

This section explains how to design and operate daylighting controls for electric lighting systems. These *Guidelines* define daylighting controls as devices that regulate the level of illumination provided by electric lights in response to the presence of daylight.

Saving Energy with Skylights 4.1.

Without daylighting controls, a skylit building will not save any energy. Indeed, if it is heated or cooled, it will consume more energy than if it had no skylights. However, with daylighting controls, a skylit building will require less energy for lighting and can also result in significant savings in cooling costs. These savings can range from about \$.05/sf to \$.75/sf depending on building type, operation, location, and energy costs. *SkyCalc* allows a designer to quickly assess the magnitude of those savings for a given building design, operation, and location.

Control over the electric lighting can be exerted through an automatic device (automatic control), human intervention (manual control), or both. Some degree of manual control is usually desired, but only an automatic system can bring about guaranteed, sustained energy savings.

4.1.1. Occupancy versus Daylight Availability

Daylight is usually available during those hours when most commercial buildings are occupied. The amount of lighting energy savings is a function of the daylight availability in relationship to the occupancy pattern of the building, plus the daylighting control strategy. For example, an elementary school classroom typically operates from 9 a.m. to 3 p.m. So, even though there is daylight available after 3 p.m., there will be no lighting savings during those hours. Similarly, if a retail store does not open until noon, there will be no lighting

savings during the morning daylight hours. A restaurant that only serves dinner may have very minor savings from installing daylight controls. Those buildings operating during the most daytime hours will have the greatest savings from daylighting.

Coincidentally, the greatest abundance of daylight occurs during the hours of utility peak demand (typically 3 to 6 p.m.). At these times, the electric energy from the utility is usually the most expensive, and demand charges may be imposed. If used as an energy saving strategy, skylights may help to significantly reduce peak demand and time-of-use charges¹. Also, with the advent of the restructuring of the electric utility industry, energy providers may begin offering lower energy prices to customers that can reduce consumption during peak periods. An effectively designed daylighting control system can provide these benefits.

4.1.2. Manual Lighting Controls

With manual lighting control, the occupants are responsible for switching off the lighting when there is adequate daylight. Because it requires no additional hardware, manual lighting control is by far the least expensive photocontrol system—*if it is used*. For large, complex commercial buildings, manually controlled lighting is unlikely to result in any significant energy savings since there are too many conditions to consider. However, for small or single space commercial or industrial applications (retail boutiques, simple warehouses) where a single manager can adjust the electric lighting according to current daylight conditions, manual controls may be effective.

The reliability of manual switching is dependent upon the following:

- **Accessibility** of the switch to the users. If it is not easy to get to, it is unlikely anyone will use it.
- **Size** of the control zones relative to the number of people using the space. The person controlling the switch should have authority over the space. Thus a building manager may control the whole floor of a warehouse, while each individual should control the switch in their own private office.
- **Vigilance** of the user. It is typically assumed that people are highly unreliable as control devices. However, there is growing evidence that we have been too pessimistic. Building managers charged with saving energy are often very vigilant about turning off switches. Occupants of private offices can be more effective than occupancy sensors in turning off lights when not needed² and have also been observed to take advantage of bi-level switching on a regular basis³.

The opportunity for manual control of lighting may also be important psychologically. Numerous studies have shown that people are happier when they have some control over their work environment. A light switch is an important symbol of such control.

4.1.3. Automatic Lighting Controls

The alternative to manual control is automatic control. While automatic control does not rely on the daily decisions of the building occupants, its success is dependent upon a number of crucial factors:

- **Selection** of the proper equipment. This manual provides some guidance, but a knowledgeable electrical engineer should have full responsibility for the final specifications.
- **Commissioning** of the system. The system should be calibrated and adjusted to suit the unique conditions found at each building site. Failure to commission is the single greatest cause of the failure of daylighting control systems to perform properly. The system must also be easily adjustable if conditions change, such as a reconfiguration in the building layout.
- **Understanding** by the building manager and occupants. Photocontrols remain rather mysterious to the average person. It is an excellent idea to explain the system to the people who will be living with it. Without basic understanding, strange things can happen, as shown in the stories below:

A grocery manager worked in a store with skylights and photocontrols for three years. She never understood why the lights would go off sometimes, and she didn't know how to answer employees' questions about the lights. She wondered if the store had a bad electrical connection. Finally, she got an electrician to come in and fix the problem. He, of course, disconnected the photosensor.

In another recently constructed daylit building, automatic photocontrols were provided with a photosensor mounted in the ceiling. However, no electrical connections were made during construction. The company had occupied the new building for over a month when the controls team returned to connect the photocontrols and commission the system. They found, to their surprise, that the occupants had already taped over the photosensors. Why? The system certainly couldn't have been causing any problems since it wasn't even functional yet. Did they think they would get more light? Or stop lighting conditions from changing? Did they dislike the idea of an "automatic" system? Probably the best explanation is that they just didn't understand the system.

Photocontrol Strategies 4.2.

The following sections address the specifics of how to design and implement a successful automatic daylighting control system.

4.2.1. Components

An automatic daylighting control system consists of the following components:

Light source: The type of electric lighting system to be controlled. Critical decisions include the type of light source (fluorescent, metal halide, high pressure sodium, etc.), the type of ballast driving the light source (on/off, dimming, hi-lo), the wiring to the fixtures (standard, split), the number of fixtures per circuit, and the physical layout of the fixtures.

Control unit: The control unit is the physical device, either a dimmer or a switch, that varies the amount of power applied to the light source. A dimmer is capable of continuously varying the amount of electric power flowing to the light source, thus providing a wide range of light output from the source. A switch (or relay), on the other hand, is a control unit that can only switch its load on or off. A switch provides less control flexibility than a dimming unit, but is also much less expensive.

