light output is reduced below 50 percent unless the dimmer is specifically rated for electronic low-voltage transformers.

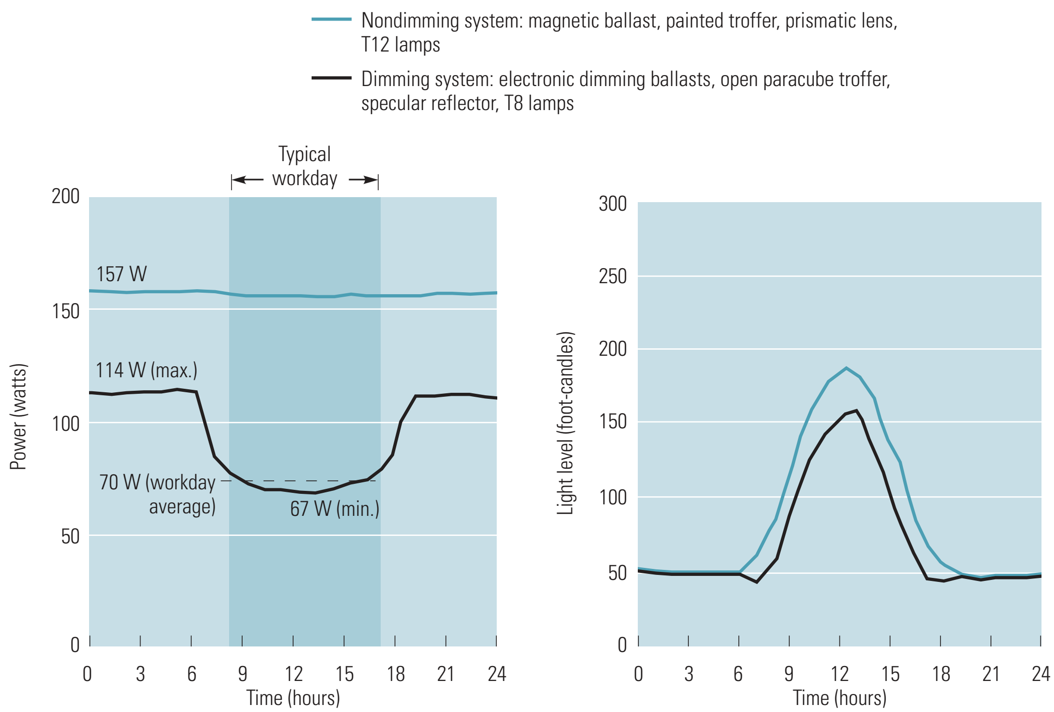
**Fluorescent lamps.** Dimming ballasts for fluorescent lamps may be used for two purposes: “energy management dimming,” which includes products that allow dimming as low as 20 percent of full light output, and “architectural dimming,” which drops light levels as low as 1 percent. If the goal is energy savings, products that meet the former definition may be sufficient, as they usually cost less than full-range dimming products. For example, if the goal is to provide dimming for visual presentations, light levels below 10 percent may be necessary; otherwise the ambient light may wash out the image on the screen.

One popular application for dimming fluorescent ballasts is to displace the less-efficient incandescent dimming systems. For example, it is common to find conference rooms equipped with fluorescent fixtures for maximum light levels and incandescent fixtures on dimmers to accommodate visual presentations that require a much lower ambient light level. By specifying dimmable fluorescent ballasts, the incandescent lights can be eliminated altogether. Alternatively, the incandescent luminaires may be replaced with dimming compact fluorescent luminaires.

