energy design resources

design brief

LIGHTING CONTROLS

Workers tend to be more productive in a well-lit space that fosters better visual comfort.

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. Some examples of the value that lighting controls can add to a building include these:

- 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:

- *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.

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

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 otherwise 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 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 with much benefit, but by creatively combining them, designers can deliver even greater value to their clients.

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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 base their 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. In other instances, less expensive options may work just as well. In such cases, timed switches are often an excellent choice.

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 1**). 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.

Table 1: Typical range of savings from occupancy sensors

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

Type of room	Energy savings (%)
Private office	13–50%
Open-plan office	20–28%
Classroom	40–46%
Conference room	22–65%
Rest room	30–90%
Corridors	30–80%
Storage area/closet	45–80%

Source: Advanced Lighting Guidelines, U.S. EPA

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, rest rooms, 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 Company 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.[2]

Designers can sometimes produce better estimates by observing the future occupants of a building in their current workspaces. 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 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.

- *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.

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).

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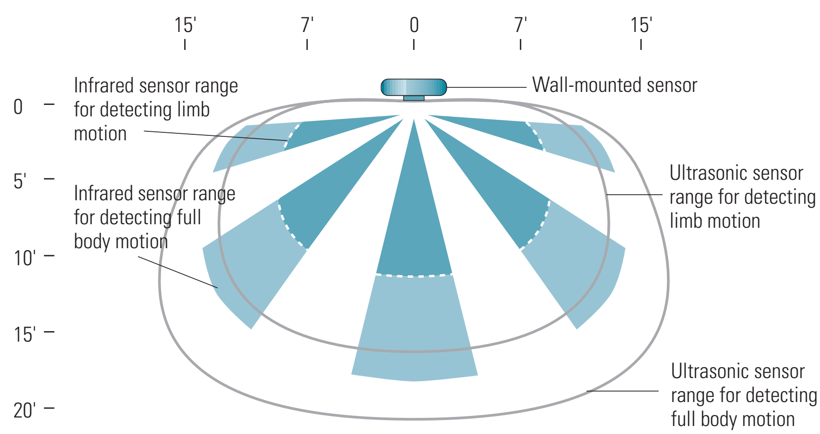
Infrared sensors "see" only in the wedge-shaped zones, and they don't generally see as far as ultrasonic units.

Passive infrared (PIR) sensors, the cheapest 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. 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 human and animal audible ranges 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.

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 further straight ahead than to the side. The ranges shown here are representative; some sensors may be more or less sensitive.



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 ultrasonic sensors, taking advantage of the PIR units' resistance to false triggering and the sensitivity of the ultrasonic sensors.

Having selected the right type of sensor, 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. 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' view.

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.

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Although it may sound intimidating to use occupancy sensors, 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.[3]

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. Some projects may benefit from an energy management system that can automate the switching.

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.

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, size, or the tasks being done there, elapsed-time switches are much simpler to specify than occupancy sensors, and they are less prone to user maladjustment. Due to their low cost ($15 to $40 plus installation), these switches offer an economical way to cut unnecessary lighting usage, 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 also available. These simple devices can suffer mechanical failures relatively quickly if used in high-traffic areas such as school libraries or public spaces.[4]

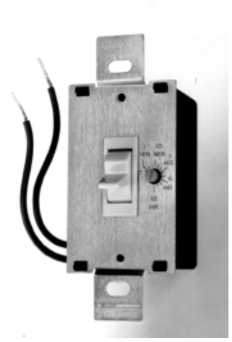
Like the spring-wound type, electronic elapsed time switches provide a defined maximum "on" time, after which lights are turned off automatically. The user does not, however, set the interval; this is done by the installer, using a hidden adjustment screw. Because they look like conventional toggle switches (**Figure 2**), 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.

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, short intervals resulted in so much user frustration that the switches were disconnected and the stacks returned to 24-hour lighting operation.[5]

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 2**, on the next page.

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.



Source: Paragon Electric Company

Table 2: Typical prices of clock switches for lighting control

24-hour mechanical	$40
7-day mechanical	$85
7-day mechanical with battery backup	$265
1-channel 365-day electronic	$160 + relay
4-channel 365-day electronic	$480 + relay

Source: Manufacturer quotes

Mechanical clock switches may require manual correction for daylight savings 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.