Photosensor: Automatic systems use a photosensor to measure the daylight illumination entering the skylit building space. By producing an electrical signal proportional to the amount of incoming daylight, the photosensor provides the control system with the information it needs about the lighting conditions in the space.

Controller: The controller translates the photosensor signal into a command to the control unit. For dimming applications, the controller reads the photosensor signal and then commands the control unit to dim in proportion to the intensity of the signal. Thus, the electric lights will dim significantly if there is an abundance of incoming daylight but only slightly if the daylight is low. For switching applications, the photosensor signal is compared to a preset value and the control unit is commanded to switch lights on or off depending on the comparison.

These components may each be housed separately or they can be combined into complete units. There are even examples of lighting fixtures that combine all elements with individual integral photocontrols. When the photosensor is located remotely, such as high in a skylight well, it is advisable for the control unit and controller to be combined into one physical device that can be placed in a more accessible location for ease of calibration and adjustment.

4.2.2. Control Zones

During the design phase, electric lights that are to be controlled together should be organized into control zones. All the lights in a control zone are dimmed (or switched) together and are regulated by one controller (and one photosensor). Zones should be determined by identifying areas with similar:

- task illumination needs
- lighting schedules
- daylighting conditions
- electric lighting systems

The designer should be informed as to the types of tasks to be performed in each major area of an installation, including the location and heights of any major light obstructing objects, such as storage racks, tall equipment, or high partitions. Although this seems simple, lack of this knowledge is a common reason for poorly performing control systems. The designer often does not have the luxury of waiting until all interior partitions and shelving are located before laying out lighting circuits. Section 2.5.3 presents a few helpful hints to increase the probability of success.

From an electrical standpoint, all the fixtures in a control zone are on one lighting circuit or subcircuit (switchleg). The size of control zones is also limited by the electric current capacity of the lighting circuit. For the 30-amp breakers common in most commercial building lighting electrical systems (277 VAC), this corresponds to a maximum control zone size of about 4,000 Watts, or roughly 3,000 square feet.

4.2.3. Switching versus Dimming

The choice between a switching and a dimming system is an important design decision which affects the potential for energy savings, user acceptance, and initial cost.

Dimming systems remain much more expensive than switching systems. Since dimming systems alter light output continuously, however, they are more likely to be acceptable to the building occupants, especially those working at a fixed task. Dimming systems follow the pattern of daylight availability very closely, and thus tend to produce more energy savings, especially in areas with highly variable cloud cover.

Dimming systems also have one other important feature that can lead to additional energy savings. Since the dimming system is designed to maintain a fixed illuminance (50 footcandles, for example), the system will also respond to decreased light output due to dirt accumulation or aging of the lamps. Most lighting systems are over-designed by 15 to 25 percent to account for these “depreciation factors.” Thus, the initial light output of a lighting system is typically 15 to 25 percent higher than at the end of its life. A photo-controlled dimming system will reduce the light output at the beginning of system life to the target illumination level (instead of target plus 25 percent) and then gradually increase power to maintain light output as the lamps age. This process, often called the “lumen maintenance” effect, can result in an additional five to 10 percent energy savings over the life of the lamps.

Switching systems create wide differences in light output as they switch between illumination levels in response to changing daylight conditions. Rapid changes in electric light level may be confusing or annoying to some building occupants, although the changes in illuminance will often go unnoticed. Because they are simpler, switching systems are typically less expensive than dimming systems. They tend to be most effective at saving energy in areas with fairly constant daylighting conditions (either all sunny or all cloudy). Switching systems also tend to be more acceptable to occupants who are moving around a great deal, such as

shoppers or workers in a warehouse. The use of switching systems should be carefully considered in any hazardous environments, such as around fast-moving machinery, as sudden shifts in lighting conditions might cause dangerous distractions.

FIGURE 4-1:
SWITCHING VERSUS
DIMMING CONTROLS
ILLUMINATION PATTERNS

The pattern of illuminance achieved under two sample control strategies is illustrated in Figure 4-1 for two different daylight conditions. On the right are two graphs for a high level of daylight illumination, at twice the design target, and on the left are graphs illustrating a lower daylight illumination condition, at 75 percent of the design target. The idealized parabolic curve for daylight illumination is similar to that seen on a perfectly sunny day or an evenly cloudy day. A day with variable clouds would see more variation in illumination levels.

The top two graphs show the total illumination resulting from a three-step switching strategy. Abrupt changes in total illumination levels are seen as the lights switch off. While these illumination spikes may seem dramatic, it should be remembered that our brains do not perceive illumination on an arithmetic scale, but rather on a logarithmic scale. Thus, any changes less than one third of total illumination are generally not noticed. Thus, these spikes, at one third of the target illumination, may be just at the threshold of perception.

The bottom two graphs show the total illumination resulting from a 20 percent dimming strategy. For the high daylight illumination pattern on the left, once the design target has been reached, the total illumination levels very closely follow the daylight pattern. For the low daylight illumination pattern on the right the dimming system maintains a constant level of illumination, exactly at the design target.

The choice of dimming versus switching will also be influenced by the type of lighting system selected. Fluorescent lamps work well with either system. They can easily be dimmed, or switched on and off, and suffer only minor shifts in color when operated at less

than full power. High intensity discharge (HID) sources, including metal halide and high pressure sodium lamps, are a bit more problematic. They both take a while to restart after being turned off, making them less attractive for a switching system. Dimming ballasts for HID lamps are available, but still fairly rare. An alternative approach is to use ballasts that can operate at two levels of light output, which solves the restarting problem. However, metal halide lamps tend to shift in color appearance when operated at low power. Because of these limitations, HID lamps are more common in manufacturing, warehouse, and discount retailing applications where lighting quality and fast system response are less important.