Another good application is to use dimming fluorescent ballasts for daylight harvesting—that is, to reduce electric light output whenever daylight is available. A recent study provides an example of the energy savings available from this application.[12] Two identical offices with south-facing windows were measured, one with a conventional, nondimming lighting system (magnetic ballasts, white-painted troffer, T12 lamps, and prismatic lens) and the other with an energy-efficient dimming system (dimming electronic ballasts, open paracube troffer, specular reflector, and T8 lamps). **Figure 3** (page 20) shows the power consumption and average lighting levels in the two spaces for a typical sunny day. Installing an energy-efficient fixture alone drops the maximum lighting power from 157 watts to 114 watts, a 27 percent reduction. But during daylight hours, the dimming controls cut power down to about 70 watts, effectively doubling the power reduction to a total of 55 percent compared with the conventional system. As would be expected, light levels were lower with the dimming system, but they were always well above the 50-foot-candle design level—indicating that even deeper dimming could have

**Figure 3: Power and lighting levels for dimming and nondimming systems**

In this test, more-efficient lighting equipment cut connected load by 27 percent (from 157 to 114 watts). Dimming cut average workday power consumption even further, for a 55 percent total savings (157 to 70 watts).




Courtesy: Platts; data from Danny Parker et al. [12]

been used. (For more information on daylighting, see the EDR Daylighting Brief.)[13]

Almost all dimming ballasts are rapid-start or programmed-start units that dim the lamps by limiting current flow. Dimming ballasts are at least twice as expensive as nondimming ballasts of the same type, and, because instant-start electronic ballasts are less expensive than programmed-start ballasts, the price ratio between an electronic programmed-start dimming ballast and a high-volume electronic instant-start ballast is typically 3:1 or more.

Electronic dimming ballasts can be divided into four categories, depending on the way the dimming controller communicates with the ballast. Most dimming ballasts are controlled by a low-voltage analog signal that is carried over a separate pair of wires. Other electronic dimming ballasts work with phase-control dimmers that are very similar to standard incandescent-type dimmers, eliminating the need to run additional wiring. Though less common, some systems use three-wire power line control. These three types of dimming ballasts are most often used with a local controller, such as a switch or sensor in the occupied space. A more-recent development is the introduction of “smart” ballasts that use low-voltage digital signals carried over shared control wires. Various control protocols are used that allow dimming of individual ballasts or groups of ballasts. These ballasts are most useful with EMSs that provide centralized control for a large space or an entire building.

*Low-voltage-controlled fluorescent ballasts.* Electronic dimming ballasts controlled by low-voltage analog signals are among the most popular and least expensive type of fluorescent dimming ballast available. Most of the low-voltage analog dimming ballasts use a 0- to 10-V direct current (DC) signal to control the light output, with 10 V providing maximum light and 0 V providing minimum light. This standardized control signal makes such ballasts compatible with a wide range of sensors and controls manufactured by other companies. For example, they can be easily connected to and controlled by EMSs, which offer 0- to 10-V output channels.

*Power line–controlled dimming ballasts.* Several types of electronic ballasts can dim fluorescent lamps with special phase-control thyristor wall dimmers that are very similar to those used to dim incandescent lamps. In fact, most or all of the phase-control dimmers designed for these ballasts can be used to dim incandescent lamps, but not all incandescent lamp–quality phase-control dimmers can be used to dim power line–controlled ballasts. Most manufacturers of power line–controlled dimming ballasts list compatible phase-control dimmers on the ballast specification sheet or associated documents. The main advantage of these dimming ballasts is that no extra wires are necessary because the phase-control dimmer is wired in series with the hot power lead providing power to the ballast.

One key advantage of these digitally controlled ballasts is that each is assigned an identifier, or "address," and can be controlled individually on a single network.

*Three-wire power line–controlled dimming ballasts.* These ballasts are controlled using a third power line voltage wire connected to a special control switch. This type of ballast enables dimming to very low levels and does not need a separate low-voltage control wire. However, these ballasts would be hard to retrofit into an existing installation if the third voltage-level line was not already available.

*Low-voltage digitally controlled ballasts.* These ballasts use control protocols such as DALI, LonWorks, BACnet, or other, proprietary, protocols. One key advantage of these digitally controlled ballasts is that each is assigned an identifier, or "address," and can be controlled individually on a single network. This allows the lighting to be easily controlled from a central location in a building while not requiring a dedicated control wire between each ballast and the central control point. The control protocol can be delivered over a dedicated control network or over the Ethernet network already present in most office buildings. Some protocols, such as DALI, are designed for use over a dedicated low-voltage network, but DALI-to-Ethernet converters are available so DALI can be used in buildings with existing Ethernet networks without the need to run additional control wires. Some digital ballasts include a built-in DALI interface; others use a proprietary protocol. You can add conventional low-voltage-controlled dimming ballasts to digital lighting control systems by using special interfaces that connect to DALI systems and convert the DALI commands to standard 0- to 10-V DC control signals.

