The California State University
Office of the Chancellor

Indoor Lighting Design Guide

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The California State University
Office of the Chancellor
Capital Planning Design and Construction
401 Golden Shore, 2nd Floor
Long Beach, California 90802-4210
Attention: Wesley R. Morgan, Energy Program Manager
Telephone: (562) 951-4121
E-mail: wmorgan@calstate.edu

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1.0 INTRODUCTION

This guide is intended to provide campuses with useful, practical interior lighting design tools that are up to date, cost effective, and are intended to enable a comprehensive approach to lighting design and not simply retrofit. The guide is comprised of the following topics:

- CSU Policy
- Applicable Codes and Regulations
- Economic Analysis methods
- Design Goals and Approaches
- Lighting design and layout strategies
- Lighting control strategies
- Lighting technology selection
- Utility rebate/incentive programs
- Lighting technology and design resources

2.0 LIGHTING DESIGN GOALS AND REQUIREMENTS

2.1 CSU Policy

The policy driving the improvements in lighting design is Executive Order 987 and the CSU's alignment with the CEC's loading order for energy related investment, that is, energy efficiency comes first. For an entire facility, CSU buildings are required to exceed Title 24 (2010 edition) by 15-20% for new construction and 7.5-10% for renovation.

Specifically, the Title 24 requirements are as follows:

- With connection to a central chiller plant supported by a central Thermal Energy Storage (TES) system:
  - 20% Outperform for new construction
  - 10% Outperform for renovation construction
- Without connection to a central chiller plant supported by a central Thermal Energy Storage (TES) system;
  - 15% Outperform for new construction
  - 7.5% Outperform for renovation construction
- All individual T-24 calculations for building components (envelope, lighting, mechanical systems and domestic hot water) shall be neutral or positive. Individual negative compliance margins are not allowed.

Maintaining a pleasant campus environment is another important factor and must be balanced with cost effective operation and maintenance. These decisions will be made by a comprehensive life cycle cost benefit analysis and not based solely on simple payback.

2.2 Applicable Codes and Regulations

Indoor lighting and controls must comply with the California Energy Code, California Code of Regulations Title 24, Part 6. The Energy Code contains requirements regarding amount of power used for lighting, and lighting controls for indoor lighting. Lighting control devices, ballasts, and luminaires shall be certified that applicable components meet Energy Code and California Appliance Efficiency requirements.

All electrical and lighting installations must comply with the California Electrical Code, California Code of Regulations Title 24, Part 3, including but not limited to, wiring and grounding methods, and luminaire installation requirements.

The California Building Code, California Code of Regulations Title 24, Part 2, contains requirements pertaining to illumination requirements for egress lighting.

The California Green Building Standards Code, California Code of Regulations Title 24, Part 11, contains mandatory and voluntary measures necessary to meet CALGreen building tiers established in the Code. In general, a project must exceed California Energy Code requirements by 15% to be considered CALGreen Tier 1, and by 30% to be considered Tier 2.

2.3 Economic Analysis

Typically owners and designers will limit the level of economic analysis to the simple payback method. While quick and convenient, it does not provide the full economic impact necessary for decision makers and operators to be able to justify investment or develop budgetary forecasts that can adequately maintain modern lighting systems.

LCCA vs. Simple Payback

The National Institute of Standards and Technology (NIST) Handbook 135, 1995 edition, defines Life Cycle Cost (LCC) as "the total discounted dollar cost of owning, operating, maintaining, and disposing of a building or a building system" over a period of time. Life Cycle Cost Analysis (LCCA) can have various levels of complexity depending on the desired depth of understanding on the part of the owner and the sophistication of the system being evaluated. The key components of any LCCA are costs of ownership, the span of time across which the costs are realized, and the discount rate applied to those future costs relative to current values. This present versus future cost aspect is also commonly known as net present value (NPV). Taking each of those three components individually, common metrics for lighting products are used to develop the analysis. Cost items include first costs such as equipment purchase cost and cost to hire labor to install the systems. Ongoing costs are also considered which include replacement parts (lamps, ballasts, etc) as well as maintenance labor. The time span used in the analysis should correspond to the Effective Useful Life (EUL) as published and accepted by the owner's utility company. For lighting systems this can be anywhere from 5 to 20 years. The discount rate is set by the owner's typical financing abilities and is usually 5% to 6%. O&M Considerations

As part of a complete LCCA, the operational and maintenance O&M costs and resources of a campus must be taken into account. Conveniently, it is relatively easy to identify the ongoing costs for replacement parts for lighting systems such as lamps, ballasts, occupancy sensors, lenses, dust protectors, and many more. Campuses should also factor in whether it will use in-house trade labor or contract maintenance labor to conduct regular maintenance. When lighting systems are not maintained properly, they are prone to many issues. These include:

- reduced light output due to dust accumulation and lamp lumen depreciation leading to potentially underlit and thus unsafe areas
- premature lamp and/or ballast (or in the case of LEDs, driver failure) failures which leads to unnecessary replacement costs
- control systems can, over time and without recommissioning, stop functioning optimally and lead to premature failure and/or an unpleasant or unsafe environment

3.0 LIGHTING DESIGN GOALS

3.1 Provide Visual Comfort and Attractive Interior Spaces

Visually comforting spaces "appear" inviting, and have been shown to increase student or employee productivity. Indoor lighting systems should have adequate illumination levels for tasks performed in each space, lighting uniformity, and avoid glare or "cave effect" in order to enhance visual comfort.

Providing illumination to perform tasks is obviously one of the main functions of a lighting system. The interior lighting system should enable occupants to perform the intended tasks without straining due to inadequate illumination. A higher illumination level than necessary for a given space or task is not always beneficial. Successive revisions of lighting system recommended practices have reduced the illumination levels recommended for several tasks.

Appropriate lighting uniformity aids in visual comfort by reducing glare and noticeably dark/light "spots" within the area, requiring the eye to adjust less frequently to varying illumination and luminance levels. Illumination recommendations specify foot-candle values for ambient lighting throughout the area and for specific tasks.

3.2 Operation and Maintenance Best Practices

Operation and Maintenance considerations should be included during design and installation of an interior lighting system.

Interior lighting design should minimize the types of lamps and ballasts for a given area, wherever feasible, in order to limit the amount of replacement components that must be maintained in campus inventory. Lamps and ballasts are the items that are replaced most frequently in a lighting system; therefore maintenance costs to replace these items should be minimized. Interior lighting design should promote fixtures that provide easy access to these components. Use of long-life lamps and lamps that are suited for the installation environment reduces the frequency of replacement. Luminaires should be located in accessible locations to minimize the effort, time and equipment required to replace components. In addition, group relamping of fixtures should be encouraged and pursued where possible and applicable in existing facilities to reduce maintenance costs and provide uniform illumination levels.

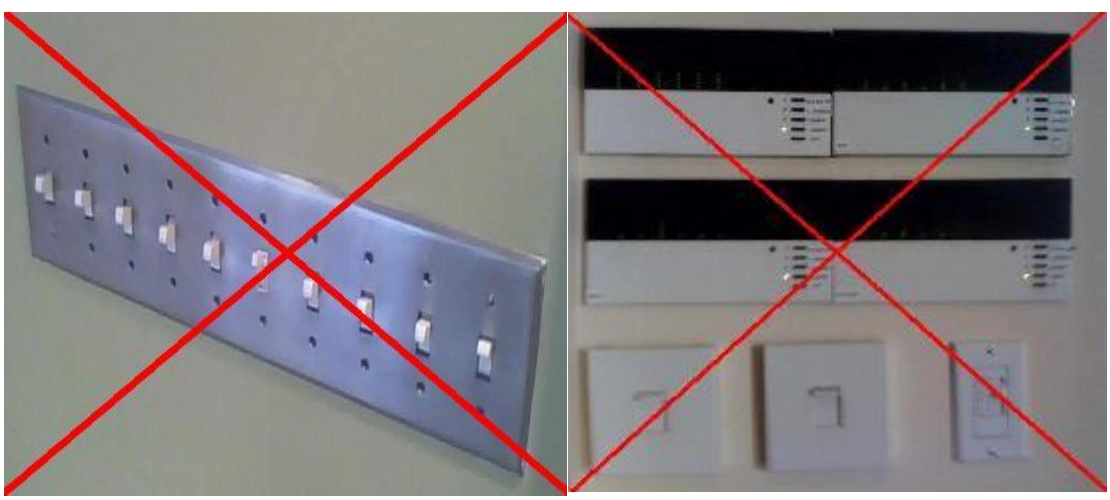
Accurate documentation of lighting systems that include fixture types, lamps/ballasts, and control systems is critical to reduce maintenance time and ensure the lighting systems continue to provide the desired illumination levels and the intended savings. Lighting control systems that include relays and panelboards should include diagrams and bills of material showing interconnections between controls, relay panels, and panelboards, and manufacturer's part numbers for each component. A system with outdated or inaccurate documentation will increase the time required to make repairs, resulting in higher maintenance costs.

3.3 Energy Efficiency

During interior lighting design, maximizing energy efficiency should be a high priority goal, once functionality and safety is adequately addressed. Specification of energy efficient luminaires, ballasts, and lamps, coupled with lighting system control methods that promote optimal control of the lighting depending on the area's function and its usage, should provide measurable energy savings. Title 24 Part 6 requirements were already addressed in sections 2.1 and 2.2. In addition, there are cases where those levels can be exceeded. Too often designers and/or contractors will recommend retrofit products that provide an attractive amount of energy savings at a relatively low cost to them and thus enable a simple design process and substantial profit margin. However, these recommendations are usually limited to one-to-one replacements of existing products and the addition of the occasional occupancy sensor. When considering a facility for lighting upgrade, a redesign rather than a simple retrofit should be taken into account. This can include rearranging fixtures or switching from one fixture type to another in order to optimize both light delivery as well as energy efficiency. An example of this would be upgrading a classroom from recessed 2x4 troffer fixtures to a two row pendant mounted linear fluorescent system with integrated controls. While first costs may be higher, the LCCA can often show a lower cost to the campus over the system's useful life.

3.4 Lighting Control Utility

Lighting controls should be sophisticated to save the maximum amount of energy given the interior environment and tasks performed, yet simple for occupants to operate. A lighting control system that is difficult to operate is worse than no system at all, because the controls will not be used as intended, energy savings might not be realized, and system payback will be negated.



Lighting controls should be intuitive, and marked with the area that is controlled or lighting scene. Systems that enable the occupants to easily select the appropriate amount of lighting required for the task or function will provide energy savings and greater visual comfort.

Lighting control systems exist in many varieties and can vary widely in sophistication and cost. They may be local controls such as simple occupancy sensors on a line voltage or low voltage circuit. Controls can also be fully integrated with local sensors for occupancy, daylight levels, and even CO2 sensors that report back to a centralized computer that can be programmed to fit the needs of occupants and maximize energy savings. As technology continues to improve, wireless controls are gaining acceptance. Such systems involve lower installation labor costs since they do not require extensive wiring to connect multiple sensors and fixtures. Wireless mesh networks provide easy installation and reprogramming as well as redundancy and thus safety and persistence of functionality.

Another important application of lighting controls involves utility Demand Response Programs that incentivize campuses to shed non-essential load during a critical peak event. By employing overrides and/or dimming control of large arrays of light fixtures combined with daylighting and task lighting, campuses can shed significant load during critical peak events while not drastically impacting occupants for brief periods of time.

4.0 LIGHTING DESIGN STRATEGIES

4.1 Campus and Building Aesthetics

Interior lighting systems should be coordinated to match the aesthetics of the building and campus. Lighting systems should highlight special architectural features within the building. Luminaires and controls should complement colors and materials of surfaces, such as walls and ceilings. Campuses may have an overall architectural theme that should be followed. Consult with the campus architect regarding campus standards for luminaires and controls, and any particular architectural periods or styles that are employed on the particular campus.

4.2 Appropriate Light Levels

Illumination levels are provided by IESNA and other organizations depending on tasks performed. Tasks that only involve identification of large objects, such as in a warehouse or closet, require less illumination than precision drafting tasks. However, in the past, lighting systems were designed to provide much more illumination than necessary. This was due to higher illumination levels recommended by IESNA, conservative depreciation factors taking into account dust accumulation and lamp aging, and a general “more is better” attitude to illumination. Illumination levels that are higher than required can result in glare and increased maintenance and operating (energy) costs, not only from the excessive number of luminaires or lamps within the space, but from increased air conditioning operation required to remove the heat generated by the luminaires.