4.2.4. Dimming Controls

Dimming can be implemented in different ways with current technology. There are dimming ballasts that control just two to four fluorescent lamps, as well as large circuit-based dimmers that can dim large blocks of fluorescent lights. As a rule, it costs more to dim many small groups of fixtures than one large group. Also, the lower a light output at which a dimming system can be operated, the more expensive it is. Thus, a system which only dims lights down to 20 percent will cost less than one that can dim the lights all the way down to one percent.

Dimming hardware includes the following:

Dimming Ballasts

Controllable electronic ballasts dim fluorescent lamps in groups of two, three, or four lamps. The three most common light output ranges for controllable ballasts are 20-100 percent, 10-100 percent and five-100 percent. Ballasts that dim to one percent are also available, but are rarely used in daylighting applications. Magnetic dimming ballasts are available, although they are less common and less efficient. Controllable electronic ballasts have the added feature of preserving lamp life by assuring that proper fluorescent lamp electrode power is maintained throughout the dimming range.

Dimming core-coil ballasts are usually used for controlling individual HID lamps. HID dimming ballasts have less of a range than the equivalent technology for fluorescent lamps, typically dimming to only 25 percent of light output. Dimming HID ballasts use core-coil (magnetic) components while electronic dimming ballasts dominate the fluorescent dimming market.

It should be noted that all ballasts are less efficient when operating at partial power. The precise relationship between light output and power input depends on the specific product. Specifiers are advised to seek this information from manufacturers. Figure 4-2 illustrates some typical efficiency relationships for various products.

Circuit-Based Dimmers

Branch circuit-based dimmers control all the fluorescent lights on a lighting branch circuit.

(There are few commercially available circuit-based dimmers for HID sources). While few of these systems require the use of dimming fluorescent ballasts, if dimming ballasts are not employed, the control range is usually limited to 40-100 percent of light output. The specifier should also take care to assure that the system does not violate any ballast or lamp warranties.

Autotransformers are large, simple dimming controls that are usually applied on a large-zone basis, with one autotransformer controlling one or more branch circuits, or all three phases of a lighting panel. These systems work by changing the input voltage to all ballasts on a circuit. They can dim most standard HID and fluorescent ballasts which are designed to tolerate a wide range of input voltages. On the other hand, the dynamic range of dimming achieved with autotransformers is very limited, usually 55-100 percent of light output. Also, the use of autotransformers may prohibit the use of mixed light sources, such as HID and fluorescent, or mixed-ballast technologies, such as electronic and magnetic, on the same circuits.

4.2.5. Switching Controls

Switching controls create discrete changes, or steps, in illumination levels, rather than the smooth transitions provided with dimming controls. The smaller the steps, the less noticeable they are. Many smaller steps will save more energy than a few large steps, but there are always additional costs associated with additional complexity. In general, stepped controls with two or three levels of illumination, plus “off,” have been proven more than adequate in most applications.

As a rule of thumb, people generally do not notice changes in illumination levels that are less than one-third of the current illumination level. Thus, changing from 30 to 40 footcandles is barely noticeable, and changing from 30 to 35 footcandles is generally imperceptible. Similarly, if illumination levels are set at 100 footcandles, an increase to 130 or a decrease to 70 footcandles will probably not be noticed by most people.

Stepped controls can be implemented in two ways, with hi-lo ballasts or split-wiring. Hi-lo ballasts usually have two, or sometimes three, levels of light output. These are also referred to as step ballasts or multi-level systems.

Split-wiring also provides multiple levels of light in a control zone. Split-wiring involves having separate circuits driving multiple fixtures, or separate circuits driving different lamps within fixtures, that can be controlled independently. This is often referred to as bi-level switching, or two-step or three-step on/off. We describe each in greater detail below.

Hi-Lo Ballasts

Step, or Hi-Lo, ballasts are specially designed ballasts that can operate lamps at one of two (or sometimes three) light output settings. Since these systems only have to produce a few discrete light levels, the ballast manufacturer can optimize the energy performance at each

designated light level. Thus, all else being equal, step systems can provide a few light levels slightly more efficiently than a continuous-dimming ballast.

Hi-Lo ballasts are available for both fluorescent lamps and HID lamps. Fluorescent step ballasts typically offer one-half light output, or one-third and two-thirds light output. HID two-level systems usually feature full and about one-quarter light output, or “high and low.”

Fluorescent step ballasts are available and meet California Title 24’s requirement for bi-level switching. However, true bi-level switching at the circuit level produces similar results and is generally the more economical alternative. As fluorescent step ballasts have a relatively small market, they may be only slightly less expensive than a much more capable dimming system.

For HID lamps, a step ballast solves a very important problem. When an HID lamp is switched off, it has to cool off before it can be restarted. For some lamps, this “re-strike” period can be as long as 20 minutes. However, when an HID lamp is powered down to a low light output level, it can resume full light output almost immediately (within seconds). Thus, HID Hi-Lo ballasts allow an HID system to have the same nearly instant response to photocontrols as a fluorescent system. HID Hi-Lo ballasts were extremely rare at the beginning of the 1990s, with only one manufacturer marketing them. Since then, additional manufacturers have entered the market and the price has decreased, thereby increasing the market share for these ballasts.

