APPLICATION NOTE

An In-Depth Examination of an Energy Efficiency Technology

Dimming Controls for Lighting

Summary

Dimming controls reduce the output and energy consumption of light sources. Compared to on-off controls, they can increase energy savings, better align lighting with human needs, and extend lamp life. Unfortunately, they also add complexity and expense and may shorten lamp life under some conditions. They should be carefully compared to simpler systems that may also produce the desired results.

A variety of dimming technologies give the designer or retrofitter options including:

- **Manual Dimmers:** Dimmers are available for incandescent, fluorescent, and certain high-intensity discharge (HID) sources. Both step and continuous dimming are available for incandescents. Multiple dimming methods are available for both fluorescents and HIDs, though HID dimming is limited by color rendition and flicker problems.

- **Photosensor-Activated Dimmers:** Daylighting control may be the most important dimming technique. It matches the available natural daylight and lighting system output to produce consistent illuminance. Electronic or other dimming ballasts allow for control of the light level. These systems require carefully integration of control systems and sensors.

- **Programmable Dimmers:** Lighting output is adjusted to predetermined levels set by the user.

Revised 4/25/97

How This Technology Saves Energy

Dimming controls reduce the output and energy consumption of light sources. Compared to on-off controls, they potentially increase energy savings, better align lighting with human needs, and can extend lamp life. Unfortunately, they also add complexity and expense, and may shorten lamp life under some conditions. Dimming systems should be considered carefully and compared to simpler systems that may also produce the desired results.

Dimming control systems provide required light where and as needed, while minimizing electricity consumption. Five common lighting control configurations involve dimming:

- **Tuning:** Power to lights is reduced in accordance with the exact lighting needs of the user and work task. For instance, older workers and those doing highly detailed tasks need more light. Younger workers, those doing fairly easy-to-see tasks, and those using video terminals often need less light than is being supplied.

- **Daylighting:** A photosensor-controller device linked to a dimming unit varies electric lighting in response to natural light from windows and skylights.

- **Lumen Maintenance:** A photocell maintains constant ***illuminance***[1] across an entire maintenance cycle (time between lamp replacement). When lamps are new and fixtures and room surfaces are clean, lighting is reduced to the design illuminance level and no more. Over time, as the photocell detects the slow decrease in light level, input power is automatically increased to maintain the design illuminance. Not until the end of the cycle will the lighting system actually consume full power.

- **Demand-Limiting:** Electric lighting levels can often be reduced 10 percent or more with minimal impact on visual performance or productivity by shaving or shedding non-essential lighting loads. Automatic dimming controls do this without occupant awareness.

- **Adaptation Compensation:** In extended-hour interior applications such as 24-hour markets and exterior applications such as tunnels, electric lighting must be brighter in daylight hours so people with daylight-adapted eyes can see in darker or covered areas. But lighting power can be reduced substantially at night, as human eyes night adapt and require less light in those same areas. Dimming devices vary illuminance accordingly.

Photoelectric lighting controls that respond to the available light in a building space are a common element of daylighting and ***lumen maintenance*** strategies. A photoelectric lighting control system, illustrated in Figure 1, typically has the following components:

- **Photosensor (or Photocell):** Measures light level within the controlled space and generates an electric signal

[1] Bold italicized words are defined in the section titled "Definition of Key Terms"

in proportion to the illuminance striking it.

- **Controller:** Converts the signal from the photosensor into a command signal to the dimming unit.

- **Dimming Unit:** Varies light output by altering the amount of power flowing to lamps.

Figure 1 illustrates how daylighting control components are interconnected in a typical application with a standard ceiling-mounted photosensor. The sensor reports ambient light levels (electric and daylight) to the controller, which adjusts electric light output according to a built-in algorithm. The same central equipment, minus photocells, can be used for tuning or adaptation compensation strategies.