Due to better, more reliable light sources and more robust controls, we are now able to minimize energy consumption during non-occupied periods and with proper assessment and design, provide optimal light levels during occupied times. Some of the main usage types on campuses are listed below. There are many nuances to assigning lighting levels due to wall and floor reflectivity, climate, age of occupants, time of day, etc. Additionally the amount of light on a horizontal surface, task plane illuminance, is not the only metric to consider. The amount of light on walls, vertical illuminance, is important as well to provide visual acuity and comfort. Additionally, the uniformity of light levels throughout a space is key. An example of the necessity for good uniformity is in a long hallway. If fixtures are spaced too far apart there will be sections of bright pools of light on the floor and walls alternating with dark sections, effectively a zebra strip pattern down the hallway. This can lead to slip and fall issues and other liabilities that can easily be avoided by proper lighting design. Campuses often fall into the trap of aiming for quick energy savings by de-lamping hallway fixtures, but as we have just discussed, this is not a best practice. A moderate amount of work from a reputable lighting designer/contractor can provide significant energy savings and proper light levels. Refer to the 10th Edition of the IESNA Lighting Handbook and the most recent version of the Recommended Practices from IESNA for specific lighting applications for greater detail.

Some examples of illumination levels for typical campus activities:

Campus Application	**Illumination** *footcandles (fc)*
Common areas leading to dark exterior surroundings (parking garages, foyers)	2-5
Entry ways (office buildings, libraries)	5-10
General office areas (copy rooms, break room)	10-15
Theaters, storage	15
Classrooms, offices, meeting areas	25-35
Library study areas, detailed office work	50
Laboratories, Mechanical Shops, Art Studios	50-100

4.3 Lighting for Visual Tasks

Visual Tasks encompass a wide range of applications. In a campus environment, this includes administrative and service areas, offices, libraries, laboratories, food service, and dormitory study lounges. As discussed previously, the nuances involved with proper lighting design are many and dependent on multiple factors. This section will provide some simple guidelines and metrics when considering areas in which visual tasks are commonly performed. In addition, please refer to the table in 4.2 for typical illuminance values for common campus applications.

Campus administrative areas can be large open spaces with long task planes, high ceilings, and large windows. They can also be small office environments with open desks, cubicles, and waiting areas. Typically a great deal of paperwork is processed in these areas and thus task plane illuminance should be similar to classrooms and other offices ranging from 20-40 footcandles depending on furniture type, wall reflectance, and daylighting. Lighting should also compliment the architectural style of the building especially when in larger atrium style designs.

Offices present another variety of challenges, especially when redesigning and retrofitting the space. Here again, visual tasks are many, including computer related activities which increasingly dominate day to day office activities. A key aspect to high quality lighting in office spaces is to provide proper contrast ratios between adjacent areas and minimize discomfort glare. Too often offices are lit with down lights and parabolic troffers which create a “cave effect”. This is discussed in greater detail in section 4.6. Some amount of indirect lighting and daylighting can reduce high contrast ratios and eye strain. Since campus staff is a diverse group of people, age of occupants is a major consideration. Some staff may have one or more disabilities which require special lighting needs as well. Some office staff may need supplemental lighting in the form of desk mounted or under cabinet mounted task lighting. Many high quality fluorescent and LED task lighting systems are now commercially available to accomplish this. Energy efficiency gains may be achieved when combining task and ambient lighting in this manner.

Libraries are unique in that a wide variety of visual tasks all take place in one building. Lighting must be sufficient for detailed map reading but not so intense as to make a student in a reading room or an audio listening station uncomfortable. Additionally, there may be art galleries and artifact displays that require special spot lighting. Therefore, fixture type and orientation will be a key consideration.

Laboratories typically require relatively high and uniform lighting levels due to the detailed nature of the work conducted therein. Depending on the type of research being done in the lab, special light fixtures with impact resistant lenses may be required. Light levels are expected to be approximately 50-100 fc. A combination of overhead and task lighting should be considered to reduce lighting power densities and thus energy consumption.

Dining commons and food service areas typically have a mix of commercial fluorescent lighting and high quality, high intensity retail style lighting such as halogen spot lights. Dining commons and university club rooms will often have lower light levels and a more subdued appearance. Fast food venues in a student union will be more brightly lit.

Student study lounges throughout dormitories should follow similar design paths as study rooms in libraries with illuminance levels between 30-40fc. Due to variable occupancy and traffic, occupancy sensors and daylight harvesting can provide added energy savings during day time periods.

Emphasis needs to be on selection of highly efficient fixtures (Efficiency of a fixture is defined as the amount of lumens delivered from a fixture divided by the amount of lumens produced by the lamps themselves) that deliver the same footcandle levels with lesser wattages to minimize energy consumption in all spaces.

4.4 Maintaining Lighting Uniformity/Visual Comfort, Color Rendition

Most people can recognize poor lighting quality though they may not be able to exactly describe what it is that actually causes discomfort or displeasure. Common causes of poor lighting quality are low color rendition, extreme color temperature, high contrast ratios, poor uniformity, and glare. Color rendition and color temperature are also addressed in section 6. Color rendition is basically the light source's ability to make reds very red, blues very blue, and so on. Color rendering index (CRI) is indicated as a value between one and 100. CSU best practices are such that light sources for interiors below 80CRI are not adequate. Color temperature is basically whether the source appears warm (reddish) or cool (white or bluish), and it is referred to as correlated color temperature (CCT). It is measured in degrees Kelvin (K). Most incandescent lamps are 2000K to 3000K. Most office fluorescent lamps are 3500K to 4100K. Low CRI and low CCT reduce visual acuity and put strain on the human eye leading to fatigue and reduced comfort and productivity.

The other main aspects of lighting quality noted above, contrast ratios, uniformity, and glare, are more related to fixture orientation and facility geometry. High contrast ratios mean that there is a significant difference between the luminance of the item you are looking at and the luminance of the background. This too can lead to disorientation and eye strain as the eye rapidly adjusts from one to the other. Uniformity is similar to contrast ratios in that it deals with varying light levels. While a desk and a floor do not need to be the same illuminance, the uniformity throughout each of those surfaces independently should be constant. Finally, glare is simply high intensity light striking the human eye either directly from a source or reflected from a shiny, or specular, surface. This can be mitigated by employing proper diffusers and lenses in fixtures and by using indirect lighting in applications such as office environments.

4.5 Coordinate with Interior Architectural Spaces and Features

Lighting systems should be coordinated with not only the ceiling-mounted equipment, but general features, furnishings and equipment located within the area. For example, luminaires in library stack areas should be located parallel to the shelving aisles, requiring coordination between electrical, architectural disciplines and the building occupants. Work areas or equipment where specific tasks will be performed should be provided with luminaires suitably located to provide the required illumination.

Colors and finishes of interior spaces, including walls, furniture, and floor and ceiling affect the reflectance of light from the surface. Darker colored objects and surfaces absorb light, resulting in less reflectance, while lighter colors reflect a greater amount of light. Differences in reflectance can affect the illuminance values on work surfaces and overall appearance of the area. Obtain architectural renderings and color or material samples for the area(s) to be constructed or renovated.

In the photograph below, the right side of the room appears brighter. Light-colored surfaces increase the perceived brightness of the space, and make the space more attractive to occupy. However, having all light-colored surfaces can cause the space to appear "bland" or "sterile". Dark-colored, contrasting areas in limited quantities may be desirable to add visual interest, and increase the sense of space within an area. (Illuminating Engineering Society of North America, 2000)

Glossy surfaces of furnishings are mirrorlike and are likely to produce reflected glare and distracting areas of brightness or reflections on work surfaces. Glossy work surfaces, such as desks, should be avoided.

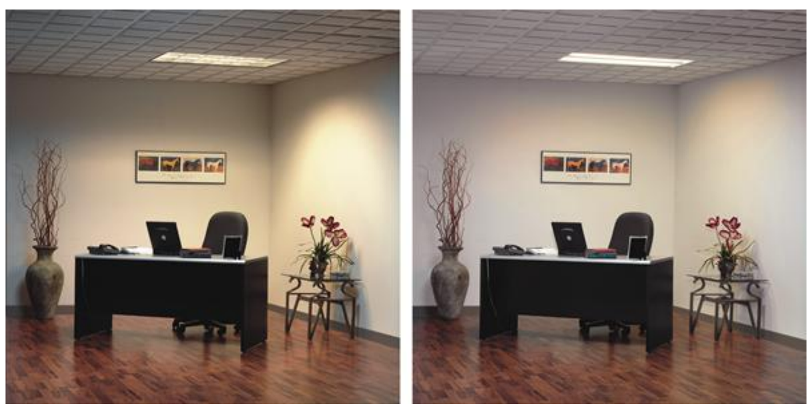
4.6 Direct and Indirect Lighting

Significant energy savings can be realized by reducing ambient lighting within a given area, such as an open office or computer laboratory, and providing task lighting at each desk. The task lighting can be switched on as desired to provide adequate illumination for the activity, while the softer ambient lighting increases visual comfort.

Recessed luminaires including certain types of troffer and "can" luminaires provide light that is primarily directed down. Unfortunately, very little light is directed on or along the ceiling, resulting in a "cave effect" of a dark ceiling and dark upper walls.

“Cave Effect” created by recessed luminaires.
Note the perceived dark ceiling and upper walls. (Knisley, 2004)

Luminaire manufacturers have responded to this phenomenon by designing models of can and troffer luminaires that provide an even, softer distribution of light, as well as models that can direct light further along the ceiling plane. Retrofit kits are available from several manufacturers for existing 2’ x 4’ and 2’ x 2’ troffers, and recessed can lights.



Light output from traditional parabolic recessed luminaire (left), illustrating the cave effect of a dark ceiling and upper walls.
Modern recessed luminaires (right), diffuse light, reducing or eliminating cave effect.
(DiLouie, 2009)

Typical recessed troffer luminaire retrofit kit,
intended to reduce glare and cave effect. (LaMar Lighting Company, 2011)

Classroom lighting is a large energy consumer on campuses and the lighting systems employed there are typically old style 2'x4' troffers with parabolic or prismatic lenses. There is significant light loss factor associated with this design and the similar cave effect noted above. Such applications often do not even have occupancy sensors or proper switch/controls arrangements to enable users to engage an A/V presentation mode or employ daylight harvesting. Numerous direct/indirect lighting systems with integrated low voltage or wireless controls now exist that can reduce “cave effect”, provide added functionality to users, and integrate occupancy and daylight sensors to maximize energy savings. Some of these products are noted in Appendix C. Pendant or cable hung fixtures, direct/indirect for common areas can dramatically improve visual comfort and functionality of the space. Proper maintenance of fixtures should be addressed to ensure optimal output.

Office lighting is also a large portion of campus lighting electricity use and represents an even greater diversity of application styles than classroom lighting. Spaces are often underlit, overlit, users experience glare, shadowing from improper fixture placements and many other design issues that impact user comfort. Many systems are also older generation and not in line with CSU best practices. Simply conducting a lamp and ballast change out will address a portion of the energy efficiency aspect of the problem but not the user functionality and comfort item. Referring to the “redesign” not “retrofit” concept again as a best practice, pendant or cable hung direct/indirect fixtures coupled with high efficiency task lighting can significantly improve efficiency as well as user comfort and control. Light output and luminance from a source follows the inverse square law. That is, for every unit of distance from the source, the illuminance at a target plane is inversely proportional to the square of that distance. As an example, moving a light 4 feet farther than its current position reduces the illuminance to 1/16 its original value. Thus, if all the light sources in an office are at ceiling level, more output is required to provide adequate light on a desk. However, by adding task lighting close to the desk surface, lower power is required to provide the same illuminance levels. This results in reducing overhead lighting power and overall power density. Ensuring occupancy sensors and daylight harvesting is employed can enable greater savings.

4.7 Safety and Emergency Lighting

Per the California Building Code, means of egress illumination shall not be less than 1 foot-candle (fc) at the walking surface. Exceptions are made for residential dwelling and sleeping units, accessory (Group U) buildings such as sheds or barns, and certain areas within theaters and auditoriums. Emergency lighting systems shall provide illumination for at least 90 minutes upon loss of normal building power, and shall be arranged to provide initial illumination that is at least an average of 1 fc, and a minimum of 0.1 fc at any point along a path of egress. For auditoriums, theaters, concert or opera halls and similar assembly occupancies, the illumination at the walking surface is permitted to be reduced during performances to not less than 0.2 foot-candle (2.15 lux), provided that the required illumination is automatically restored upon activation of a premises' fire alarm system where such a system is provided. Refer to the California Building Code for specific areas requiring emergency illumination.