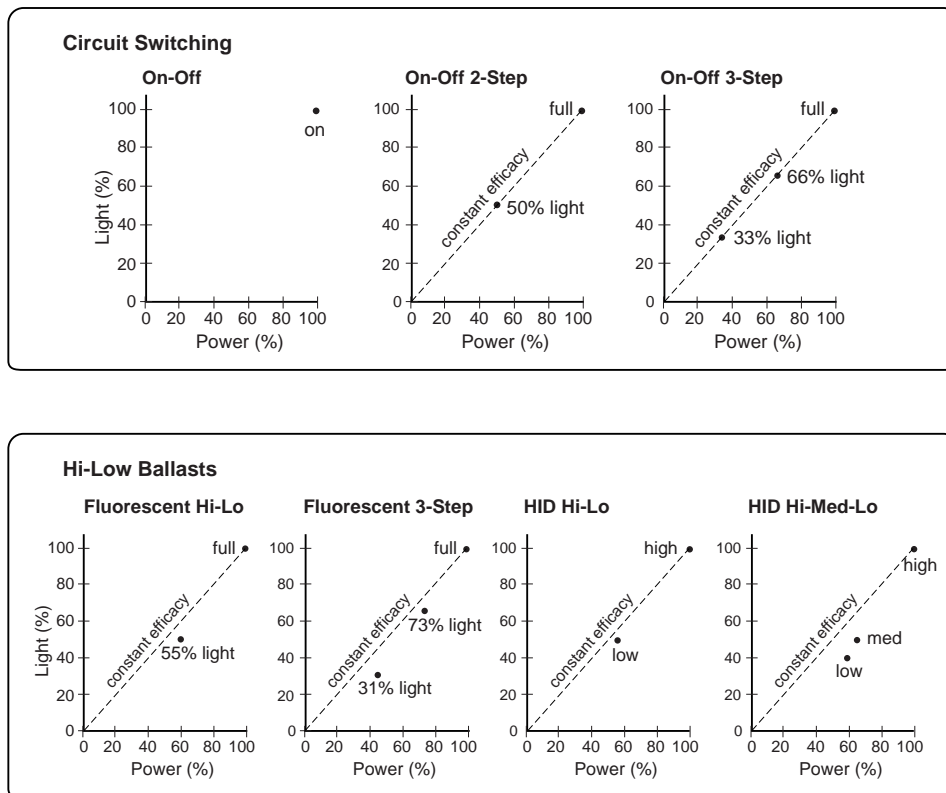
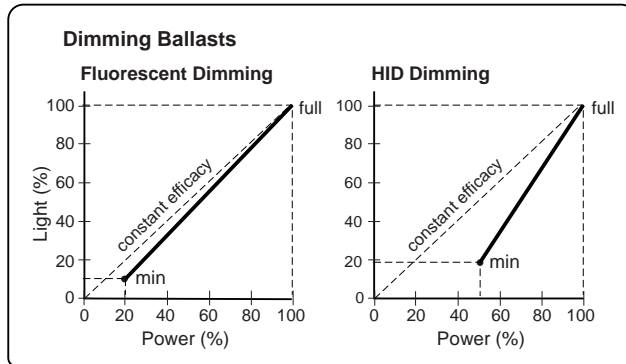


FIGURE 4-2:
CONTROL TYPE RESPONSE
 A KEY CHARACTERISTIC OF AN AUTOMATIC CONTROL SYSTEM IS THE RELATIONSHIP BETWEEN THE LIGHT OUTPUT OF THE ELECTRIC LIGHTING SYSTEM AND THE INPUT POWER; NOTE THAT BOTH THE STEPPED CONTROL AND DIMMING SYSTEMS ARE SOMEWHAT LESS EFFICIENT AT DIMMED OR STEPPED LEVELS THAN AT FULL POWER.

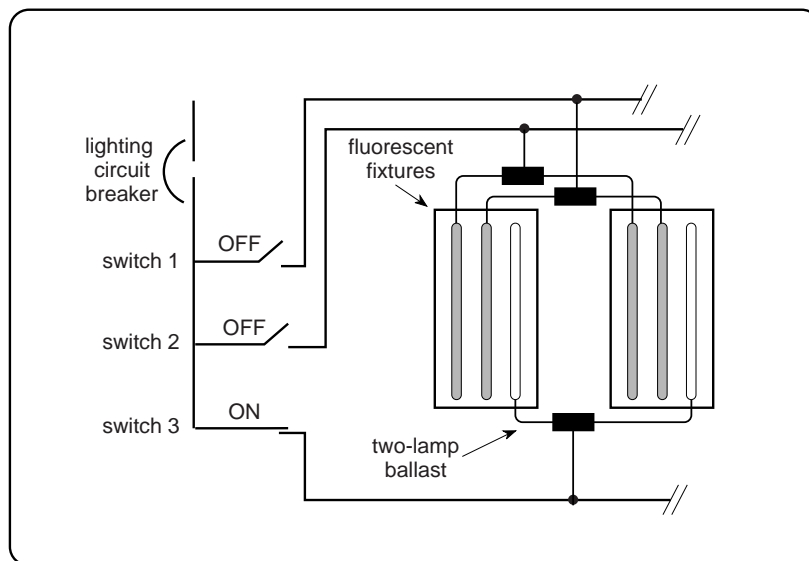


Step Switching

Step switching can be achieved in two ways; either multiple fixtures within a space can be operated on separate switches, or multiple lamps within each fixture can be operated separately. Typically, step switching involves two or three steps of illumination levels.

A common technique for obtaining stepped control from fluorescent lights is to use split wiring that separately controls each lamp within multi-lamped fixtures. An example of a split-wired fluorescent lighting system is shown in Figure 4-3. Here, a single ballast drives one lamp in each of two or more fixtures. Thus, a fixture can be operated with one, two, or three lamps on, providing three equal levels of illumination. A second approach puts the center lamp on one switch and the two outer lamps on another switch. This is sometimes called the “inboard-outboard” method. The first approach requires three switches and three circuits, and the second approach requires only two switches and two circuits. While the first approach is thus slightly more expensive, it provides a more gradual change in illumination levels and a greater opportunity for energy savings.