*Wireless controls.* Wireless ballasts are the newest wrinkle in lighting controls. Wireless controls have been available on a limited basis for a number of years, but they have been installed chiefly as an amenity rather than to provide energy savings. New systems, just entering the market, have the potential to enable significant energy and demand savings, especially in retrofit applications. Advantages of wireless systems include ease of installation, lower maintenance costs, and ease of reconfiguring a control scheme as needs change. However, at this stage in the development of such systems, cost-effectiveness, scalability to large installations, and security and reliability are still unknowns.

**Choosing fluorescent dimming ballasts.** When choosing dimming fluorescent ballasts, the key considerations are:

Dimming ballasts are not available for as wide an array of lamp configurations as nondimming ballasts.

- *Dimming level.* What is the minimum dimming level needed in the space? Although most products can dim to 1 or 5 percent of full output, these "architectural dimming" ballasts typically cost significantly more than ballasts that dim to 20 or 30 percent—levels sometimes referred to as "energy management dimming."

- *Lamps served.* Dimming ballasts are not available for as wide an array of lamp configurations as nondimming ballasts, but they are available for the most popular lamp types, including F32T8, F28T5, and F54T5HO linear lamps as well as most compact fluorescent lamps (CFLs). The low-wattage, linear 4-foot T8 lamps (25-, 28-, and 30-watt products) are not compatible with dimming ballasts. For a particular lamp, check with the manufacturer to make sure that it can be dimmed.

- *Technical specifications.* Check ballast manufacturers' data for total harmonic distortion, power factor, and crest factor at various dimming levels, not only at full power. Review independent lab reports to verify the information if the manufacturer does not provide complete data.

- *Control system compatibility.* The ballast, controller, and any additional devices, such as photocells or occupancy sensors, must all be able to work together—not an easy feat when each item may come from a different manufacturer. A

A good warranty will replace failed ballasts for at least five years and will provide a labor allowance to cover the replacement of failed ballasts.

small-scale test should be conducted to help sort out these issues before specifying products for large installations.

- *Availability*. Many systems or products are “introduced” before they are truly available. Also, new products are often available in only one configuration (such as two 4-foot T8 lamps).
- *Reliability*. Some manufacturers cite failure rates, although these are not tabulated by any official means. If requested, manufacturers or sales reps may be able to supply references to previous purchasers so that you can gauge their experience with the product.
- *Warranty*. A good warranty will replace failed ballasts for at least five years and will provide a labor allowance to cover the replacement of failed ballasts.

With CFLs, there are several ways to achieve a dimming effect, including:

- Intelligent design with a mix of light sources, including some that don’t dim and others that do;
- Multiple lamps on separate controls;
- Step-control; and
- Continuous dimming.

Not all light sources in a space necessarily need to be dimmable in order for a dimming effect to be created. In settings such as conference rooms, on-off CFLs can be used for general ambient lighting, and dimmable incandescent lamps can be used for low ambient light during presentations. This can often be much less expensive than using dimming CFL technology throughout because the increase in energy use is minimal when compared with an all-CFL approach.

Another option is to wire CFL downlights in every-other-fixture patterns and place them on separate switches so that each switch controls alternating fixtures. Because many CFL fixtures yield wider and more even light distribution than most incandescent installations, this approach can work well as a "dimming" strategy without creating hot spots and dark zones.

Three-way switching of CFLs is available for both floor and table lamps. There are also a number of portable torchiere fixtures that use CFL lamps in place of the far less-efficient and more-hazardous tungsten-halogen lamp; most of these have continuous dimming ballasts.