Emergency power sources need to be provided to meet the 90-minute illumination requirement. Luminaires are available from several manufacturers that include an integral battery. Upon loss of power, the battery will keep one or more lamps illuminated to provide egress lighting. Providing luminaires with individual batteries is suitable for small buildings with a limited number of luminaires required for egress lighting. For larger buildings or spaces, connecting certain luminaires to an emergency uninterruptible power supply and/or generator may be more practical than providing each luminaire with a battery. In large buildings or spaces, a single UPS or generator will have reduced maintenance costs compared to a large number of individual batteries in luminaires.

If an automatic lighting control or dimming system is provided within the building, ensure the controls have an interface to the emergency power source. Some lighting controls require an interface module to override the normal lighting control schedules during an emergency. Other lighting controls will automatically default to “full brightness” upon loss of normal power. Consult with the controls manufacturer to ensure the lighting controls are properly integrated with the emergency power source to provide adequate egress illumination upon loss of normal power.

4.8 Lighting for Special Needs and for the Physically Challenged

Illumination and visual requirements vary considerably with the age and needs of the occupants. Increased lighting is required for older persons because the retinal illuminance decreases with age. Retinal illuminance, defined as the luminous flux incident on the retina, is a measure of the perceived “brightness” of a visual stimulus. The retinal illuminance of a typical 60- to 80-year old person is about one-third that of a typical 20-year person. (Illuminating Engineering Society of North America, 2000) The decrease in retinal illuminance is due to absorption and thickening of the eye lens and a reduction in pupil size. Since the retinal illuminance is decreased, higher task illuminances are required than typical values. Special consideration is needed for areas where persons with special needs will be located. In these areas increased illuminance levels may be needed. However, increasing the illumination levels also intensifies glare, therefore, a greater focus to minimize glare in these areas is needed.

5.0 LIGHTING CONTROL STRATEGIES

5.1 Applicable Codes for Lighting Control

The California Building Energy Efficiency Standards and California Energy Code are the primary codes governing lighting controls in the State of California. The standards are produced by the California Energy Commission. Regulations regarding types of controllers and their locations and installation are provided for residential and non-residential buildings.

The California Green Building Standards Code, California Code of Regulations Title 24, Part 11, contains mandatory and voluntary measures necessary to meet CALGreen building tiers established in the Code. In general, a project must exceed California Energy Code requirements by 15% to be considered CALGreen Tier 1, and by 30% to be considered Tier 2.

Note that locations and types of lighting controls are restricted in areas where qualified personnel may service or inspect equipment, such as electrical and mechanical rooms. In these areas, controls shall be readily accessible, and shall not be controlled solely by automatic devices.

5.2 Lighting Controls Selection Process

The requirements provided in the California Building Energy Efficiency Standards and California Energy Code should be followed at a minimum. The standards dictate vacancy (or occupancy) sensors or other means to automatically turn off lighting, bi-level switching of luminaires within a given room, and separate switching of luminaires located adjacent to windows. These controls will provide energy savings by switching off lights during periods of inactivity, and encouraging users to switch on only the lights that are needed to provide proper illumination.

Additional systems can be specified that incorporate daylight sensors, dimming ballasts, including fully networkable dimming systems controlled by a master server. The more features that are included in the lighting controls provide increased opportunities for energy savings. However, the initial costs of installation and maintenance increase with the complexity of the lighting control system.

Table 5.2 provides a comparison between the minimum requirements specified in the California Energy Code, with more advanced lighting control systems currently on the market.

Table 5.2 Lighting Controls Comparison			
Control System	**Components**	**Pros**	**Cons**
California Energy Code Minimum Requirements	1. Occupancy Sensor 2. Alternate (A/B) Switching of Luminaires 3. Separate switching of luminaires by windows (C switch leg)	• Low Cost • Ease of maintenance-components can be provided by virtually any major manufacturer.	• No automatic daylight harvesting • Realistically, "C" switch will not be turned off.
Daylight Switching	1. Occupancy Sensor 2. Alternate (A/B) Switching of Luminaires 3. Daylight Sensor to switch on/off luminaires by windows (C switch leg)	• Low Cost • Automatic switching of "C" leg results in energy savings	• When "C" leg switches off or on, it is distracting to occupants in room.
Dimmable Controls	1. Occupancy Sensor 2. Daylight Sensor 3. Wall-Mounted Dimmer Controls 4. 0-10V Dimming Ballasts	• Dimming results in smoother transition of lights depending on available daylight. Less disruption compared to switching of lights.	• Increased costs to provide dimming ballasts.
Dimmable Controls with Distributed Panel	1. Occupancy Sensor 2. Daylight Sensor 3. Wall-Mounted Digital Dimmer Controls 4. 0-10V Dimming Ballasts 5. Relay Panel(s)	• More precise control of dimming and automatic switching • Relay Panels are networkable • Several manufacturers offer lifetime programming assistance for relay panel.	• Increased costs to provide and maintain relay control panels. • Components used in relay control panels are often unique to each manufacturer.

Table 5.2
Lighting Controls Comparison

Control System	Components	Pros	Cons
Addressable Dimming	1. Addressable Occupancy Sensor 2. Addressable Daylight Sensor 3. Wall-Mounted Addressable Digital Dimmer Controls 4. Addressable Dimming Ballasts 5. Module to power and control dimmer signaling circuits.	• Reprogrammable-can be reconfigured easily when needed • Easily adaptable to changing room uses. • Lights can be programmed to not exceed 90% power. Immediate 10% in energy savings with minimal perception of change in level levels	• Increased costs to provide and maintain addressable dimming ballasts and components. • No real standard in addressable components. Components are often unique to each manufacturer, and may not be interchangeable.
Addressable Dimming with Computer Integration	1. Addressable Occupancy Sensor 2. Addressable Daylight Sensor 3. Wall-Mounted Addressable Digital Dimmer Controls 4. Addressable Dimming Ballasts 5. Relay/Dimmer Control Panel(s) 6. Lighting Network Control Panel 7. Server with lighting control software installed	Same benefits of Addressable Dimming above, plus: • Remote control of any addressable luminaire(s) • Load Shedding • Reporting of power usage • Reporting of failed ballasts or controls	Same disadvantages as Addressable Dimming above, plus: • Increased costs to provide and maintain server and lighting control software • Increased learning curve for operations/ maintenance staff. Factory training and commissioning is often required.

5.3 Specifying Control Systems for Building and Energy Managers

Campus standards regarding control schemes, components, and manufacturers should be developed, maintained or updated, and implemented to standardize system operation and maintenance. Campuses may have standards regarding networking of components, and integration into the building or campus energy management system. These standards should be followed when specifying equipment for retrofit or new construction.

If there are no restrictions on suppliers, such as proprietary legacy systems, for a given lighting control system, components from well-established firms should be specified. Since several components in a lighting control system are vendor-specific, particularly in dimmable and addressable systems, it should be verified that the vendor will be able to provide replacement components over the expected life of the lighting control system.

Several vendors also provide startup programming and commissioning, as well as lifetime programming assistance. Warranty and training options should be considered. Technical support options should be evaluated and specified. Manufacturer technical support may be needed outside normal business hours, particularly in campus buildings that operate beyond normal working hours. 24-hour manufacturer technical support is an important factor and consideration when selecting lighting control systems for essential campus buildings.

5.4 Lighting Control System Maintenance

Lighting control systems, like any building system, require periodic inspection, maintenance, calibration, and retro-commissioning. In order to achieve energy savings, it is essential that all lighting control systems are regularly inspected and tested for proper operation. The more complex the lighting control system, the more crucial the need for periodic inspection, because of the increased number of components in the system. Failure of any of these components can negate the energy savings realized by the system. For example, relays may become stuck in the "on" position, or a sensor may fail, resulting in lights remaining on for long periods of time. Occupancy and daylight sensors may become mis-aligned, resulting in false triggers.

Periodic inspections should include functional tests of all components in a lighting control system to ensure proper operation of components. The following components should be included in the inspection:

- Wall-mounted lighting controls for a given area – Where multiple switches are ganged, switches or buttons should be marked with the area that is controlled.
- Occupancy Sensors – Ensure good physical condition, proper operation and adequate sensor coverage area.
- Daylight Sensors/Photocells – Ensure that the sensor is aimed correctly, and that no obstructions exist that can create false triggers.
- Time Switches – Inspect for good physical condition, and that time durations are appropriate for the intended use.
- Theme-based lighting controls – Ensure all scenes operate as intended, and that each scene provides illumination appropriate for the task. Wall-

mounted controls should be inspected for good physical condition, and that each scene is properly identified. If there are handheld remote lighting controls, ensure that each remote control functions properly.

- All relays in each lighting control panel should be tested for proper operation. If the relay state is displayed on a screen or server, ensure that the state is properly reported. Relay panel schedules should be posted in the panel, and updated when the relay or branch circuit connections are modified.
- Server and any lighting control system software installed. If the lighting control software is in command of an addressable system, server logs should be reviewed for any ballast failures or communication errors.

It is recommended that all components in a lighting control system be inspected once a year, or in accordance with manufacturer's instructions. An inadequately maintained lighting control system may experience component mis-operation or failures resulting in a loss of energy savings. Properly maintained systems will ensure that specified energy savings are realized throughout the life of the system.

5.5 Lighting Control Components

A. Wall Switches

Wall Switches are the most basic component for any lighting control system, with the lowest material and maintenance costs. Standard toggle switches may waste energy if lights are left "on" while spaces are unoccupied for extended periods of time. For this reason, the California Energy Code requires every floor in a building be equipped with separate automatic controls to shut off the lighting. To comply with the California Energy Code, standard toggle switches can be paired with an occupant sensor, automatic time switch, or other device capable of automatically shutting off lighting.

Note that lighting in rooms accessible only to qualified personnel, such as electrical and mechanical rooms, shall not be controlled entirely by automatic means. Standard toggle switches can be installed in electrical and mechanical rooms, readily accessible to qualified personnel, in order to provide proper illumination while work is being performed on equipment.

B. Occupancy/Vacancy Sensors

Occupancy and vacancy sensors are effective for realizing energy savings in new or existing lighting systems. Occupancy sensors turn on lighting automatically when a person enters the area, and turn off lighting after a period of time during which no motion was detected. Vacancy sensors turn off lighting after a period of inactivity; they do not turn on lighting automatically. Vacancy sensors require the user to manually turn on lighting. These sensors are simple to install and maintain, and can either be standalone or integrated with a networked lighting control system. Ceiling-mount and wall-mount sensors are available. The specific type of sensor to be used will depend on the room dimensions and shape, intended use of the room, and the furniture or equipment located within.

The two major sensor technologies include passive infrared (PIR), and ultrasonic. Both technologies are suitable for certain applications. Use of a sensor technology that is not suitable for the environment can result in false activations. Examples of sensor mis-operations include sensors turning off lights prematurely, or sensors poorly detecting occupancy. Dual-technology sensors are available from several manufacturers that combine PIR and ultrasonic technologies into the one sensor.

PIR is designed to detect motion from a heat-emitting source, such as a person moving into the room, within the sensor's field of view. PIR sensors have segmented lenses that cause the sensor to view the area with several bands of vision. For units to sense motion, the person must cross between two bands. Because of the bands of vision, the sensor does not view the area in a continuous manner. As the distance from the sensor increases, the bands spread apart, requiring greater motion in order to cross two bands and activate the sensor. Figure 5.1 shows the coverage area of a typical PIR sensor.

PIR sensors best detect major motion within its line of sight, such as persons walking through an area. PIR sensors are therefore best suited for areas of major motion where persons are moving within the sensor's coverage area, such as corridors and lobbies.