FIGURE 4-3:
FLUORESCENT THREE-
LEVEL SWITCHING
 A MULTI-LAMP BALLAST
 DRIVES ONE LAMP PER
 FIXTURE. THREE LEVELS OF
 ILLUMINATION ARE
 AVAILABLE.



The success of the first approach described above has as much to do with psychology as it does with good lighting practice. It is common for occupants of buildings to want to have

at least one lamp per fixture operating at all times, even if it is not needed for illumination. The fact that a lamp is visibly “on” is commonly interpreted to mean that we are in business: The store is open, the librarian is in, the class is in session. If one light is always left on, two gradual increases in illumination are still available, which can respond to subtle changes in daylight availability. If one light is left on in the “inboard-outboard” method, then the only option is to turn the other two lights on or off. This creates a much larger illumination threshold before the lights can be switched off, and therefore saves less energy. It also creates a much more noticeable change in illumination levels, which is less acceptable in some occupancies.

HID fixtures typically only contain one lamp per fixture, so split wiring of lamps within fixtures does not apply. However, HID fixtures are commonly operated on multiple circuits that can be switched separately. By designing these circuits so that they provide appropriate illumination at different levels of daylighting, each circuit can be on a separate photocontrol. Thus, with HID step switching, the layout of the circuits becomes a critical issue.

Most commercial buildings use a three-phase electric distribution system. Electrical engineers often use branch circuits from different phases to provide illumination to one large area, because this lowers the load on each circuit and largely eliminates flicker and stroboscopic effects from HID lighting systems.⁴ Consequently, three-phase HID lighting is commonplace.

Once the HID fixtures are to be wired on three circuits, there is an obvious opportunity to control each circuit separately, in order to provide multiple levels of light. Figure 4-4 illustrates four alternate patterns for three-step switching on a uniform grid. These have been successfully applied in many retail, industrial, and warehouse applications. The HID fixtures in these systems need to have a very wide throw of light to ensure that even with only one-third of the fixtures on there is still fairly uniform distribution of light in the space. On an HID photocontrol system, often one-third of the lights are not controlled, to guarantee a minimum light level at all times, with the other two circuits operated on photocontrols.

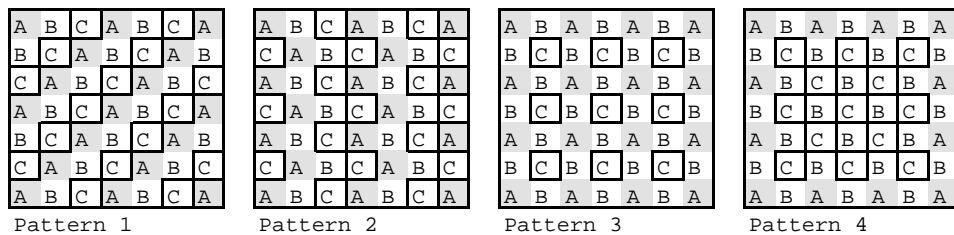


FIGURE 4-4:
HID THREE LEVEL
SWITCHING

In patterns 1 and 2, each circuit simply controls every third fixture. The first pattern has the most uniform distribution when one or two circuits are switched off. The second pattern has a linear pattern which may be compatible with certain shelving configurations, especially if some aisles are guaranteed to receive more daylight than others. Circuit A is shaded to help you visualize the pattern of lighting if only that circuit is operating. In patterns 3 and 4, one-half of the perimeter lights can be left on so that they are always operating. Note that

the number of fixtures on each circuit varies with each pattern.

It is possible to combine multi-level switching systems with step ballasts for even greater control of light levels. This is especially true of HID systems, where one-third of the fixtures could be operated on step ballasts to ensure instant response to demands for increasing light levels, while the other two-thirds could be operated more economically on regular on-off ballasts.

4.3. Photosensors

Automatic daylighting control systems use a photosensor to measure the daylight illumination entering the skylit building space. The photosensor produces an electrical signal that varies according to the amount of light striking its light-sensitive surface. The photosensor typically consists of a photocell, a light diffuser, and a rugged housing, all in one unit that can be mounted in a skylight well.

4.3.1. Types of Photosensors

Photosensors are of two basic types: photodiode and photoconductive. Photodiode sensors produce a voltage that is directly proportional to the detected light. Photoconductive photosensors produce a voltage that is inversely proportional to the detected light, and that increases roughly exponentially in intensity. The latter type of photosensor can handle a larger dimming range and is less expensive, however they are also less accurate than the former and have a very important drawback: Their sensitivity cannot be adjusted in the field.

4.3.2. Photosensor Sensitivity

The sensitivity of a photosensor is determined both by its type and its adjustment range. The responses of typical photodiode and photoconductive sensors are shown in Figure 4-5. Note that the response of the photodiode is linear with respect to changes in illumination, and that the slope of the response can be adjusted. The photoconductive sensor has a non-linear response to incident light and its sensitivity to incident light cannot be changed. Photodiodes designed for skylighting applications typically detect up to 10,000 footcandles at minimum sensitivity and up to 1,000 footcandles at maximum sensitivity. The sensitivity of photodiode sensors is adjusted in the field during system commissioning (See Section 4.5). Photoconductive sensors effectively compress the range of detected light so they do not require sensitivity adjustment. Photoconductive sensors specified for skylighting applications typically have a range of 400 to 3000 footcandles.