Another key category is hardwired fixtures designed to be used with pin-base CFLs. One option is multilamp step-dimming CFL downlight fixtures. For example, one manufacturer offers three-level switching fixtures that have three 18- or 26-watt CFLs. A lower-wattage lamp can be specified for the center lamp, depending on the light level desired. Multilamp step-dimming fixtures rely on the use of two separate ballasts: one for two lamps and a second for the third lamp. These systems are becoming less popular as higher-power CFLs reduce the need for multiple lamps and the cost of dimming ballasts comes down. The price of one dimming ballast will be somewhat higher than the cost of two nondimming ballasts, but this higher ballast cost is offset by the lower lamp cost and the greater control flexibility.

Various self-ballasted CFLs with integral ballasts and self-ballasted adapters for pin-base CFLs are configured to step-dim when used in three-way incandescent lamp fixtures. Continuous dimming of CFLs is limited to a few self-ballasted products and electronic ballasts driving four-pin rapid-start lamps of 13 watts or more. Magnetically ballasted CFLs cannot be dimmed at all. Full-range dimming ballasts and controls for CFLs are currently available from a number of manufacturers, but they tend to be expensive.

The price of one dimming ballast will be somewhat higher than the cost of two nondimming ballasts, but this higher ballast cost is offset by the lower lamp cost and the greater control flexibility.

Adding dimming capabilities can easily double the price of a luminaire. Competition has yet to bring down dimming ballast prices as rapidly as initially expected.

**High-intensity discharge lamps.** Dimming of HID lamps has been problematic, but the introduction of electronic ballasts has helped. Limited dimming of HID lamps using magnetic ballasts can be accomplished with voltage-reduction technologies. HID dimming is more limited in application because of color shifting, reduced color rendering index (CRI), increased flicker, impact on lamp life, and inadvertent lamp shutdown during line voltage variations.

Dimming of HID lamps has been problematic, but the introduction of electronic ballasts has helped.

With magnetic ballasts, the color of HID lamps shifts considerably during dimming, making them inappropriate for use in aesthetic applications. Clear metal halide lamps can experience an increase in color temperature of over 1,000 kelvins and a drop of 35 percent in CRI when dimmed to 50 percent. This problem is mitigated somewhat for coated metal halide and mercury lamps, due to the color constancy of their phosphors. Dimming may also reduce HID gas pressure, which makes flickering more visible, especially in high-pressure sodium lamps.

Recent testing funded by the California Energy Commission's Public Interest Energy Research (PIER) program found that electronic ballasts improve the efficiency of HID systems by at least 10 percent over similar magnetically ballasted systems and also decrease color shifting. Electronic ballasts, combined with ceramic metal halide lamps, which have excellent color-rendering characteristics, make an excellent choice to replace inefficient halogen and incandescent sources in retail and other applications. The PIER research also showed that electronic dimming ballasts were a good choice for lamps of 175 watts or less, but not as effective for lamps rated at 200 watts or larger.[14]

**Panel-level dimming.** Panel-level dimming uses an external power controller, typically known as a lighting circuit power reducer, and standard ballasts to reduce light levels by lowering circuit voltage upstream of the ballasts. The best applications for this technology are overlit facilities; lumen maintenance, in which power reducers can be used to reduce lighting levels when lamps are new and can increase light output as the lamps age; cases where retrofitting individual fixtures would be difficult; and cases where electronic ballasts can't be used. Dimming is limited to 25 to 40 percent reductions in lighting output—substantially less in many cases—making such systems mainly suitable for energy management and demand response purposes rather than for full-range light control. It's also important to note that power reducers aren't compatible with all types of ballasts, although some products are more versatile than others. For fluorescent lighting, some products work with only magnetic ballasts, and some work with both magnetic and a few types of electronic ballasts, but none work with active front-end electronic ballasts. The active front-end ballasts, which compensate for fluctuations in incoming voltage and would therefore defeat the action of a power reducer, currently make up about 10 to 15 percent of the market for fluorescent electronic ballasts. However, the active front-end ballasts are expected to become more prevalent in the future. A lighting upgrade can often provide greater savings more cost-effectively, and in a more permanent manner, than panel-level dimming.

The active front-end ballasts compensate for fluctuations in incoming voltage and would therefore defeat the action of a power reducer.