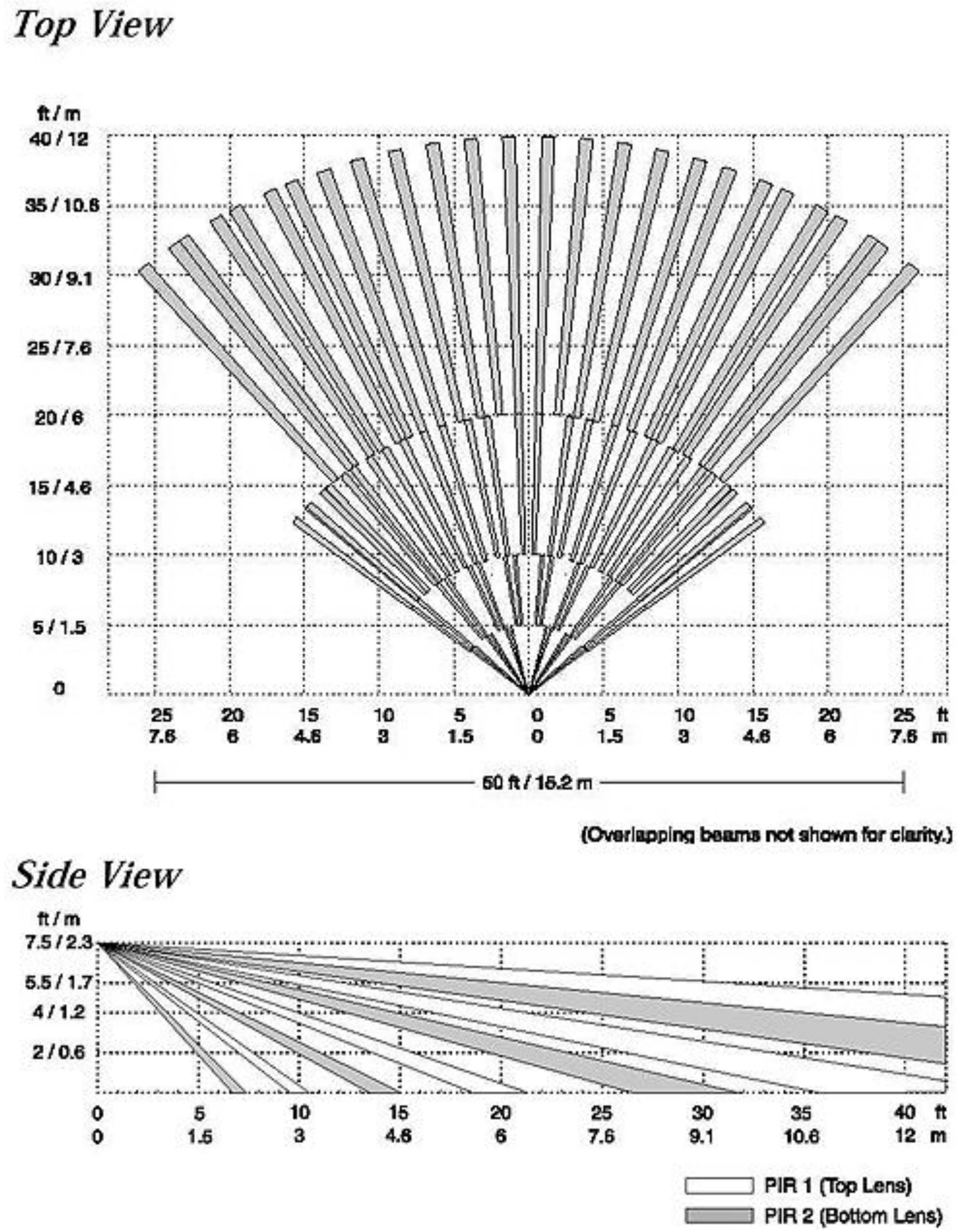


Figure 5.1 – Example beam spread from PIR sensor

Ultrasonic sensors emit low intensity, inaudible sound and detect changes in sound waves caused by motion. Since ultrasonic detectors rely on changes in sound, they are not line-of-sight dependent. Ultrasonic detectors sense minor movement, such as a person reaching for a telephone, moving in a chair, or picking up an item. Because ultrasonic detectors fill a room with inaudible sound and are not line-of-sight dependent, they are ideal for oddly shaped rooms or rooms with partitions, such as restrooms and open area offices with cubicles. There are no blind spots or gaps in the coverage pattern as with PIR sensors. However, ultrasonic detectors do not perform well when mounted on very high ceilings or areas subject to extreme air flow or vibration. Ultrasonic sensors should be located away from HVAC registers, as the air flow can cause false sensing of motion.

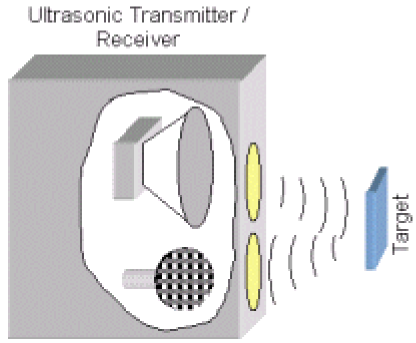


Figure 5.2 – Operating principle of ultrasonic detector

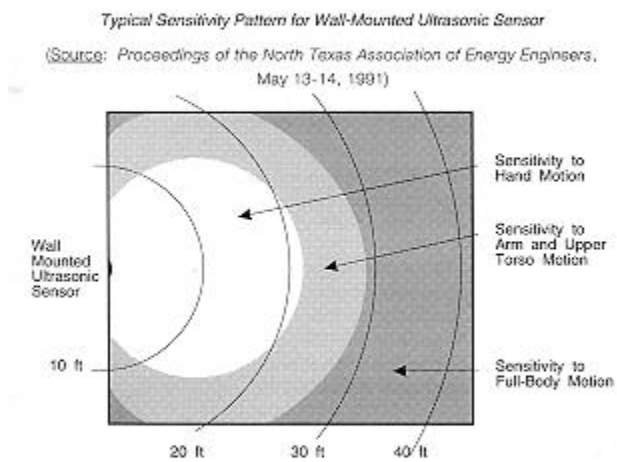


Figure 5.3 – Typical ultrasonic coverage area

Dual-technology sensors are available from several manufacturers that include both PIR and ultrasonic sensors. By having both technologies included in the same sensor, false triggers (either ON or OFF) are reduced. The sensors are ideal for areas that include both major and minor motion. For example, in a classroom, the first motion detected is primarily major, as students enter the classroom. Once the class commences, the motion is primarily minor, since students are usually seated throughout the lesson. Dual-technology sensors can detect both major and minor motion, resulting in fewer false triggers.

The following factors should be considered when specifying and locating sensors, as they will affect sensor performance:

- Sensor mounting height and coverage area. Refer to manufacturer's specification sheets for coverage patterns and areas.
- Type of motion typical to the space (major or minor), and location and activities of occupants.
- Room/space dimension and shape.
- Location of walls, doors, windows and drapes or blinds.
- Location of shelves, large equipment, or items which may block sensor coverage.
- Ceiling height.
- Partition location and height.
- Location of HVAC ducts, registers, and fans.
- Location and types of luminaires. Pendant-mounted luminaries could block sensor coverage.
- Equipment which may vibrate or emit different sounds during normal operation.
- Extreme temperature conditions.

Occupancy sensors can be either standalone, or provide input to a lighting control network. Standalone sensors include a relay or switch pack that switches the line voltage conductor, and also provides control power to the sensor. There is a minimum of additional wiring required to install standalone sensors. Existing toggle switches can remain to provide manual control of lighting. These sensors can be easily retrofit in existing buildings, and are a cost-effective method of providing automatic switching in new construction. Refer to Figure 5.4 for a typical sensor wiring diagram. With standalone sensors, there is no way to remotely examine a sensor for proper operation since there is no network communication provided. Maintenance personnel need to visit the standalone sensor to verify proper operation.

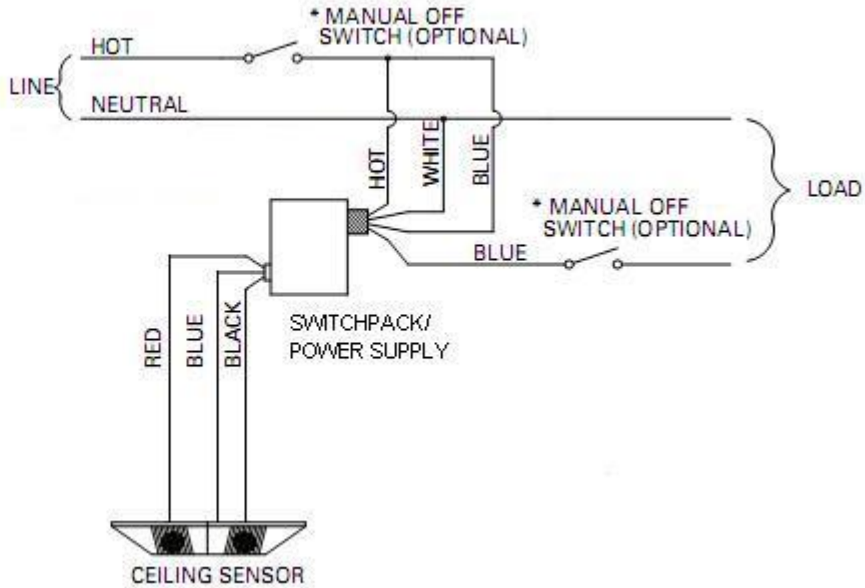


Figure 5.4 – Typical Occupancy Sensor Wiring

Wireless sensors have recently been introduced from several manufacturers. These sensors eliminate the wiring between the sensor and switchpack or relay, transmitting occupancy status wirelessly over a dedicated communication frequency. These sensors are well-suited for retrofit applications, since new wiring does not have to be installed to each sensor. In addition, the sensors can be easily relocated to provide better coverage. Most wireless sensors use a long-life battery as a power source. The battery in a wireless sensor lasts between 5-10 years. Many sensors will provide an indication, such as flash an LED on the sensor, that the battery needs replacement.

Wireless sensors require careful attention to sensor placement, interference and range of wireless communication. For more information, refer to Section 5.6.

Some manufacturers have introduced wireless sensors that are powered from solar panels, such as the sensor shown in Figure 5.5. These sensors are able to operate off ambient lighting, avoiding the maintenance requirement when a sensor uses a battery (Batteries can be installed optionally, as a backup to the solar panels). Currently, solar-powered PIR sensors are only available. Solar-powered ultrasonic sensors are not currently available because the power requirements to emit the sound waves required for sensing are too great. Improvements in solar panel efficiency may allow solar-powered ultrasonic sensors to become available in the future.

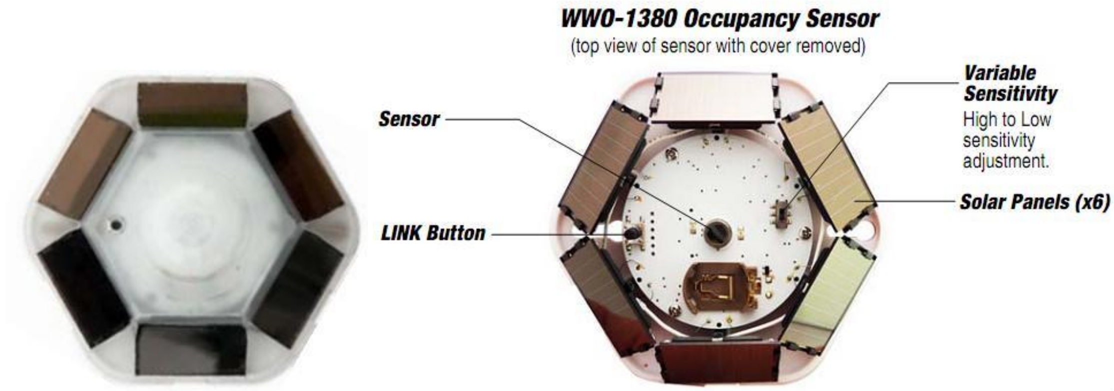


Figure 5.5 – Wireless, solar-powered occupancy sensor
(Douglas Lighting Controls, 2011)

Occupancy sensors should be inspected after installation to ensure adequate coverage and sensitivity. Some sensors include adjustment knobs that vary the level of sensitivity and time delay. The sensitivity and time delay should be adjusted to match the activity level within the room. The sensor should be specified based on compatibility with the ballast or switch pack to be controlled.

C. Daylight Sensors

Daylight sensors used in a “daylight harvesting” control strategy is one of the most cost-effective means to conserve energy. Daylight harvesting reduces electric lighting load when there is available sunlight. According to IESNA RP-5-99, it is estimated that daylighting controls can reduce energy use up to 30%. Less air conditioning will be required since luminaires controlled by daylight sensors will be switched off when not needed. Lower maintenance costs may also be realized by prolonging lamp life in luminaires controlled by daylight sensors.

Daylighting controls are required by the California Energy Code in areas illuminated by a skylight. All of the general lighting in the skylit area shall be controlled by an automatic daylighting control device. General lighting in primary sidelit areas shall also be controlled independently by an automatic daylighting control device.