Electronic clock switches, on the other hand, routinely include battery backup and can be easily programmed to adjust for the shift to daylight savings time or for holiday schedules. For fluorescent lamps, electronic clock switches should be specified without a certain kind of solid-state relay known as a triac relay. Triacs are problematic because they may trickle a small amount of current to ballasts and lamps, even when they are off. This trickle current may damage the lamps, shortening their life.

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 only occupied 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.

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

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.[6]

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 electronic ballasts—do not create a large inrush current during start-up. Caution is suggested when retrofitting such a system with electronic ballasts; it may cause circuit breakers to trip when they are confronted by the large inrush current from many electronic ballasts turning on simultaneously. Two 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 $200 to $1,500, 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.* For example, a $100 local controller can handle several hundred watts for about 30¢ per watt. To be equally cost-effective, a $600/point EMS would need to control at least 2,000 watts of lighting at each point. If it handles more wattage per point, then it will be more cost-effective than local controls. The next question is whether, after a lighting upgrade, it is possible to shut off (or dim) 2,000 watts at one time without compromising the flexible use of a space. At a power density of 1 watt per square foot, this would involve controlling a 2,000-square-foot area with one EMS point. Are there spaces equal to or greater in size that can be controlled remotely without interfering with their operation? If so, consider EMS controls; if not, use local controls (such as sensors, timers, and photocells).

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.

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 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.[7]

There are two ways to dim lighting systems. The most basic, step-dimming, offers several distinct levels to which lights may be dimmed. 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-Dimming

Step-dimming 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-dimming product currently available. For non-incandescent lighting systems, there are two different ways to step-dim: put banks of lamps on different switching circuits or use ballasts designed for this purpose.

When step-dimming is achieved by the first of these two methods, it is often referred to as bi-level switching, even though this term may be a misnomer. For example, for 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 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.

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 offer more light control and greater energy savings than nondimming ballasts, yet they cost less than the more versatile continuous-dimming ballasts.

Step-dimming ballasts are especially useful for HID fixtures with either metal halide or high-pressure sodium lamps. Because these lamps typically require long starting times (three to five minutes), 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 do shift their color a bit when lamp wattage is cut by 50 percent or more, but the resulting illumination is acceptable in most industrial applications.

Continuous-dimming controls offer far more flexibility that step-dimming controls and can be used in a wide variety of applications.

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 re-strike 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 has paid for itself in less than three years.[8]

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 cut light output but not energy consumption. 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. Also, because power does not drop linearly with light output, they do reduce lamp efficacy at dimmed conditions. Because of the reduction in voltage, however, lamp life is usually increased greatly in standard lamps but may be reduced in halogen lamps, which should be burned at full power occasionally to redeposit tungsten on the filament. 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.

Fluorescent lamps. Dimming ballasts for fluorescent lamps may be used for two purposes: "energy dimming," which includes products that allow dimming as low as 10 to 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. If the goal is to provide dimming for visual presentations, light levels below 10 percent are necessary; otherwise the human eye will perceive that there is too much light.

Dimming ballasts for fluorescent lamps may be used for "energy dimming," which includes products that allow dimming as low as 10 to 20 percent of full light output, or for "architectural dimming," which drops light levels as low as 1 percent.