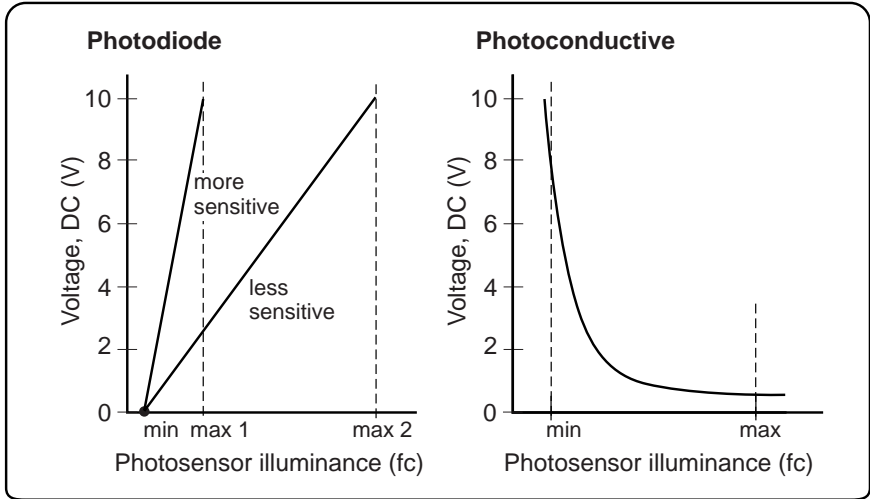


FIGURE 4-5:
PHOTOSENSOR RESPONSE

Either type of sensor can be used with switching systems, depending on accuracy requirements of the application. Photodiode sensors should be used for dimming applications as they are more accurate and allow system performance to be adjusted in the field.

4.3.3. Placement Issues

Unless the manufacturer recommends otherwise, the photosensor for most skylighting applications should be mounted high within a representative skylight well, with the light-sensing element aimed vertically upward. The advantage of locating the photosensor in the skylight well is that it is protected from the weather, and it senses the available daylight through the filter of the skylight, including any dirt accumulation or shadows falling on the skylight.

It is very important that it be located in the most representative area. For example, if a photosensor were located in a well that was shaded by a cooling tower in the late afternoon, it could cause the lights in the building to turn on unnecessarily. On the other hand, if a tall building were located next door that cast large shadows that moved across the roof during the day, the photocell should be located so that it is in the shadow for most of the time, rather than on the edge of the shadow.

The photosensor should preferably be mounted to a standoff so that it is at least one foot from the nearest face of the skylight well (See Figure 4-6). This mounting location reduces any confusing of the photosensor by self-shadowing of the skylight curb.

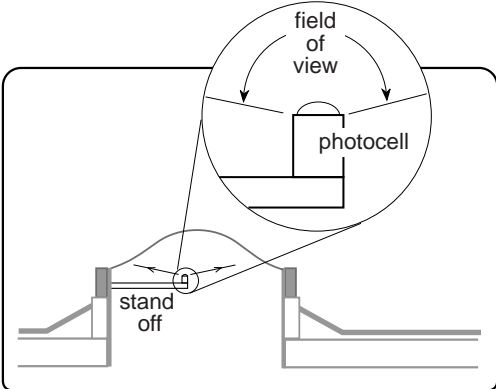


FIGURE 4-6:
PHOTOCELL MOUNTING

If the skylight geometry is particularly ornate or if the photosensor must be located near a large, light-reflecting surface, a different type of photosensor that is sensitive to reflected light may be preferable. In this case, the photosensor manufacturer should be contacted for specification and installation recommendations.

In the rare circumstance where there is a light fixture within view of the photosensor, it may be necessary to shield the sensor from this electric light. This can occur from a strong uplight inside the building or a flood light located outside the building on the roof or on an adjacent structure.

4.4. Controllers

The controller takes the electrical signal from the photosensor and converts it into a control signal to the dimming ballast or switch. The controller is the “brains” of an automatic control system, since it determines how electric light output varies as a result of changing illumination on the photosensor.

4.4.1. Types of Controllers

There are two basic types of controllers for daylighting applications:

- proportional controllers, which are used in dimming applications, and
- setpoint controllers, which are used for switching systems

A proportional controller imposes a linear relationship between the electric light output and the photosensor signal. This relationship is such that an increase in photosensor signal (i.e., an increase in the light detected by the photodiode) results in a decrease in electric light output. Simply stated, as the photosensor sees more light, the electric lights dim in proportion. With a proportional controller one can adjust how much the electric lighting system will dim for a given change in photosensor illuminance. This ability to change system sensitivity allows one to tailor the lighting system response to the specific conditions within the space. Sensitivity adjustment in the field is particularly advantageous since it is rarely possible to predict precisely during the design phase the range of daylight conditions that will occur at the photosensor location.

A setpoint controller is used with switching systems to determine at what daylight levels the electric lighting will switch on and off, or step up and down.