Daylight harvesting controls may be “closed loop” or “open loop” systems. The systems differ in sensor locations and illumination that is measured.

Closed-loop systems typically have sensors aimed at the working surfaces. These sensors measure the combined contribution to light level from both daylight and the electric lighting system, then adjust light output to maintain the desired level of illumination. Because the photosensor measures the electric lighting system’s light output, it “sees” the results of its adjustment and may make further adjustments based on this feedback—creating a closed loop.

Open-loop systems measure only the incoming daylight, not the contribution from the electric lighting. The photosensor does not see any electric light.

Typically, photosensors are mounted outside the building or inside near a window. In the case of a switching system, the photosensor signals the lights to shut off when daylight reaches a predetermined level. In the case of a dimming system, the photosensor measures incoming daylight and signals a controller to proportionately dim the lights based on the estimated daylight contribution.

The primary advantage of open-loop systems is that they are able to control multiple fixture groups from a single photosensor, as opposed to closed-loop systems, which require that each area be controlled by a dedicated photosensor. Because a single photosensor can be used for control of multiple areas, open-loop systems are generally economical for control of larger areas (e.g., an open office). Open-loop systems are also recommended for high-bay applications or large lobbies with skylights, as the photosensor can be mounted in the lightwell of the skylight, while with a closed-loop system, it may be difficult to find a good photosensor viewing location in such areas. In addition, open-loop systems provide greater calibration flexibility than most closed-loop systems, and are less prone to errors in placement of the sensor or its field of view.

There are two main disadvantages of open-loop systems. The first is that they respond only to exterior daylight availability and not actual daylight contribution in a space; if an occupant closes window blinds, the system will not recognize the change and dim the lights anyway. The other main disadvantage is that erroneous readings of illumination levels may cause problems throughout the controlled space. For example, a tree or other obstruction may block the sensor, or excessive glare from adjacent windows may cause an abnormally high reading. All controlled lights will respond to these erroneous readings, which may result in inadequate or excessive illumination in areas. Local override switches for the lighting may be useful. In addition, in applications where a single area is controlled, open-loop systems do not provide cost savings over closed-loop systems.

The primary advantage of closed-loop systems is that unlike open-loop systems, they measure actual light level on work surfaces, so they will respond to users opening and closing blinds, obstructions casting a shadow such as nearby trees, and other changing conditions. As a result, closed-loop systems are more suitable for control of smaller spaces, or larger spaces with low ceilings and window blinds, such as an open office. However, there is more setup required; closed-loop systems must be configured with light level readings under both daytime and nighttime (or approximating nighttime—i.e., with blinds closed) conditions. Changes in the layout of furniture or interior reflectance (i.e. wall or floor/carpet colors) in the controlled area may require sensor re-calibration.

Most daylight sensors include an adjustable low threshold as well as high threshold. As the sensor detects a light level that is diminishing and corresponds with the LOW setpoint, the controller switches on lamps. When the sensor detects an increasing light level corresponding with the HIGH setpoint, the controller switches off (or dims) lamps. The two setpoints prevent the sensor from interpreting the light emitted from the luminaires as daylight and avoid cycling lamps ON and OFF repeatedly.

Daylight sensors are paired with a relay/switch pack to switch lamps on or off, or a dimming controller to dim lamps. Daylight sensors are most effective when the luminaires controlled are dimmable. With a dimmable lighting system, the light output from the lamps can be continuously varied depending on available daylight to provide a constant foot-candle value on work surfaces. The dimmable lighting system can provide a proper combination of electric light and daylight to provide constant illumination within the area controlled. If daylight sensors control switched, non-dimmable luminaires, the lamps switching on or off may be a distraction to occupants, particularly in weather conditions where the amount of daylighting may vary frequently. Much like occupancy sensors, daylight sensors can be either standalone, or integrate into a networkable lighting control system. Refer to Figures 5.6 and 5.7 for typical daylight sensor wiring with switch packs and dimmable ballasts.

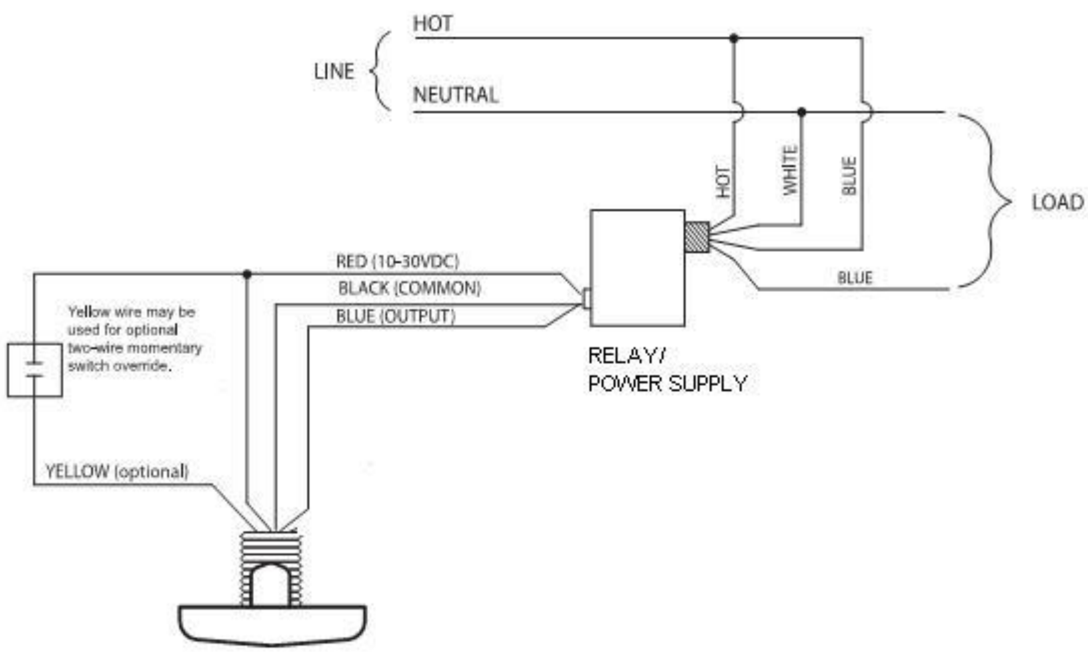


Figure 5.6 – Typical Daylight Sensor Wiring

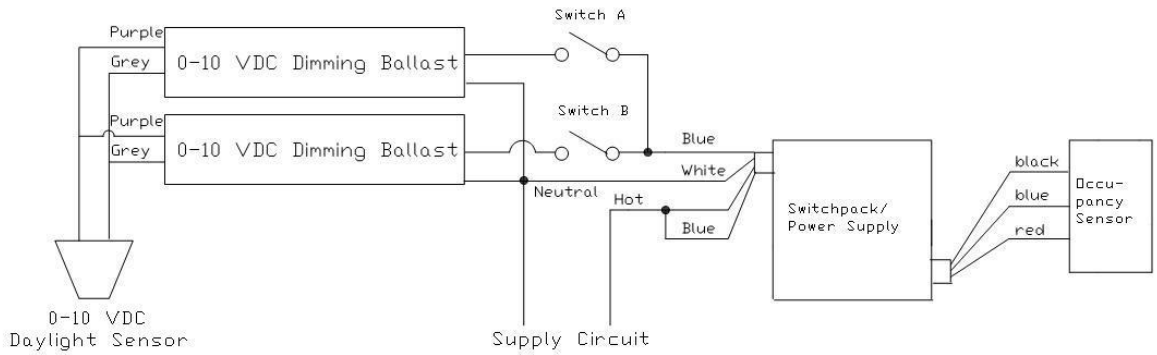


Figure 5.7 – Typical Daylight Sensor Wiring with Occupancy Sensor and Dimming Ballasts

Wireless daylight sensors have recently been introduced from several manufacturers. Similar to wireless occupancy sensors, communication between the switchpack or relay and sensor is performed using radio signals, eliminating control wiring between the components. Sensors may be powered from a long-life battery, or solar panels, or a combination of both. Solar-powered daylight sensors are ideal for the application, since these sensors will be located in areas of high ambient light.

For details on wireless communication and sensor placement considerations throughout a building, refer to Section 5.6.

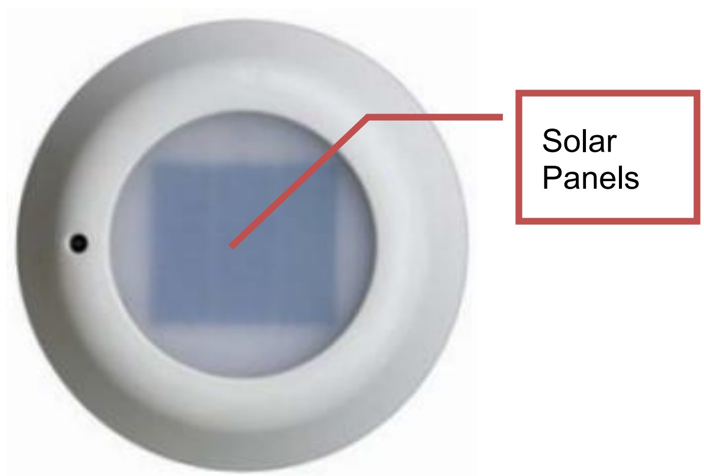


Figure 5.8 – Solar-Powered Photosensor (Douglas Lighting Controls, 2011)

Photosensors should be located to accurately measure the available daylight for the given area. The sensor location should avoid obstructions that can affect sensor measurements, such as tree branches or adjacent buildings. After installation, the light level setpoints on each sensor should be adjusted to avoid unnecessary cycling of the lamps. The sensor should be specified based on compatibility with the ballast or switch pack to be controlled. Proper operation after installation must be verified.

D. Time Clocks

Time clocks can be utilized to automatically turn off lighting circuits during periods when the building floors or areas are unoccupied. To comply with California Energy Code requirements, time clocks shall be astronomic, and capable of programming different schedules for weekdays and weekends. Time clocks shall also have program backup capabilities that prevent the loss of the device's schedules for at least 7 days, and the device's time and date setting for at least 72 hours if normal power is interrupted. It is recommended that schedules be arranged to maximize energy savings while providing sufficient illumination for activities that typically occur after normal campus/facility hours.

E. Dimming Controls

Dimming switches provide local control of lighting and offer an energy savings opportunity. Verify with the dimmer manufacturer that the specified dimmer is suitable for use with the lamp/ballast to be controlled. In some cases, lamps should not be connected to a dimming switch such as certain compact fluorescent types. Dimming controls also have a maximum load rating that is typically less than standard toggle switches. Verify that the load to be controlled does not exceed the rating of the dimming controls.

F. Theme-Based Controls

Theme-based controls provide ease in lighting management by turning lamps on or off, or dimming to pre-set levels in order to provide illumination appropriate for the theme or function. For example, a conference room may require high levels of illumination during a meeting. During an audio/visual presentation, the room should be darkened. Theme-based controls can be provided with buttons on the controllers marked "Meeting" and "Presentation", along with other control selections. Before a presentation begins, the occupant can press the "Presentation" button, and the lights in the room will dim accordingly to darken the room. At the conclusion of the presentation, the occupant can then press the "Meeting" button to turn on or brighten lights within the room. Theme-based controls offer precise control of the lighting within an area by pressing one button to achieve desired illumination levels. These types of controls avoid the need to adjust multiple switches or dimming controls to achieve desired illumination levels.

Controls in each space should be marked with the space or luminaires that are controlled. Several manufacturers offer engraving on control buttons for identification, which can be performed for little to no additional charge. Clear identification of areas or luminaires controlled encourages occupants to use the lighting control system to suit their needs. Energy savings will be realized when occupants adjust the controls to provide only the desired amount of light.