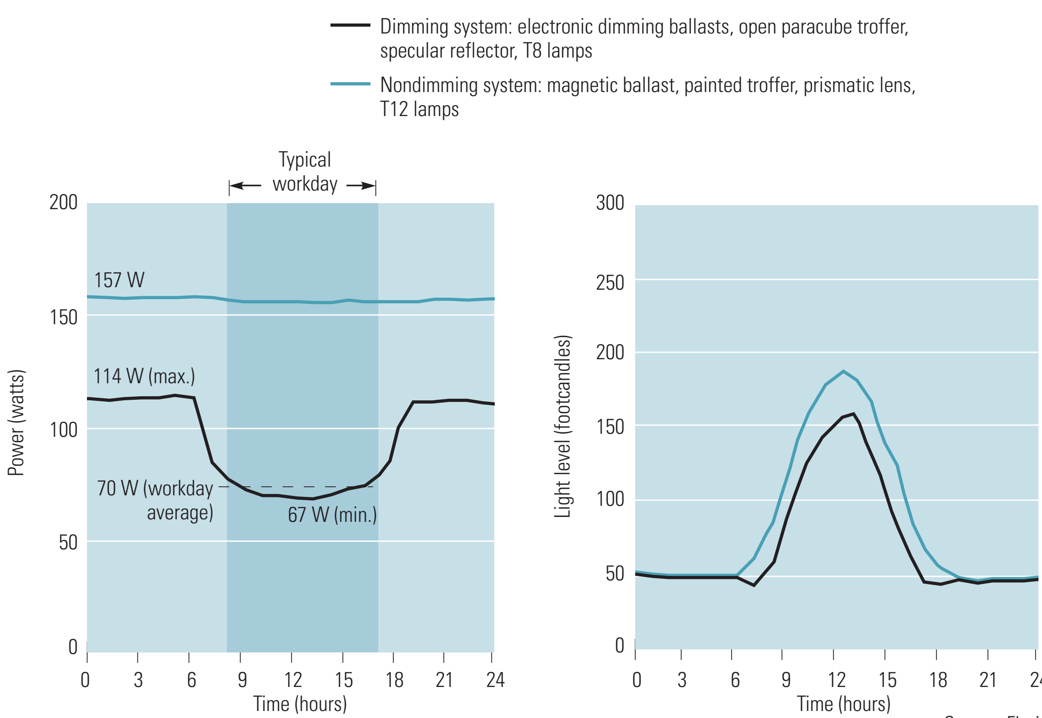
One popular application for dimming fluorescent ballasts is to displace the less-efficient incandescent dimming systems that are often used for accent lighting. For example, it is common to find conference rooms equipped with fluorescent fixtures for maximum light levels and incandescent fixtures on 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.

Another good application is to use dimming fluorescent ballasts to reduce artificial light output whenever sunlight is available. A recent study provides an example of the energy savings available from this application.[9] 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** 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-footcandle design level—indicating that even deeper dimming could have been used.

Two techniques are used for dimming standard fluorescent lamps: low voltage control and power line control. Most dimming fluorescent ballasts are controlled by a separate low-voltage electrical circuit. Although this method does necessitate additional

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).



Source: Florida Solar Energy Center

control wiring, these ballasts are compatible with a wide variety of dimming controllers. For example, low-voltage-controlled ballasts can be easily connected to and controlled by energy management systems, which offer 0- to 10-volt output channels.

Power-line-controlled ballasts, however, can dim fluorescent lamps with standard or specialized thyristor wall dimmers ("incandescent" dimmers) installed directly on the line-voltage switch leg—no extra wires are necessary. If such a dimmer were installed on an ordinary ballast, the light would flicker or shut down altogether. Typically, these ballasts are not compatible with all incandescent dimmers, however. If ballasts and dimmers are mismatched, symptoms may include the inability to reach full light output, humming or other noise at the dimmer, and the inability to start the lamp except at a high setting.

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Although differences exist among dimming ballasts (such as minimum light output level, type and quantity of lamps controlled, and controller compatibility), the dimming ballast for four-foot T8 lamps is slowly approaching commodity status. Prices are dropping, but dimming ballasts still cost at least twice as much as nondimming products.

When choosing dimming fluorescent ballasts, the key considerations are:

- *Dimming level.* What is the minimum dimming level needed in the space? Most dimming ballasts are useful for "energy dimming," but only a few can be used for "architectural dimming." Ballasts for the latter use typically cost significantly more.
- *Lamps served.* Dimming ballasts are not available in as wide an array of lamp configurations as nondimming ballasts.
- *Technical specifications.* Independent lab reports should be reviewed to verify the ballast's dimming range and its power

A good warranty will replace failed ballasts for at least three years and provide a labor allowance of at least $10 per failed unit.

input, total harmonic distortion, power factor, and crest factor at various dimming levels.

- *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 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 only for two four-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 three years and provide a labor allowance of at least $10 per failed unit.

Although the dimming of full-size fluorescents is becoming relatively commonplace, until recently, dimming compact fluorescent lamps (CFLs) was an expensive proposition. There were only a few reliable products available and none of them worked on existing incandescent dimming circuits. Now a number of new products are changing that picture. New screw-based, dimmable compact fluorescent lamps provide dimming capabilities down to the range of 10 to 20 percent, and early reports are that they work well with most existing incandescent dimmers. These screw-based products cost just a few dollars more than standard CFLs. Several new hardwired CFL dimming products are coming to market as well, expanding the options for dimming down to lower levels.