**Personal dimming control.** Now that inexpensive desktop remote controls are available, giving workers the ability to dim their individual workspaces is becoming an affordable option. Such personal dimming control has been shown to contribute to high potential energy savings and occupant satisfaction.[15]

Numerous studies, including research conducted by the Lighting Research Center in the U.S. and the National Research Council of Canada's Institute for Research in Construction concluded that:

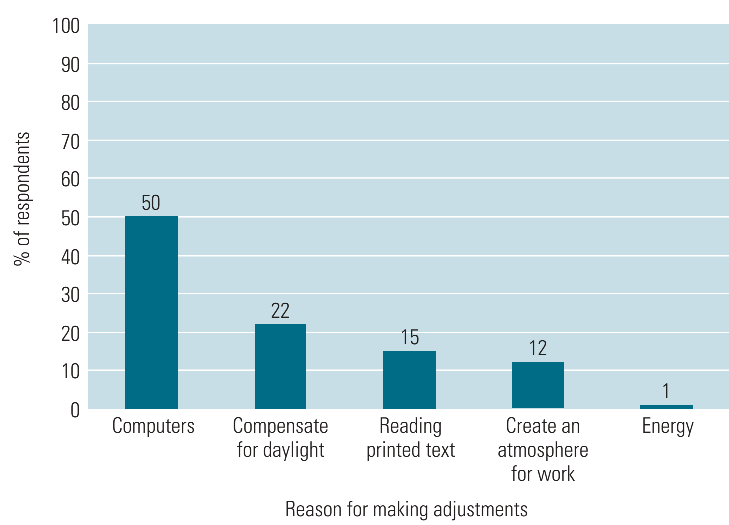
- Occupants desire and use dimming controls when they are provided.
- Light settings are a matter of personal preference and cannot be predicted.

- Many occupants work with their lights off when provided with good indirect daylight.
- Occupants frequently decrease light levels to compensate for brighter windows.
- Occupants frequently make lighting adjustments during the day to reduce computer screen glare.
- Lighting levels in facilities with personal dimming controls are usually at or below recommended levels.

At the National Center for Atmospheric Research in Boulder, Colorado, employees preferred desktop over door-side dimming control by a ratio of 6:1. During the study, they adjusted the lighting two-thirds more often when desktop controls were provided. Another interesting finding from the study was that the two most frequent reasons workers gave for using the dimmers was to adjust for computer area lighting and to compensate for changes in daylight intensity (see **Figure 4**).

**Figure 4: Reasons given for adjusting lighting levels**

Workers at the National Center for Atmospheric Research in Boulder, Colorado, were given the opportunity to adjust lighting levels in their work spaces. Of those workers who used the controls, the most common reason given for doing so was to minimize veiling reflections on computer screens and to compensate for changes in daylight intensity.




Courtesy: Platts; data from D. Maniccia et al. [15]

A study funded by the Light Right Consortium found that providing workers with the ability to control their own lighting increased their motivation to perform their assigned tasks. The persistence and vigilance of office workers normally declines over the course of a workday. However, workers who controlled their own lighting kept going longer on difficult tasks and were more accurate when performing tasks that required sustained attention.[16]

## Combined Technologies

Creative designers can get the most benefits by combining more than one lighting control strategy in the same control system. For example, multifunction controllers can take signals from photosensors, occupancy sensors, and energy management systems to provide daylight harvesting, tuning, and scheduling capabilities. The savings achieved from combining these techniques, however, cannot be determined by simply adding the savings achieved by each technique individually. This principle was illustrated at the Phillip Burton Federal Building, the second-largest building in San Francisco, where a 180,000-square-foot testbed for advanced lighting control was established. Researchers at this site implemented occupancy sensors, manual dimming, daylighting dimming, and bi-level switching. In general, they found that when occupancy sensing and dimming were combined, the combined savings achieved were less than the mathematic sum of the savings achieved when each strategy was implemented alone (**Table 4**).[17]

**Table 4: Energy savings from combined strategies**

At an advanced lighting testbed established at the Phillip Burton Federal Building in San Francisco, a variety of lighting control strategies were tested, both individually and in combination with other strategies.