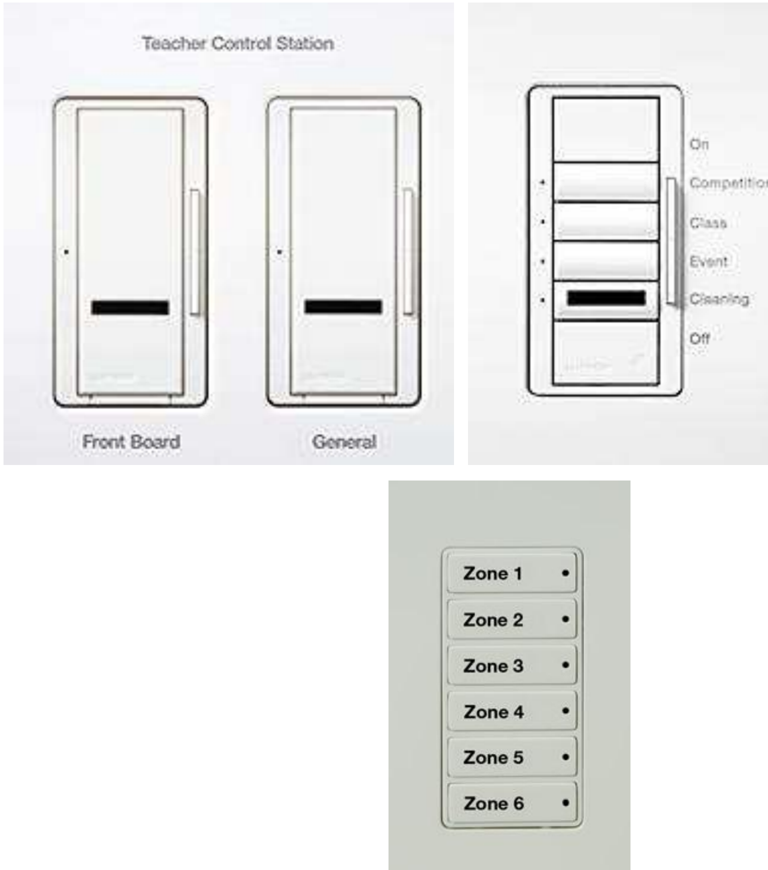


Figure 5.9 – Examples of wall-mounted controls that include identification of areas controlled, or pre-set lighting "themes" (Lutron)

G. Personal Remote Controls

Remote controls using infrared technology are available from several manufacturers. Remote controls use a handheld control that transmits to an infrared sensor mounted in the luminaire. The remote control gives occupants control over the lighting in the given area without requiring additional wall-mounted controls. For the greatest flexibility, the infrared receivers communicate with addressable ballasts to control specific luminaires.

Remote control schemes are ideal for office areas, lecture halls, and conference rooms. In open office areas with cubicles or partitions, each occupant can be provided with a remote control that can be used to adjust the lighting within his or her space. Each occupant will be able to adjust the lighting to his or her needs and preferences, resulting in less glare and visual discomfort, energy savings, and greater productivity. Remote control systems are also suited for conference rooms and lecture halls. The presenter can use the remote control to adjust the lighting without interrupting the presentation.

Figure 5.10 – Examples of handheld lighting controls and infrared receiver. (Lutron, Blue Ridge Technologies)

Software-based lighting controls are available from several manufacturers that provide personal lighting control within a given area. In this control scheme, software plug-ins are installed on a personal computer within the space to be controlled. The software plug-in has lighting control options that the computer user can select. Refer to Figure 5.11 for a software plug-in example. The personal computer then sends a command over the building local area network to the lighting control panel, which is also connected to the network. The lighting control panel sends commands to the luminaires and lamps in the space to increase or lower intensity depending on the option selected on the personal computer.

Figure 5.11 – Example of personal computer lighting control software (Exergy Controls, 2009)

These personal controls require networkable lighting control panels and addressable ballasts in each luminaire. During commissioning and initial programming, luminaires and lamps are mapped to each personal computer to provide control over the luminaires in proximity of the personal computer. This control scheme is suitable for open-office areas, where each cubicle is likely to have a personal computer present. Occupants can then be in control of luminaires located within their cubicle. Software-based lighting controls eliminate the maintenance chore of replacing lost or damaged controllers.

With the advent of smart phones and tablet computers, lighting control will eventually be performed by applications installed on these devices. Several lighting control manufacturers are developing applications for handheld smart devices. In the future, these applications may replace software plug-ins installed on desktop personal computers.

5.6 Lighting Control Methods for Buildings

A. Digital Lighting Controllers

For lighting control of a large area or building, use of digital lighting controls with a lighting control panel provides the greatest flexibility in control. Modern lighting control panels include digital controls that receive inputs from wall controls, photosensors, occupancy sensors, and send commands to relays or addressable ballasts to control lighting for a particular area. Digital lighting control panels usually include an astronomic time clock within the controller to provide the capability of reducing lighting during periods of limited or no occupancy.

Since the lighting control system is digital, control schemes and areas can be modified when building needs change. If the hours that a building is occupied change, the lighting control schedules can be changed to provide lighting appropriate for the revised hours. If the building function or layout changes, as in the case of an open-office environment, digital controls can be reprogrammed to control different luminaires without re-wiring. This capability exists because the digital controls (wall switches, remote controls, etc.) send a digital signal to the controller when a button on the control is pressed. The lighting control panel then controls either a relay or dimming ballast located in the area where the controller is located.

Most digital lighting control systems require control wiring from sensors or switches back to the lighting control panel, and from the lighting control panel to the relay panel or addressable ballasts. Typically, control components use topology-free wiring that can reduce the amount of control wire needed. When selecting a digital lighting control system, the type of wire or cable required for digital communications should be investigated. Some systems use wires that can be run in the same conduit as the lighting power wires, while others require the communication wires or cables to be run in a separate conduit, which will increase installation time and material costs. Installation of the additional communication wires may be nominal in new construction, but can be cost-prohibitive in retrofit applications. Therefore, the type of wiring required, and connection topology between the controllers, lighting control panel, and relays or ballasts should be determined.

As wireless systems become ubiquitous in buildings, lighting control systems are also embracing wireless means of communication among digital devices. Wireless systems are ideal for retrofit applications, since retrofit of communication cabling is eliminated. Additional considerations regarding wireless control are given in Section 5.6E.

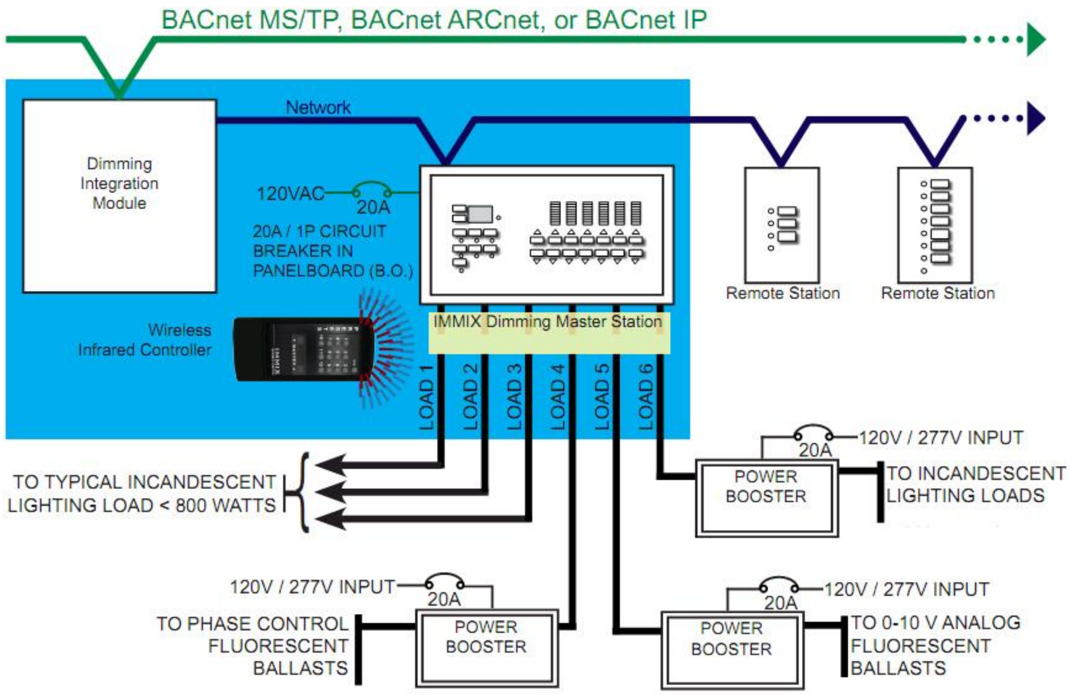


Figure 5.12 – Sample digital lighting control system including personal remote control and wall-mounted controls (Blue Ridge Technologies)

B. Addressable Devices

In an addressable lighting control system, each control device, such as wall switches, remote controls, occupancy sensors, and photosensors, is connected to the lighting control panel via communication cables. Each control device has a unique address. Each device being controlled, such as a relay or ballast, also is connected via communication cables and has a unique address.

Since each device has a unique address, any lighting control can be programmed to control any other addressable relay or ballast, offering the greatest flexibility in management of lighting. As building needs change, the addressable control devices can be reprogrammed to control different spaces, or numbers of luminaires. Addressable ballasts or relays in a given area can be programmed to dim or turn off lighting depending on daylighting, occupancy, or the area's use, as demonstrated in the illustration below.

Figure 5.13 – Typical office environment demonstrating various illumination levels according to task, occupancy, and daylight (McGraw-Hill Construction, 2006)

Operational considerations of an addressable lighting control system need to be taken into account. Some addressable systems are “self-learning” in that when a component such as a ballast or sensor is replaced, the system will automatically realize that a component has been replaced, and program the replacement device to function in the same manner as the original device. Other lighting control systems require an address to be set manually using DIP switches or dials on each device. Replacement devices must be set to the same address as the original device, or system malfunction will result. These systems may require a database of devices, device locations, and addresses be created for maintenance personnel to track device addresses.

C. Dimming Panels

Early dimming panels consisted of rheostats and other devices to limit the voltage and corresponding current to luminaires. Current- or voltage-limiting panels that dim large areas of a building are still available on the market, but are being superseded by electronic lighting controls and digitally addressable devices. Electronic dimming controls are more efficient, offer more precise dimming, and greater flexibility over traditional dimming panels. Refer to Section 5.6 A and 5.6 B for an overview of electronic lighting controls. When specifying a dimming panel, ensure the dimmer is compatible with the lamps (fluorescent, LED, etc.) to be dimmed, along with the lamp ballasts or drivers.

D. Switching Panels

Switching panels consist of relays to switch lighting branch circuits on or off. Switching panels may include digital lighting controls within the switching panel, or be controlled by a digital lighting controller or energy management system.

Panels are available in various configurations and quantities of relays that can be installed. Switching panels are available that include branch circuit breakers for protection of the branch circuits controlled by the relay. Where panels include circuit breakers on each branch circuit, only a main feeder is required to be installed to serve the switching panel. However, switching panels that include circuit breakers are more costly. If branch circuit breakers are not specified within the switching panel, each branch circuit must be protected from an upstream circuit breaker. Typically, an electrical panelboard is located in the vicinity of the switching panel, and each lighting branch circuit is wired from the panelboard circuit breaker to the relay within the switching panel. The configuration and number of relays within the switching panel affects the space required for panel installation, and should be coordinated with existing or new equipment to be installed.

E. Wireless Controls

With wireless systems becoming more prevalent, lighting control systems are also embracing wireless means of communication among digital control devices. Wireless systems are ideal for retrofit applications, since retrofit of communication cabling is eliminated. Retrofit communication cabling may require separate conduit or re-pulling of conductors at significant expense. Wireless devices can be installed in any suitable location. By using battery or solar-powered devices, electrical connections to controls are eliminated, enabled, allowing control devices to be installed anywhere in a building or space. Wireless controls can be readily relocated if sensor coverage is inadequate or if furniture, such as partitions, block access to the control or sensor.

Two main types of wireless networks are available: fixed and mesh networks. In a fixed network, a group of devices communicate with a designated repeater. Each repeater maintains a record of devices in its coverage area. Commands sent to or from the lighting control system are passed from repeater to repeater until the repeater responsible for the given relay, switch or sensor receives the message. The repeater then transmits the command to the given device.