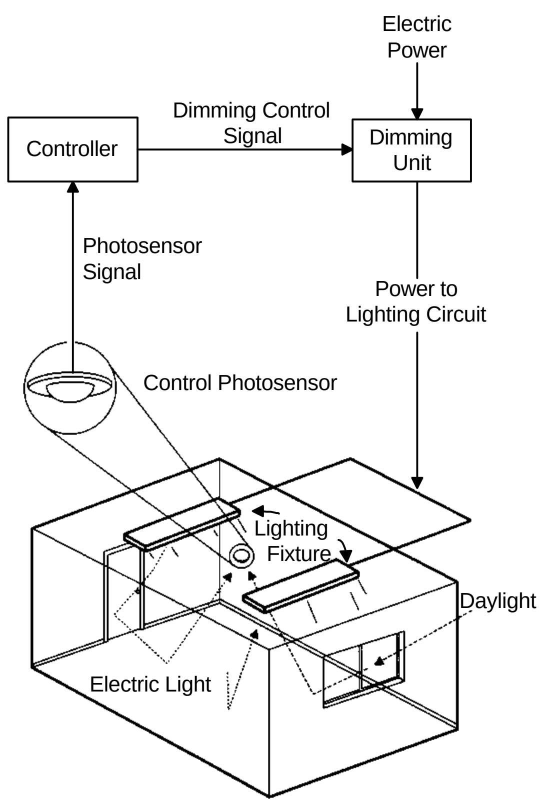

Figure 1: Photoelectric Lighting Control System (Source: CEC)

Types of Dimming Controls

A variety of dimming technologies gives the designer or retrofitter several options, including those described below.

Manual Dimmers

Dimmers for incandescent, fluorescent, and certain high-intensity discharge (HID) sources offer flexibility, versatility, and energy savings.

Incandescent Dimming

The familiar 3-way lamp is the most popular manual, step-dimming product. It provides three discrete reductions in light output. Continuous dimmers reduce energy consumption without visible flicker; the filament runs cooler, reducing ***color temperature*** and making spaces appear more yellow. Wattage does not drop linearly with light output, resulting in reduced efficacy at dimmed settings. Lamp life is usually increased in standard lamps, but may be reduced in halogen lamps. The rapid cycling of dimmed incandescent lamps may create a high-pitched hiss audible in quiet locations.

Fluorescent Dimming

Dimming can be achieved for nearly all fluorescent systems, whether magnetic or electronic, rapid- or ***instant-start***, and ”dimmable” or "nondimmable." Control methods include:

- **Auto-Transformers:** The simplest controls, usually applied on a large scale, with one unit controlling many branch circuits. Can dim most sources, including HID, but have very restricted dimming range, typically from 100 percent to about 75 percent light output.

- **Branch-Circuit-Based Dimmers:** Dim entire branch circuits and do not require that ballasts be changed. They are usually solid-state, employing waveform-shaping dimming circuits. Generally dim lamps from full output to about 50 percent. At 50 percent, lamp operating characteristics can shorten lamp life.

- **Dynamic Controllers:** Dim individual ballasts, or small groups. Typically use waveform-shaping electronic circuits. Do not require changing ballasts. They generally dim between 30 percent and full output, and may increase lamp flicker.

- **Dimming Core-Coil Ballasts:** Dim individual lamps or lamp pairs. Depending on lamp and control circuitry, can dim from 100 percent down to about 5-8 percent of full light output. Other systems, using specific combinations of ballasts, lamps, and controllers, provide about 20 percent to full output. Dimming core-coil ballasts may increase audible hum.

- **Dimmable Electronic Ballasts:** Dim individual lamps or groups of two, three, or four lamps. Depending on the control circuit, they can provide full-range dimming (from less than 10 percent to 100 percent).

Dimming controls may reduce the lifetime of instant-start lamps or ballasts.

High-Intensity Discharge (HID) Dimming

Limited dimming of HID lamps can be done with the methods described for fluorescents. Dimming is limited because of color shifting, reduced ***color rendering index*** (CRI), increased flicker, and inadvertent lamp shutdown during line voltage variations. HID lamp color shifts considerably during dimming, limiting them in many aesthetic applications. In general, dimming HIDs much below 50 percent is not practical.