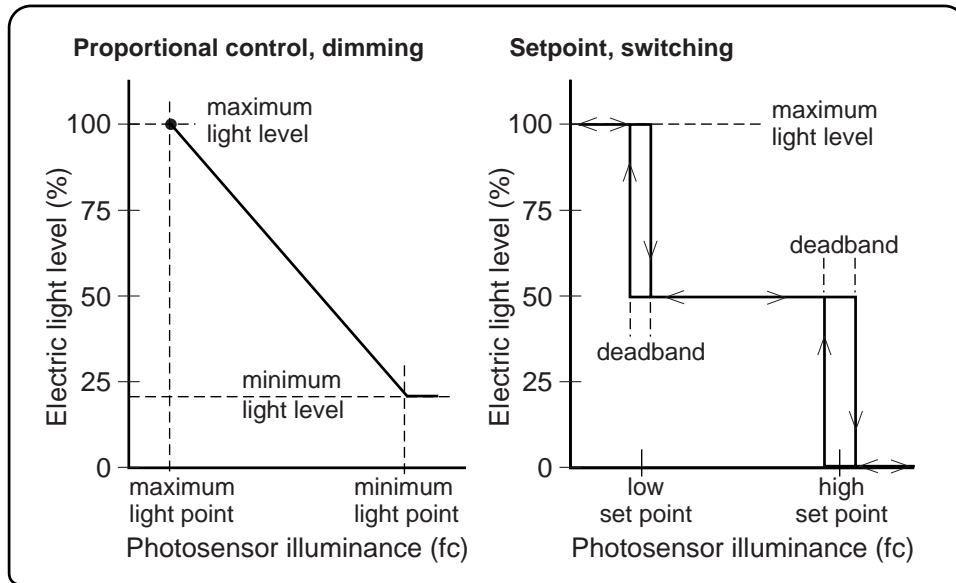


FIGURE 4-7:
PROPORTIONAL AND
SETPOINT CONTROLLER
RESPONSES

The responses of the two types of controllers are shown in Figure 4.7. The proportional controller has a simple linear relationship, with a selected minimum and maximum. A setpoint controller also has a selected minimum and maximum, but a sudden drop between these readings. With a setpoint controller, as the daylight detected by the photosensor increases, the electric light output remains at full until the photosensor illuminance hits the first setpoint. As soon as the photosensor exceeds the lower setpoint, the step control is commanded to produce 50 percent light output. Additional daylight on the sensor does not cause any additional light reduction until the second setpoint is exceeded, at which time the lights are turned off. In a three- or four-step controller, this scenario would be similar, but with additional intermediate setpoints.

To avoid rapid switching between light levels under changing daylight conditions, such as from partly cloudy skies, setpoint controllers incorporate a deadband. With a deadband, a lighting system which is set to switch from “high” to “low” once the photosensor detects a target illuminance (1,000 footcandles, for example), would not restore the lighting to “high” until the illuminance had dropped below 900 footcandles. With this 10 percent deadband, the lighting would be less likely to cycle between on and off states, improving user acceptance even under difficult daylighting conditions. Some manufacturers allow the deadband to be adjusted in the field.

In addition to deadbands, manufacturers can also build in time-delays to setpoint controllers, typically in minutes, which also reduce the amount of switching even if the daylighting conditions vary rapidly near the switching illumination threshold. Finally, scheduled lockouts can also be used. These are most common in conjunction with an energy management system (EMS). With scheduled lockouts, daylight-triggered light level changes are limited to specific times of the day. This approach clearly is not optimal from an energy efficiency standpoint, but may be appropriate under certain conditions, such as shift changes

in factories or scheduled classroom changes in schools.

A controller also provides functions such as the ability to set a lower limit on the dimming level, a maximum output level, a time delay, and sometimes the fade rate. These additional controls are useful for reducing any lamp flickering that might occur at very low light output levels and for adjusting how rapidly the electric lighting dims or brightens upon a sudden change in photosensor illuminance (as might be caused by a passing cloud).

4.5. Commissioning

Automatic daylighting control systems must be calibrated after they are installed, ideally after the building is occupied. All major room furnishings, obstructions, and window treatments should be installed to assure that the lighting control system is commissioned under typical lighting conditions. In a supermarket, the shelves should be stocked so that the light reflected from the shelves is typical of normal operation. In a warehouse, the storage racks should be partially filled with boxes. In an office building, the furniture and office partitions should be in place.

The calibration adjustments are usually physically located at the controller. The controller should therefore be easily accessible to authorized personnel and should be within line of sight of the corresponding controlled area.

Calibrating a dimming control system ensures that the electric lights will dim an appropriate amount for each increase in daylight level. Calibrating a switching system ensures that the step down in electric light occurs at appropriate daylight levels. Since commissioning occurs at the end of the construction process, there is an unfortunate tendency to push it aside in the last minute rush to move in. However, several studies have shown that failure to commission control systems is the single greatest reason for the failure of daylighting systems to save energy.

A True Story

Lockheed Building 169 in Santa Clara, California was designed to be a showcase for efficiency, daylighting, and a high quality work environment. The building's architecture employs an extremely effective light well and deep daylighting techniques. To "harvest" the daylighting, dimming controls for the fluorescent lighting system controlled by photocells were installed.

However, as often happens, the architect-engineer's original design was "value engineered" out to save first costs of about \$50,000. In addition, the less expensive system that was installed did not include commissioning. The architect-engineer offered to commission the revised daylighting control system for \$5,000, but the owner decided not to accept the A/E's

proposal, and commissioning was left up to the installers.

Five years later, scientists from Lawrence Berkeley National Labs and faculty from the University of California were invited to study the building, considered by Lockheed to be very successful. They determined that the building's daylighting system had been so well designed that, on most days, electric lighting was not needed in most of the building. Unfortunately, they also discovered that due to incorrect adjustment and commissioning, the daylighting controls were not working at all—and never had been. The result was the unnecessary consumption of more than 500,000 kWh annually, for five years. The total cost of energy that was not saved was about \$175,000⁵.

4.5.1. Calibrating Lighting Levels

The key to successful commissioning is knowing when to undertake calibration most effectively. The best time is when the daylight level at the task is close to, but not exceeding, the design target light level. For example, if you have a 50-footcandle design level, try to calibrate when the illuminance from daylight alone is between 40 and 50 footcandles. If you calibrate when daylight levels are particularly low (on a rainy day or in the morning on a winter day), the lighting system will not be dimmed enough to calibrate the system even roughly. On the other hand, if you try to calibrate when there is an overabundance of daylight, it is easy to miscalibrate so that energy savings will be minimal. It is also important to calibrate during stable weather, when light conditions will not be changing quickly.

You can use *SkyCalc* to estimate the ideal time for calibrating the system:

Example. Let the design level be 50 footcandles (fc) with an electric lighting system capable of dimming down to 10 percent. With these conditions, you should calibrate when the daylight level is at 90 percent of the design level, or about 45 fc. Now use *SkyCalc* to find when those conditions are likely to occur for a given month. Run a daylight illuminance summary for your installation using *SkyCalc* and inspect the table of daylight illuminances. Look up the row corresponding to the current month. Find those cells with values within 20 percent of your daylight calibration level and look up the corresponding hours of the day. This is a good estimate of the optimum times to calibrate the dimming system during that month.