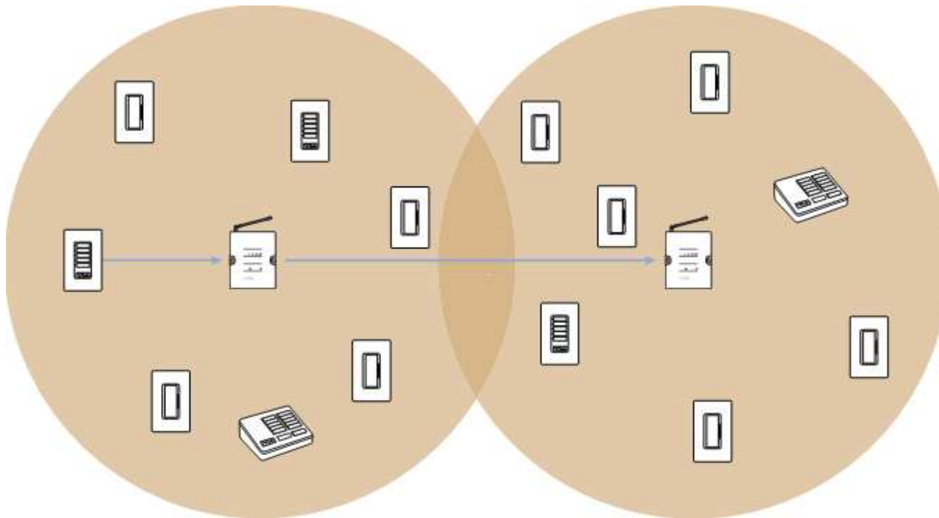


Figure 5.14 – Fixed Wireless Network Diagram (Lutron- (Black, 2009))

In a mesh network, all wireless devices-relays, switches, dimmers, and sensors-act as repeaters. Coverage areas from each wireless device overlap, creating a “mesh” of coverage. Commands or status messages are passed from device to device until it reaches the intended device. While commands travel a specific “route” on a fixed network, commands may traverse any combination of devices to its destination in a mesh network. Network control is decentralized; there are no master repeaters or control devices as in a fixed wireless network.

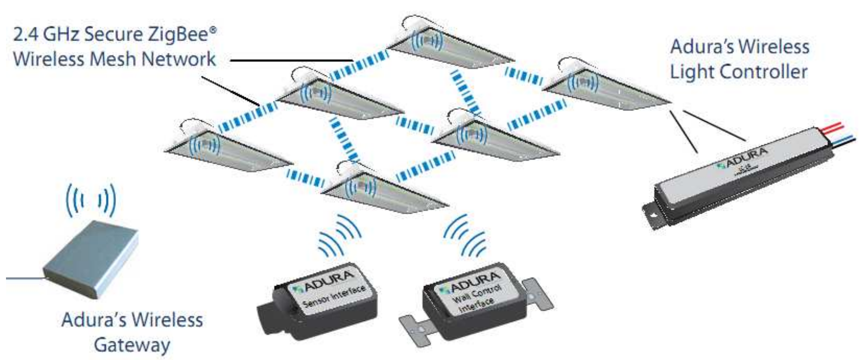


Figure 5.15 – Example of wireless mesh network (Adura Technologies, 2011)

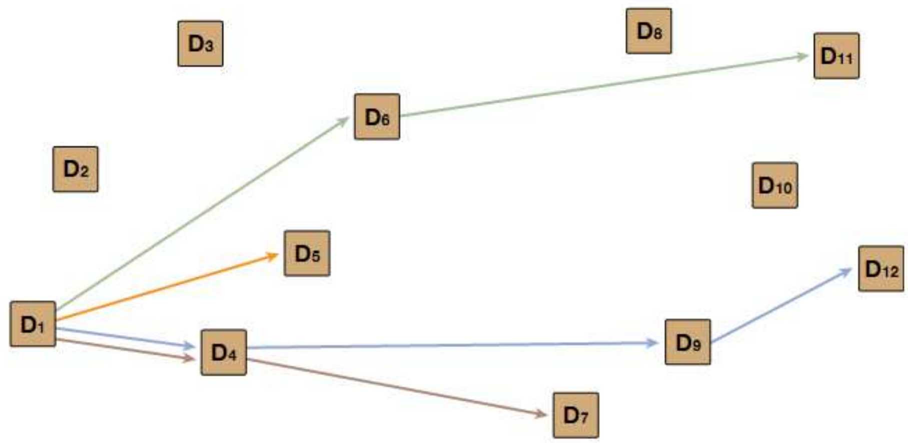


Figure 5.16 – Illustration of four directed comments sent on a mesh network (Lutron- (Black, 2009))

Advantages of a fixed network include faster response time, and better coverage in long, narrow areas such as hallways and corridors. Fixed networks have the disadvantage of a lack of redundancy. If a repeater fails, other repeaters downline may not receive signals, which may cause a large portion of the system to fail, depending on how many repeaters and devices are located downline of the failed repeater.

Mesh networks have the advantage of better wireless coverage, since each device (switch, relay, sensor, or ballast) acts as a repeater. Issues with wireless systems such as signal attenuation through thick walls is mitigated or eliminated. If a component fails, the mesh network is self-healing, since messages are routed around the failed component. Similarly, new devices can easily integrate into the mesh network. Disadvantages of a mesh network include long delays in system response if a command needs to traverse many devices. These delays can last up to one second, which will be unacceptable to most building occupants. Long, narrow spaces such as corridors and hallways may introduce delays in system response if an alternate route is not available for the message transmission.

The coverage range of wireless devices varies widely. Devices have a signal range of 20 feet or less, to over 200 feet. Some manufacturers claim a long coverage area, but this claim is based on flat, unobstructed environments, which is not typically encountered inside a building. Manufacturer's specifications regarding coverage area and instructions pertaining to device location should be carefully consulted. In general, wireless signals should avoid metal fixtures, or portions of a building that contain large amounts of metal, as the metal will decrease the signal range. If a signal needs to pass through a wall, the wireless devices should be aligned so that the transmission is as perpendicular with the wall as possible. Transmissions passing through walls are attenuated when the angle between the signal's path and the wall is decreased. This is due to the increased distance and material the signal needs to penetrate, which reduces the signal's power and coverage area. Avoid locating wireless devices along walls or nearby corners of rooms or buildings. Wireless devices should be located in the center of the room or space wherever possible for optimum coverage.

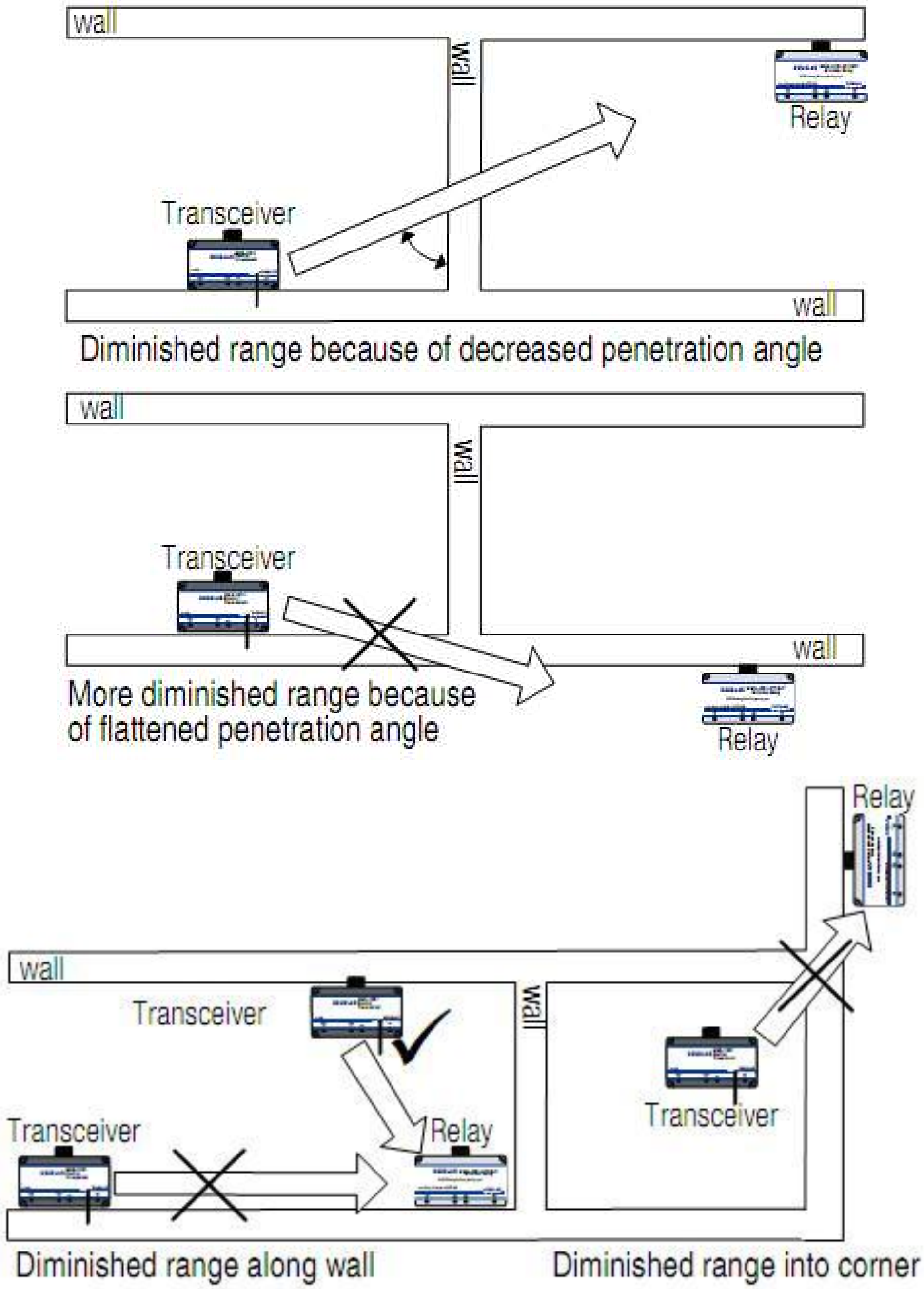


Figure 5.17 – Device locations which diminish wireless coverage and should be avoided (Douglas Lighting Controls, 2011)

Wireless systems should be thoroughly tested and commissioned. Despite manufacturer's specifications, signal coverage and response time may be significantly affected by the building construction and interior layout, or other electronic equipment in the building which may produce interference with the wireless lighting control equipment. Additional wireless repeaters or relocating existing repeaters or control devices may be required after the lighting control system's installation. Wireless systems should be tested and commissioned to prevent interference or undesirable operation of other wireless or electrical systems in the building.

F. Integration with Building EMS

As buildings become "smarter", building energy-management systems are becoming commonplace. Lighting control systems are adapting by including control inputs and outputs as standard configurations. Digital lighting control systems on the market today include the capability to communicate with building EMS units over a variety of protocols, including BACnet, LonTalk, and Modbus. Integration of the lighting controls with the building EMS will assist in electrical demand management. If an order to reduce electrical power demand is given, the lighting control system can receive this signal from the EMS, and switch off or dim lighting in non-essential areas by switching relays or by sending commands to addressable dimming ballasts to dim lighting.

Integration of lighting controls with building EMS components provides means to save energy during periods of normal building use, outside of demand response events. Controls such as occupancy sensors can be configured to not only turn off lighting when an area is unoccupied, but send signals to the EMS to reduce air conditioning or heating to the area since it is unoccupied. Significant energy savings can be realized by reducing not only lighting loads, but HVAC loads. Only one sensor is required to control lighting and HVAC loads, rather than multiple sensors.

G. Integration with Campus EMS

Similar to integration with a building EMS, lighting controls can be integrated with an energy management system for a campus. Just as lighting in non-essential portions of a building can be reduced during a demand reduction order, lighting in non-essential buildings can be reduced. To achieve maximum control and feedback to the campus EMS, it is recommended that each building electrical service be metered with a networkable meter. Electrical demand reduction can be monitored by the campus EMS after sending commands to building lighting controls to reduce lighting loads.

5.7 Control Strategies

Minimum requirements for automatic and manual lighting control in interior spaces are provided in the California Energy Code. The Energy Code generally requires sensors to turn off lighting when an area has been vacated, and provision of switching steps or dimming to reduce lighting power in a given area by 30-70%. In daylit areas, automatic daylighting controls shall be provided to reduce power consumption of the general lighting by at least 2/3 in response to the availability of daylight. The following sections include control strategies to be considered, beyond the minimum control requirements.

A. Control of Lighting in Classrooms

Today's classroom has a variety of functions and activities. Instruction may be conducted via a traditional method using blackboards, or by using computer projectors. Students may take notes using paper, on a personal computer, or a handheld electronic tablet. Lighting control systems in classrooms must be versatile and should accommodate all these activities.

In addition to the multi-level lighting controls required by the California Energy Code, consider use of additional switching steps, or a dimming system to provide additional levels of illumination. An illumination level that is suitable for note taking on paper may produce uncomfortable glare on an electronic tablet. Lighting controls that provide several illumination levels within the classroom will benefit the various instructional means and methods, and should be more conducive to learning.

Control locations should be readily accessible to instructors. Consider installation of three-way lighting controls in each classroom, with a lighting control located near the classroom doorway, and another by the instructor's desk, or adjacent to the whiteboard. During presentations, the lights can then be readily adjusted without significantly interrupting the presentation.