Photosensor-Activated Dimmers

Daylighting control may be the most important dimming technique. Photosensor-activated dimmers match lighting system output to the available daylight to produce consistent illuminance. Electronic or other dimming ballasts allow for control of the light level. These systems require careful integration of control systems and sensors.

Photosensor-activated dimmers vary in sophistication and the amount of retrofitting required. Some of those used in fluorescent systems permit use of standard lamps and ballasts; others require installing dimming ballasts. Units are also available for incandescent and HID lighting.

Control systems must be high quality for best performance. Good controls have built-in time delays to prevent rapid on/off cycling. Controls must allow calibration of the time delay. It is important to use high-quality photosensors designed for indoor use; outdoor units are not acceptable.

Typically, a photosensor is located strategically in the area to be monitored. Outputs are relayed to a remote dimming unit which automatically adjusts the power supplied to the luminaires, increasing or decreasing light output (and energy consumption) accordingly.

Photosensor-activated dimmers also are used for lumen maintenance, taking advantage of the fact that new lamps produce far more lumens than they will average over their lifetimes. Because designs are based on average output, new lamps can achieve them at less than full output. Power is increased gradually as output decreases.

Small Zone Ceiling Daylight Sensors

Ceiling daylight sensors include a photo-detector head or fiber optic wand on or recessed into the ceiling. Some systems require a control module on a junction box above the ceiling. A separate on/off control must be provided. The module either varies power to the luminaires (one or more), or sends a signal to electronic dimmable ballasts (which must also be installed). A wall switch with manual dimming adjustment may also be provided.

Ceiling daylight sensors are suitable in buildings with substantial fenestration and a correlation between wiring and daylighting control zones. Existing manual switch wiring is almost mandatory, and installation will require rewiring in buildings wired without controls. Systems designed to operate with existing electromagnetic ballasts may increase lamp flicker, have limited dimming range, and/or reduce lamp life.

Large-Zone Daylight and Lumen Maintenance Sensors

These sensors are located in the zone to be controlled, sending a signal to a comparatively large dimming module, usually near the service panel. They modify power to all luminaires in the control zone, either by solid-state or auto-transformer dimming. Separate on-off switching is required.

Large-zone daylight and lumen maintenance sensors are suitable in larger spaces with substantial daylight, or where there are significant opportunities for lumen maintenance savings. They can be extremely effective in buildings wired without controls, provided all controlled spaces in a particular zone have similar characteristics. Additionally, most controls can be directly connected to programmable time controllers (see the Automated On/Off Application Note).

Dimming modules in this category are often large and unwieldy. Large-zone dimming systems do not work well when controlling several zones with individual switches because if the entire system is dimmed, switching on an individual room's lights causes all the lights in the zone to go to high level and then dim back to the original setting.

Programmable Dimmers

Such dimmers maintain lighting at predetermined levels set by the user. One version provides four presets; in a restaurant, this would permit separate levels for lunch, dinner, after-dinner, and cleanup. An additional control permits adjustment of fade rate as the device switches the lamps from one setting to another in 1-60 seconds.

The same central equipment used for daylight and lumen maintenance controls can be installed for tuning or adaptation compensation strategies that use programmable dimmers. Here photocells are not required, and control is accomplished in time-programmed mode. This is suitable for large spaces with large groups of luminaires having the same lighting needs and schedules. Design considerations are the same as described above for large-zone daylighting and lumen maintenance control strategies.

Case Study: Impact of Dimming Controls in Offices

A recent study by the Florida Solar Energy Center shows the savings available by dimming fluorescent systems. 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 2 shows power consumption and average lighting levels in the two spaces on a typical sunny day. The more efficient fixture reduces maximum lighting power 27 percent due to a lower connected load. But during daylight, the dimming controls reduce power a total of 55 percent compared to the conventional system. As expected, light levels were lower but always well above the 50-footcandle design level—indicating that even deeper dimming could have been used.