One caveat about using *SkyCalc* for this purpose: *SkyCalc* calculates daylight illuminances based on average conditions for each month. If a month typically sees a mixture of cloudy and clear skies, then the average illuminance will be substantially different than on a perfectly clear day. Thus, in those instances, it would be wiser to choose an earlier hour, when the daylight illuminance will be lower on clear days.

Calibrating Dimming Systems:

A reliable light meter and a floor plan of the controlled spaces are extremely useful during

calibration. At the time of calibration (as determined above), place the light meter at a representative task location, pointing upward, being careful not to shade it with your own shadow. This will provide a measure of the horizontal illuminance at the work plane, typically 30 inches above the floor. Take a number of readings with the electric lights turned off to determine the most representative location, and note that location on the plans for future reference. Before turning on the electric lights, note the photometer footcandle reading (P_{daylight}). This value is a measure of the daylight currently available at the work plane. Compare this value to the optimum daylight calibration level (45 fc in the example above). If the values are within about 20 percent you can proceed with the calibration. If the daylight level is much less than the optimum you should wait until the daylight increases (assuming you started in the morning). If the daylight is much higher than the design level, the calibration time will have to be postponed until the daylight levels are closer to optimum.

Turn on the electric lights and operate them at full intensity until they reach thermal equilibrium (about 20 minutes for HID and 10 minutes for fluorescent lighting). Take a second reading (P_1). The difference between the two ($P_1 - P_{\text{daylight}}$) is the contribution of the electric lighting system. Note the photometer readings under full electric lighting *and* daylight (P_1) and compare them to the design light level (P_{target}). For a properly designed system, at the optimum calibration level, P_1 should be 1.8 to 2.0 times P_{target} . To calibrate, use the sensitivity adjustment on the controller to change the slope of the response curve (see Figure 4-6) until the total light level (daylight plus dimmed electric light) measured is 10-20 percent above P_{target} (50 to 60 fc in our example). Note the photometer reading (P_2) under this condition.

Ideally, for a 10 percent dimming system, P_2 should be 10 to 20 percent higher than P_{target} ; but this number will vary considerably depending upon the amount of daylight saturation. Record the final P_2 , and note the location, date, time, and also the values of P_{daylight} , P_1 , and P_2 on the floor plan for documentation purposes. Finally, it is a good idea to stand where the photometer is located, look around, and visually verify that light levels are appropriately bright.

Calibrating Switching Systems:

Because there are so many ways to control lighting through switching, it is not possible to produce generic calibration instructions for these types of systems. Thus, when calibrating switching systems, follow the manufacturer's specific calibration procedure. In addition, when calibrating switching systems, it is helpful to use special equipment (specifically a photosensor simulator) that is available from the manufacturer.

If commissioned correctly, a lighting control system needs to be maintained only occasionally, usually once annually (or follow manufacturer's recommendation). Maintenance consists of dusting and cleaning the photosensor and assuring that the system is dimming appropriately for the amount of available daylight. Photosensors in some dusty or dirty environments may need to be cleaned periodically (See the REMO manufacturing case study in this publication). Since the photosensors are probably located up inside skylight wells, special equipment may be required to give maintenance personnel access to the photosensors. It is a good idea to consider maintenance accessibility to this location before the photosensor is installed and calibrated. Air brushes used for cleaning photographic equipment are an excellent dusting tool. Similarly, using camera lens tissue will avoid scratches to the photosensor surface.

Photosensors are long-lived devices and should operate as long as the lighting system, if not abused. If a sensor is inoperative, make sure that it is replaced with an equivalent model and then re-calibrate the system upon installation. Always follow a manufacturer's installation instructions since the replacement photosensor can be damaged if installed incorrectly.

4.6.1. Problem Signals

The following symptoms of a daylight-controlled lighting system indicate that you should call for expert help:

- No dimming (or switching) action even under bright daylight conditions indicates improper calibration or a defective or disconnected photosensor.
- Over-frequent switching between light levels (especially under partly cloudy skies) indicates insufficient deadband or time delay.
- Excessive end-lamp blackening of fluorescent lamps indicates that the system is providing inadequate cathode voltage during dimming.
- Striations running along the fluorescent lamp under full dim conditions (also called "raccoon-tailing" or "barber pole effect") indicate unstable lamp performance.
- Frequent lamp burnouts can indicate either faulty ballast or fixture wiring, or voltage problems.

Footnotes, Chapter 4

¹ This is less true in areas with utility peaks that occur during humid, cloudy conditions. In those areas, even though a skylighting system will save energy overall, it probably will not reduce demand charges, since it will not significantly lower energy demand during the one-time peak condition upon which demand charges are usually based.

² S. Pigg et al., “Behavioral Aspects of Lighting and Occupancy Sensors in Private Offices: A Case Study of a University Building,” in Proceedings of the American Council for an Energy Efficient Economy, Summer Study 1996, p8.161.

³ F. Rubenstein, Substantive Public Comment on ASHRAE/IESNA 90.1-1989r (Draft) Based on Field Study at San Francisco Federal Building (450 Golden Gate Ave.)

⁴ In a three-phase system, three circuits are operated with alternating currents that peak at three different times. Because the HID lamps on the three circuits will have peak light output which is out of phase with each other, they cancel any flicker effects that could be perceived from only one circuit.

⁵ Per Jim Benya, in FEMP Lights Distance Learning Course, 1998, U.S. Department of Energy, Office of Federal Energy Management.