Most applications of dimming compact fluorescent lamps are in the commercial arena in conference and meeting rooms, executive offices, hotel and convention ballrooms, restaurants, offices with computer monitors, and reception areas in both new construction and retrofit installations. As dimmable compact fluorescent lamps gain acceptance, they will bring the benefits of energy efficiency and long life to millions of incandescent dimming circuits.[10]

New screw-based, dimmable compact fluorescent lamps provide dimming capabilities down to the range of 10 to 20 percent, and early reports are that they work well with most existing incandescent dimmers.

High-intensity discharge (HID) lamps. 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 CRI (color rendering index), increased flicker, impact on lamp life, and inadvertent lamp shutdown during line voltage variations.

The color of HID lamps shifts considerably during dimming, limiting them in any aesthetic applications. Clear metal halide lamps can experience an increase in color temperature of over 1,000 degrees K 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 flicker more visible, especially in high-pressure sodium lamps.

A promising new line of electronic dimming ballasts for metal halide lamps is available from Delta Power Supply. Ballasts are available for lamps of 70, 150, 200, 350, and 400 watts. These ballasts offer continuous dimming down to 30 percent of full output, have high power factor and low total harmonic distortion (THD), and auto-sense incoming voltage between 120 and 277 volts.[11]

Motorola has just introduced an electronic metal halide ballast available in 70- and 100-watt models, with other models to follow. Motorola claims consistent color and lumen maintenance at any voltage over the full life of the lamp. The ballasts feature continuous dimming from 100 to 50 percent and energy savings over magnetic ballasts of 10 percent at full light level and up to 50 percent when fully dimmed.

Panel level dimming. Panel level dimming uses an external power controller and standard ballasts to reduce light levels by lowering circuit voltage well upstream of the ballasts. This approach is best applied to large banks of lights that are switched simultaneously, such as in retail stores, supermarkets, and large open-plan offices. Other good applications are spaces that have been upgraded to electronic ballasts but that are still overlit, or spaces with HID fixtures. Dimming is limited to 25 to 40 percent reductions in lighting output—substantially less in many cases—making the system mainly suitable for energy management purposes rather than for full-range light control.

Personal dimming control has been shown to contribute to high potential energy savings and occupant satisfaction.

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.[12]

Numerous studies, including research conducted by the Lighting Research Center (LRC) in the U.S. and the National Research Council of Canada's Institute for Research in Construction (NRC/IRC), concluded that

- Occupants desire and use dimming controls when 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.

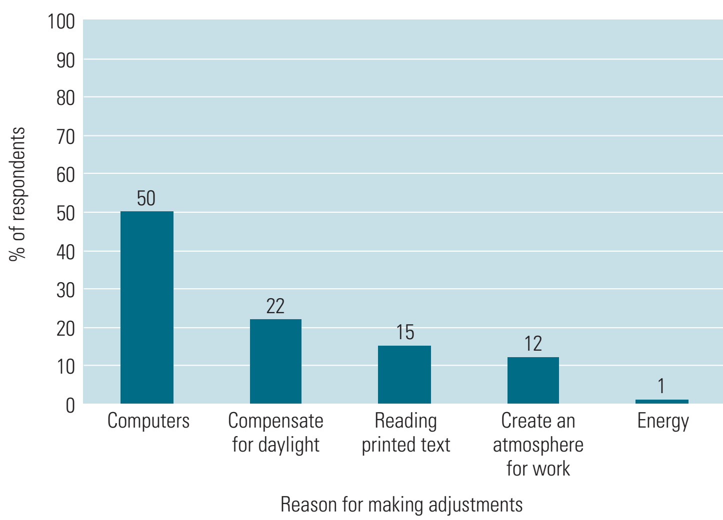
- Lighting levels in facilities with personal dimming controls are usually at or below recommended levels.

At the National Center for Atmospheric Research (NCAR) 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 daylighting intensity (see **Figure 4**).

The two most frequent reasons workers gave for using the dimmers was to adjust for computer area lighting and to compensate for changes in daylighting intensity.

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 workspaces. Of those workers who used the controls, the most common reasons given for doing so were to minimize veiling reflections on computer screens and to compensate for changes in daylight intensity.