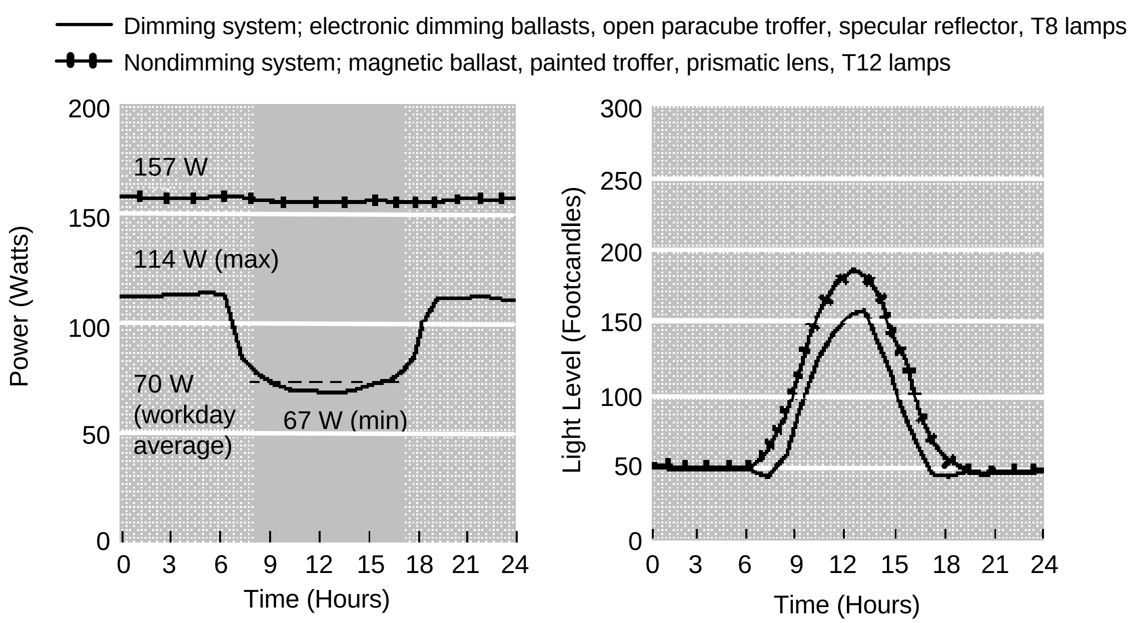

Figure 2: Power and Lighting Levels for Dimming vs Nondimming Systems
(Source: E Source)

Applicability

In general, dimming makes sense only where at least one of the following is true:

- **Lighting levels could be lowered** for long periods due to the presence of daylight.

- **Photoelectric daylighting controls are not employed**, despite having skylights or windows in most rooms.

- **Lighting could be dimmed** in response to lumen maintenance cycles, adaptation compensation or other factors.

- **Lights could be tuned** to a much lower lighting level most or all of the time.

Field Observations to Assess Feasibility

This section discusses observations to make and things to consider in selecting dimming controls. It also discusses things that can significantly influence first costs and cost-effectiveness.

Related to Applicability

Designers or retrofitters should determine as early as possible whether lighting controls will be appropriate and cost effective. Several clues can suggest a good candidate:

- **Incandescent fixtures** where changes in color rendition and slight increases in audible noise are not critical.

- **HID fixtures** where changes in color rendition and flicker are not a problem.

- **Non-instant-start** fluorescent lamps and ballasts

- **Skylights or windows** in most rooms.

- **Extended hours** in spaces where variation in illuminance between daylight and nighttime hours is a viable option

- **Spaces that are overlit** for the needs of the user and work task.

- **Recently installed or retrofitted** lighting systems at the beginning of their maintenance cycle.

Related to Energy Savings

To assure that energy will be saved, controlling electric light in synchrony with daylight should be done automatically, without human intervention. This requires photosensors that detect the available light and a controller that commands the dimmer to a particular setting based on the photosensor output.