| Dimming adjustment method | Occupancy sensor savings only (%) | Dimming control savings only (%) | Combined occupancy sensor and dimming savings (%) |
|---|---|---|---|
| Manual | 18 | 28 | 40 |
| Daylighting | 24 | 28 | 44 |
| Bi-level switching | | 23 | |

Courtesy: Lawrence Berkeley National Laboratory [9]

For example, although the occupancy sensors in the daylighting test area saved 24 percent of lighting energy and the automatic dimming controls saved 28 percent, their combined savings did not equal 52 percent. Instead, these two strategies saved just 44 percent. Why didn't the savings just add up arithmetically? Simply because dimming cannot save energy when the occupancy sensors turn off the lights, and the occupancy sensors save less energy when they turn off lights that otherwise would have been dimmed.

Another reason to combine control types is to maximize the lighting power adjustment allowed by Title 24 (2005 version). A lighting designer who finds that a project exceeds the allowable lighting power densities in Title 24 has two choices: Redesign the lighting system so that power consumption is reduced or use optional automatic lighting controls. With automatic controls, the watts of connected lighting within the building (actual lighting power) may be adjusted lower to take credit for the energy efficiency benefits of the controls. A list of the types of combined control systems that qualify for these credits, as well as the lighting adjustment factor associated with each, is shown in **Table 5**. The lighting control credits reduce the actual lighting power, giving a lower adjusted lighting power, which makes it easier to meet Title 24's allowed lighting power requirement. In order to qualify for the power savings adjustment, the control system or device must be certified by the California Energy Commission and must control all of the fixtures for which the credit is claimed.

**Table 5: Title 24 (2005) power adjustment factors for combined controls systems**

The 2005 version of Title 24 allows lighting designers to reduce the actual lighting power of a lighting system by an adjustment factor when lighting controls are included in that system. This table shows the adjustment factor for systems that combine occupancy sensors with dimming controls.

| Type of control system | Type of space | Power adjustment factor |
|---|---|---|
| Occupant sensor with manual ON or bi-level automatic ON combined with multilevel circuitry and switching in conjunction with daylighting controls | Any space 250 square feet within a daylit area and enclosed by floor-to-ceiling partitions; any size classroom, corridor, conference or waiting room | 0.10 (may be added to daylighting control credit) |
| Manual dimming with dimmable electronic ballasts and occupant sensor with manual ON or automatic ON to less than 50% power and switching | Any space 250 square feet enclosed by floor-to-ceiling partitions; any size classroom, corridor, conference or waiting room | 0.25 |

Courtesy: Platts; data from Title 24 [10]

For example, take the case of a lighting designer who finds that a particular design produces an actual lighting power density of 1.2 watts per square foot (W/ft$^2$), while Title 24 (2005) allows only 1.0 W/ft$^2$ for that space. The designer could incorporate manual dimming capabilities with dimmable electronic ballasts and add occupancy sensors, as described in the second item in Table 5, thus enabling the use of an adjustment factor of 0.25. That adjustment would reduce the system's actual lighting power density by 0.3 W/ft$^2$ for the purposes of Title 24, effectively lowering it to 0.9 W/ft$^2$. With such a lighting control system, the design would meet or slightly exceed the power density requirements under Title 24. Combining manual dimming with automatic occupancy sensing provides more opportunity for energy savings than occupancy sensing alone and tends to increase occupant satisfaction with the workplace.

## Lighting Controls and LEED

Lighting controls play a role in the Leadership in Energy and Environmental Design® (LEED) rating system. The U.S. Green Building Council, a nonprofit organization founded to promote the construction of environmentally responsible buildings, established LEED to serve as a brand for high-performance buildings and to provide a common standard for measuring the sustainability, or "greenness," of a building.

A building earns a LEED rating (certified, silver, gold, or platinum) based on how many points it earns in the following categories: Energy and Atmosphere, Indoor Environmental Quality, Innovation and Design Process, Sustainable Sites, Water Efficiency, and Materials and Resources. Lighting controls play a role in a number of these categories.