Source: National Center for Atmospheric Research

Combined Technologies

Creative designers can get the most benefits by combining on-off and dimming control. 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 3**).[13]

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. A lighting designer who finds that a project exceeds the allowable lighting power

Table 3: 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	N/A	23	N/A

Source: Lawrence Berkeley National Laboratory 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 4**. 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.

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.

For example, take the case of a lighting designer who finds that a particular design has an Actual Lighting Power Density of 1.5 watts per square foot (W/ft^2), and Title 24 only allows 1.2 W/ft^2 for that space. The designer could incorporate both occupancy sensors and dimming controls that compensate for the depreciation in lighting output that occurs as lamps age (lumen maintenance) and thus could use an adjustment factor of 0.25. That adjustment would reduce the system's Actual Lighting Power Density by 0.375 W/ft^2 for the purposes of Title 24, effectively lowering it to 1.125 W/ft^2. With such a lighting control system, the design would meet or slightly exceed the power density requirements under Title 24.

Table 4: Title 24 lighting adjustment factors for combined control systems

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 three different types of systems that combine occupant sensors with dimming controls.

Type of control system	Type of space	Lighting adjustment factor
Occupant sensor with a separate sensor for each space used in conjunction with lumen maintenance controls	Any space ≤ 250 square feet and enclosed by opaque ceiling-to-floor partitions	0.25
Occupant sensor with programmable multi-scene dimming system	Hotels, motels, restaurants, auditoriums, theatres	0.35
Occupant sensor with a separate sensor for each space used in conjunction with daylighting controls, and separate sensor for each space	Any space ≤ 250 square feet within a daylit area and enclosed by opaque ceiling-to-floor partitions	0.10[a]

Note: a: The adjustment factor for the combined system with daylighting controls may be added to other daylighting control credits.

Source: California Energy Commission

For More Information

California Energy Commission

1516 9th Street

Sacramento, CA 95814-5512

tel 800-772-3300

fax 916-653-7480

web www.energy.ca.gov

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

Energy Efficient Lighting Association (EELA)

web www.eela.com

The Energy Efficient Lighting Association (EELA) promotes the use of energy efficient lighting and related products by industry and commercial customers through its membership of educated principals, partners, and users. EELA also strives to promote the purchase and installation of energy efficient lighting products through education and networking across these lighting channels.

Green Lights/Energy Star Buildings Program

Atmospheric Pollution Prevention Division

U.S. Environmental Protection Agency [6202J]

40l M Street SW

Washington, DC 20460

tel 888-782-7937

fax 202-233-9569

web www.epa.gov/greenlights.html

Green Lights is a voluntary program sponsored by the EPA to encourage the use of efficient lighting technologies. In exchange for agreeing to pursue energy efficient lighting upgrades, Green Lights partners receive recognition and technical support.

Illuminating Engineering Society of North America

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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

Merchandise Mart, Suite 487
Chicago, IL 60654
tel 312-527-3677
fax 312-527-3680
web www.iald.org

The IALD is the trade association for lighting designers.

Lighting Research Center

c/o Rensselaer Polytechnic Institute
Watervliet Facility
877 25th Street
Watervliet, NY 12189
tel 518-276-8716
fax 518-276-2999
e-mail lrc@rpi.edu
web www.lrc.rpi.edu

The Lighting Research Center performs extensive testing of lighting fixtures such as downlights and exit signs, and it publishes reports that help specifiers sift through different lighting technologies. The LRC also provides technical support to the EPA's Green Lights program and its partner companies.

National Council on the Qualification of Lighting Professionals
401 East-West Highway, Suite 305
Bethesda, MD 20814
tel 301-654-2121
fax 301-654-4273
e-mail info@ncqlp.org
web www.ncqlp.org

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

Southern California Edison
6090 North Irwindale Avenue
Irwindale, CA 91702
tel 800-336-2822
web www.sce.com

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

The National Dimming Initiative
c/o Steve Purdy, NDI Coordinator
Advance Transformer Company
10275 West Higgins Road
Rosemont, IL 60018
tel 800-322-2086 or 847-390-5136
web www.advancetransformer.com

The National Dimming Initiative (NDI), sponsored by lighting control manufacturers, engineers, and contractors, offers a free interactive CD-ROM that explores all of the financial, energy, environmental, aesthetic, and productivity benefits of controls, in addition to aiding in the specification of control and dimming products.

Notes

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