Related to Implementation Cost

A retrofit must be installed easily to be cost-effective. Even if components are inexpensive, major hidden costs, including wiring, rewiring and labor can have a very negative impact. The following items should be considered.

- **Ceiling Materials:** Inspecting existing ceilings can often tell whether a retrofit is economically feasible. Exposed construction affords the ultimate ease of retrofit, and suspended lay-in acoustic panel ceilings are also a good indication. Gypsum wallboard and other "hard" ceilings are much more difficult to inspect and work on. Wiring in poured-in-place concrete virtually guarantees expensive rewiring.

- **Existing Wiring Methods:** It is important to determine whether the branch circuit layout or existing controls are compatible with the space partitions or use areas. The designer should select strategies that can be effective with minimum rewiring.

- **Wiring Voltages:** Mixing the wiring of systems with different voltages in the same electrical box is not permitted under some codes. Permitted or not, it is never advisable. Separate controls are required for each voltage system in each space.

- **Wiring Materials:** Wires must be in protective conduit. In most commercial buildings, power is fed to luminaires through wires in fixed or flexible conduits. Changing permanently constructed or "hard-wired" systems is generally labor intensive and not cost-effective; "softwire" flexible conduit systems may be easily reconfigured.

Estimation of Energy Savings

Energy savings from dimming controls depend greatly on the specific application, especially in regards to the base case assumptions. That is, the energy that would be used in the absence of controls must first be measured or estimated before energy savings can be calculated. Some studies indicate that between 6 a.m. and 6 p.m., daylighting controls can save 30-40 percent of the lighting energy in a typical office space daylit with vertical windows. Summer energy savings can be over 50 percent, especially if the system can dim efficiently over a wide range of light levels.

Savings from lumen maintenance are typically 12-20 percent of what would have been consumed had the lights operated at full power throughout the maintenance cycle. Adaptation compensation can cut power requirements as much as 80 percent for 10-12 hours per day. Demand-limiting strategies can reduce lighting levels 10 percent or more with minimal impact on visual performance or productivity. Because lighting can consume 40-50 percent of an office building's total electric load, even a slight reduction in lighting can bring significant savings.

Standard Savings Calculation

The following equation is recommended for use in estimating energy savings from lighting controls. Alternative equations and further information on estimating energy savings can be found in the CEE program documentation filed with the CPUC.

$$
\begin{aligned}
kW_{savings} &= \#\,fixtures\_controlled \\
&\times (Watts\ /\ fixture_{as-built}\ /\ 1000) \\
&\times Utilization\_factor \\
kWh_{savings} &= kW_{savings} \\
&\times \left(hours_{baseline} - hours_{as-built}\right) \\
&\times HCIF_{kW} \\
therm_{takeback} &= kW_{savings} \\
&\times \left(hours_{baseline} - hours_{as-built}\right) \\
&\times 0.034 \times HCIF_{heat} \\
&\div heating\_efficiency
\end{aligned}
$$

$HCIF_{kw}$ and $HCIF_{heat}$ are the heat/cool interaction factors which account for reduced electric air conditioning loads and increased gas heating loads, respectively, due to the decreased lighting energy. A table of these factors is in the program documentation.

Utilization_factor is the ratio of "on" fixtures to total installed fixtures; it accounts for fixtures or lamps which are not operational due to burned out lamps, failed ballasts, or not being turned on. The as-built hours term includes the equivalent duration of dimmed light fixtures at full light output.

Cost and Service Life

Factors That Influence Service Life

Dimming usually increases the life of standard incandescent lamps, but may reduced it in halogen lamps. Dimming may reduce the lifetime of instant-start lamps or ballasts. Dimming HID lamps has no pronounced effect on their rated life.

Factors That Influence First Cost

Decision-makers face three types of application choices: retrofit, renovation and new construction. Table 1 shows the five major cost factors to consider for each type.

Typical Service Life

The PG&E CEE program assumptions for photocells and electronic ballasts are 8 and 16 years, respectively.