**Energy and Atmosphere (E&A).** Lighting controls play a role in meeting two of the prerequisites for E&A points: commissioning and minimum energy performance. Lighting controls must be commissioned to function properly. In addition, all LEED buildings must meet either the local energy code requirements or the provisions of ASHRAE/IESNA (American Society of Heating, Refrigerating, and Air-Conditioning Engineers/ Illuminating Engineering Society of North America) 90.1-2004, whichever requirement is tighter. To satisfy codes, buildings larger than 5,000 square feet must employ some method of automatic lighting shutoff. In addition, individual spaces must use independent controls. For automatic shutoff, lighting controls such as occupancy sensors, timing devices such as clock switches, or signals from building automation systems can be used.

In addition, the more efficient a building is, the more points it will be awarded, up to an additional 10 points. Although lighting controls are not called out specifically, the more efficient the lighting systems are, the more efficient the whole building will be. Within the E&A category, points are also awarded for measurement and verification, and lighting control systems often provide measurement and verification capabilities that can be used to help achieve credit.

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

**Innovation and Design Process.** This is a general category in which innovative lighting approaches that advance the state of the art or provide a benefit that is not already rewarded under existing LEED points may receive credit. For example, projects have earned credit for the control of task lighting with occupancy based plug load controls, and for the use of DALI-based controls.

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

## For More Information

**California Energy Commission**

1516 9th Street

Sacramento, CA 95814-5512

tel 916-654-4287

web www.energy.ca.gov

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

**California Lighting Technology Center**

Contact: Don Aumann

1554 Drew Avenue

Davis, CA 95616

tel 530-757-3493

fax 530-757-3443

e-mail daumann@ucdavis.edu

web www.cltc.ucdavis.edu

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

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

Contact: Dr. R. Frank Smith, College of Engineering

Cal Poly Pomona

3801 West Temple Avenue

Pomona, CA 91768

tel 909-869-2528

web www.csupomona.edu

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

**Energy Star**

U.S. Environmental Protection Agency, Climate Protection Partnerships Division

Energy Star Programs Hotline and Distribution (MS-6202J)

1200 Pennsylvania Avenue NW

Washington, DC 20460

tel 888-782-7937

web www.energystar.gov

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

**EPRI Lighting Research Office (LRO)**

3574 Atherstone Road

Cleveland Heights, OH 44121-1356

tel 216-291-1884

fax 216-382-6242

e-mail lighting@ieee.org

web www.epri.com/lro

The LRO funds and manages lighting research worldwide.

**Illuminating Engineering Society of North America (IESNA)**

120 Wall Street, 17th Floor

New York, NY 10005

tel 212-248-5000

fax 212-248-5017

e-mail iesna@iesna.org

web www.iesna.org

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

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

Merchandise Mart, Suite 9-104

200 World Trade Center

Chicago, IL 60654

tel 312-527-3677

fax 312-527-3680

web www.iald.org

The IALD is the trade association for lighting designers.

**Lighting Research Center**

c/o Rensselaer Polytechnic Institute

21 Union Street

Troy, NY 12180

tel 518-687-7100

fax 518-687-7120

e-mail lrc@rpi.edu

web www.lrc.rpi.edu

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

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

526 King Street, #405

Alexandria, VA 22314

tel 703-518-4370

fax 703-706-9583

e-mail info@ncqlp.org

web www.ncqlp.org

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

**The Pacific Energy Center (PEC)**

851 Howard Street

San Francisco, CA 94103

tel 415-973-2277

fax 415-896-1290

e-mail pecinfo@pge.com

web www.pge.com/pec

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

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

6090 North Irwindale Avenue

Irwindale, CA 91702

tel 800-336-2822

web www.sce.com/ctac

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

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

Contact: Gregg Ander

6042 N. Irwindale Avenue, Suite B, Irwindale CA 91706

tel 626-633-7171

fax 626-633-7196

e-mail gregg.ander@sce.com

www.sce.com

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

## Notes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Pacific Gas and Electric Company

SDG&E
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Southern California Edison
An EDISON INTERNATIONAL Company

Southern California Gas Company
A Sempra Energy utility

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

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