Application	Initial Cost	Operating Cost	Installed Cost	Supply Circuit Layout	Building Design
Retrofit	√	√	√	√	√
Renovation	√	√			√
New Construction	√	√			

Table 1: Major Cost Factors for Lighting Control Applications
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Operation and Maintenance Requirements

A photoelectric lighting control system should not require significantly more maintenance than a standard system. But it is appropriate to check the controls' calibration if there are significant changes to interior furnishings and partitions. To obtain maximum benefit from lumen maintenance controls, group relamping should be practiced. Recalibration of the photosensors is not required after group relamping and/or cleaning. However, if fixtures very close to the control photosensor must be spot relamped because of lamp failure, it is good practice to recalibrate the affected photosensors.

The same maintenance principles that apply to luminaires and room surfaces should be followed for daylight photosensors. They should be cleaned periodically, ideally at the same time as the luminaires.

The following can be used as a checklist for a lighting control maintenance program:

- **Check photocells** and if necessary adjust for desired illumination levels. Refer to installation manual, if available, for proper procedures.

- **Check step dimming controllers** to ensure that time delays are set properly to avoid distracting lamp cycling.

- **Check, and calibrate if necessary,** the set screw adjusters on dimming ballasts to maintain desired lighting levels with respect to lumen depreciation.

Laws, Codes, and Regulations

California's Title 24 requires that lighting controls in non-residential enclosed spaces of 100 square feet or more have the ability to reduce lighting load by one-half while maintaining a reasonably uniform level of illuminance. Dimming controls are one way to meet this requirement.

Title 24 also requires that daylit areas in any enclosed space greater than 250 square feet have controls that control only luminaires in the daylit area and control at least 50 percent of the lamps or luminaires in the daylit area. Vertically daylit areas must be controlled separately from horizontally daylit areas.

Definitions of Key Terms

- **Color Rendering Index (of a Light Source) (CRI):** A measure of color shift objects undergo when illuminated by the light source, as compared with those same objects illuminated by a reference source of comparable color temperature.

- **Color Temperature (of a Light Source):** The absolute temperature of a blackbody radiator having a chromaticity equal to that of the light source.

- **Illuminance:** The lighting level, measured in footcandles or lux.

- **Instant-Start:** A lamp and ballast system designed to start a lamp without preheating electrode by providing a high-voltage spark.

- **Lumen Maintenance:** A lighting control strategy that uses a photocell to detect actual illuminance in a space and adjust the light level accordingly, so design illuminance is maintained at all times, not just at the end of the maintenance cycle.

References to More Information

1. California Energy Commission, "Daylighting and Lumen Maintenance," Advanced Lighting Guidelines, Second Edition, P400-93-014, March 1993.

2. California Energy Commission, "Retrofit Control Strategies," Advanced Lighting Guidelines, Second Edition, P400-93-014, March 1993.

3. Electric Power Research Institute, "Lighting Handbook for Utilities," EPRI EM-4423, April 1986.

4. E-Source, "Lighting," Technology Atlas Series, Volume 1, 1994.

5. Thumann, Albert, "Lighting Efficiency Applications," Fairmont Press, 1989.

6. Western Area Power Administration, "Electric Utility Guide to Marketing Efficient Lighting," October 1990.

Major Manufacturers

Advance Transformer Co.
10275 W. Higgins Rd.
Rosemont, IL. 60018
Tel (708) 390-5000
Fax (708) 390-5109

Magnetek Lighting and Electronic Products
200 Robin Rd.
Paramus, N.J. 07652
Tel (800) BALLAST
Fax (201) 967-0904

GE Lighting
Nela Park
Cleveland, Ohio 44112
Tel (216) 266-2653
Fax (216) 266-2780

Additional lists of lighting control manufacturers can be found in References 1,2 and 4. Information on this technology can also be found by contacting trade organizations, such as the National Electrical Manufacturer's Association and the Illuminating Engineering Society of North America.