B. Control of Lighting in Lecture Halls

Many of the same activities taking place in classrooms are also happening within lecture halls. Instruction may be conducted using traditional methods of a lecturer presenting at a podium, or via audio-visual presentations. Students may perform note taking via pen and paper, or on laptops or electronic tablets. Because of the various instructional methods taking place in a lecture hall, multi-level lighting controls are recommended within the hall to perform several levels of illumination that are favorable to each instruction presentation method.

Because of the larger area of a lecture hall compared to classrooms, strategic location and use of lighting controls is highly recommended. As with classrooms, consider installation of lighting controls located in multiple locations. Controls should be located near room entrances, and by the stage area. Because lecture halls generally require more luminaires and circuits than other areas, scene-based lighting control is ideal for control of all the luminaires in the hall. A single scene-based controller can raise or lower all luminaires in the hall based on pre-configured settings for a lecture or audio-visual presentation, eliminating the need to manipulate several switches or dimmers to achieve desired lighting levels. Remote controls with infra-red receivers are also suitable for use in lecture halls. A remote control can be installed at the podium for use by the presenter, eliminating the need to interrupt the presentation to adjust lighting controls.

C. Control of Lighting in Conference Rooms

Conference rooms are used for a variety of activities, from meetings to audio-visual presentations. Scene-based lighting control is well-suited for lighting control in conference rooms. Lighting control buttons can be marked with various room functions, e.g. “Presentation”, “Meeting”, “Cleaning”, etc. with a corresponding pre-set level for each luminaire. Scene-based lighting control will enable occupants to adjust lighting for the entire room with the press of one button, avoiding the need to manipulate several controls to achieve desired illumination levels. Consider handheld remote controls in conference rooms so that the controls are readily accessible to the occupants.

D. Control of Lighting in Laboratories

Laboratories frequently include fixed equipment and workbenches for conducting experiments. Consider controls for area lighting throughout the laboratory, and for task lighting at specific equipment or work areas. When experiments are not taking place, the task lighting can be switched off to save energy, while the area lighting provides general illumination. Note that in laboratories, large pieces of equipment may block the field of view of occupancy sensors. More sensors may be required around large pieces of equipment or other obstructions. Sensors should be calibrated such that vibrating equipment does not cause nuisance sensor activations.

E. Control of Lighting in Libraries

Lighting controls in libraries can be configured to provide general area illumination during library hours of operation, and task illumination that is switched on only when needed. In library stack areas, consider configuring certain luminaires that are on continuously for area illumination, and luminaires located in corridors between stacks controlled by a motion or occupancy sensor to provide additional illumination required for reading. Since the stack areas are occupied for short periods of time, occupancy sensors are beneficial in controlling the task lighting such that the greater task illumination is on only when needed, reverting to area lighting of a lower intensity during periods of non-occupancy. Similar control configurations can be employed in study areas or computer desks. A level of illumination that is lower than that required for reading can be provided during periods of non-occupancy. When persons enter the area, additional luminaires or lamps within luminaires can be switched on to provide adequate illumination for reading.

F. Control of Lighting in Offices

Lighting controls in offices will vary depending on the size of the office and number of occupants. Inadequacy of office lighting is a frequent complaint from occupants-the lighting is either too bright or too dim. In addition, offices will have people of various ages within the same area that will require different illumination levels. Providing additional switching steps or dimming controls will provide more flexibility in obtaining various illumination levels required. This will enable the lighting system to cater to the various needs of the occupants, and increase productivity. Multi-level or dimming controls for all luminaires in the room can be employed in small offices with one or two persons. Multi-level controls will enable the person to adjust lighting to their personal needs or tastes. In large open office areas, consider use of handheld lighting controls or tabletop luminaires at each workstation.

G. Control of Lighting in Hallways

Lighting systems in corridors or hallways is currently exempt from the multi-level lighting control mandates in the California Energy Code. However, it is recommended that luminaires in hallways be connected to multiple circuits. The circuit connections can be staggered such that a circuit can be turned off, and the remaining luminaires that are on provide a reasonably uniform illuminance level. Where multiple circuits are used and luminaires are connected in a staggered fashion, occupancy sensors are recommended for control of certain circuits or luminaires. One circuit can be controlled via a time clock to remain on during periods of occupancy, while the other circuits can be controlled by occupancy sensors. This control scheme turns off most lighting when the hallway is unoccupied, while leaving a small amount of luminaires on for safety.

H. Control of Lighting in Restrooms

Since restrooms are sporadically occupied, restroom lighting can be controlled with occupancy sensors to save energy during unoccupied periods. Ultrasonic or dual-technology sensors are recommended over sensors that only use passive-infrared technology. As described in Section 5.5B, ultrasonic sensors fill an area with sound waves, and then detect changes in wave reflection to identify motion. These waves will be able to reach oddly shaped areas, or into partition walls of restroom stalls. Infrared beams emitted from a passive-infrared sensor will not be able to penetrate stalls which may result in lighting turning off while a stall is occupied.

I. Control of Lighting in Stairways

As in hallways, luminaires can be staggered to turn off certain luminaires during periods of inactivity, leaving other luminaires on continuously to provide a minimum amount of illumination. Occupancy sensors can be employed to turn off luminaires after a certain time delay, however the location of sensors should be carefully considered. The sensors should pickup movement and activate lights immediately when a person enters the stairway. Sensors that do not turn on lighting immediately will introduce a trip hazard. Since stairwells are irregularly shaped, ultrasonic sensors may be advantageous. Ultrasonic sensors fill the area with sound waves, avoiding line-of-sight issues with infrared sensors. Consider the type and location of automatic lighting controls in stairwells to provide a balance between energy savings and occupant safety.

Stairwell fixtures equipped with integrated occupancy controls that provide a 50% or greater reduction in illumination levels during unoccupied periods should be considered.

J. Window Shade Control

Motorized shades are optimal in conference rooms, classrooms, and lecture halls with exterior windows. Shade controls can be integrated into most lighting control systems. Motorized shade controls are available that can be operated by wall controls, remote controls, or scene-based lighting controls. Shades can be configured to be in a raised position to provide daylighting during meetings or general room occupancy. When the lighting is set to a presentation setting, the shades can be lowered to block outdoor light, preventing glare or unnecessary illumination from exterior light sources.

K. Emergency/Egress Lighting Control

When specifying a building lighting control system, requirements that determine how the system should function in response to loss of normal building power or emergency alarm should be established. Several lighting control manufacturers offer emergency control modules that override normal switching or dimming systems upon loss of normal power. The control modules will turn on all lighting connected to emergency circuits at full brightness upon loss of normal power. These override modules should be specified when part of the normal lighting system will also be used for emergency or egress lighting. Backup power sources and their use with the lighting control system also need to be identified. Refer to the Safety and Emergency Lighting section of this Guide for emergency/egress illumination requirements.

6.0 SELECTION OF LAMP AND BALLAST TYPES

6.1 Selection of Lamp and Ballast Type

Lamps and ballasts should be selected to provide aesthetically pleasing illumination and minimize maintenance. Interior aesthetics are enhanced by selecting the proper type of lamp (fluorescent, LED, etc.), appropriate lamp wattage and lumens to provide adequate illumination, and color temperature and color rendering index for suitable color interpretation.

6.2 Lamp, Wattage Optimization/Standardization

Since lamps and ballasts are the items replaced most frequently in a lighting system, maintenance costs to replace these items should be minimized. Maintenance costs can be minimized by using long-life lamps and ballasts and standardization of lamps and ballasts.

Long-life lamps and ballasts have higher rated operating hours than standard components. Items having a longer rated lamp life may have a greater material purchase cost, but reduce maintenance costs over the long term, since lamps are replaced less frequently. In order to achieve the operating hours specified by the manufacturer, lamps and ballasts should be suitable for the environment where they are installed. Recommended ambient temperature ranges for operation are typically provided by manufacturers. Excessive hot or cold temperatures or poor ventilation will reduce the life of lamps and ballasts, and may create other issues such as slow starting or altered color temperature.

Standardization of lamps and ballasts provides aesthetic as well as maintenance benefits. Color temperatures and color rendering indices (CRI) of lamps are usually specified in construction documents when new construction or renovation takes place. However, replacement lamps installed by maintenance personnel may have a different color temperature or CRI. Differences in color temperature between lamps become readily apparent, as certain lamps may appear “bluish” or “warmer” than others. The photograph below demonstrates the variations in light color among different lamp types and color temperatures. For a more detailed discussion of color temperature, refer to Section 6.3. To maintain a uniform appearance within a space, all lamps illuminating a given area or task should be the same color temperature and CRI. Replacement lamps should have identical color temperatures and CRI ratings as original lamps. Lamp standardization will help avoid installation of lamps with varying color temperatures and CRI values.

Figure 6.1 – Lamp color temperature variations
(Guide to Buying the Right Lamp-Understanding Light Color Temperature)

The number of different lamp or ballast types and wattages should be minimized. Limiting the types and wattages of lamps and ballasts will reduce maintenance costs since fewer spares of various lamps and ballasts will need to be stocked. The time required for lamp or ballast replacement will be reduced when maintenance personnel do not have to manage several different types of components, or spend additional time to determine the correct replacement part.

6.3 Lamp Color/Color Rendering Index

Lamp Color and the Color Rendering Index of a lamp are two important parameters to consider during specification of a lighting system. Proper specification of these values will ensure that objects within the area are represented accurately, and provide a more pleasing interior environment.

The color temperature of a light source indicates the color of the light emitted measured in degrees Kelvin. Lighting color ranges from warm to cool tones. Colors that have low color temperature values are classified as “warm”, and progressively become “cooler” as the color temperature value increases. Different lamp types emit various colors of light, as shown on the scales below.

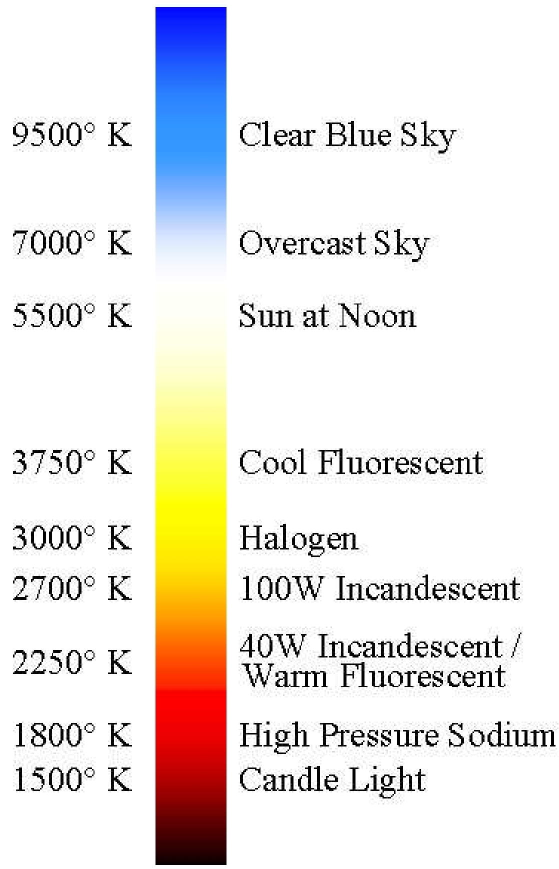


Figure 6.2 – Color Temperature Scale with typical light sources shown

The color rendering index (CRI) is a measure of how accurately an artificial light source displays colors. CRI is determined by comparing the appearance of a colored object under the subject lamp to its appearance under a reference light source. The CRI is given as a value from 0 to 100. Lamps that render colors as closely as possible to the reference source are given high CRI values, while lamps that poorly render colors are given low CRI values.

CRI values are related to color temperature in that the CRI values for a pair of light sources can only be compared if they have the same color temperature. For example, incandescent lamps have a CRI value of 100, and ceramic metal halide lamps have a CRI of 96, but objects will appear significantly warmer under an incandescent lamp. This is because an incandescent lamp has a color temperature of about 2700K, while the ceramic metal halide lamp has a color temperature around 5400K. For applications where accurate color rendition is critical, such as in art or design studios and laboratories, select a lamp with a color temperature closest to natural daylight (5500K) *and* a high CRI value. Avoid lamps at the extremes of the color temperature scale, or lamps with low CRI values, as these lamps will affect rendition of objects. Variances in lamp types and CRI values are demonstrated in the figure below.

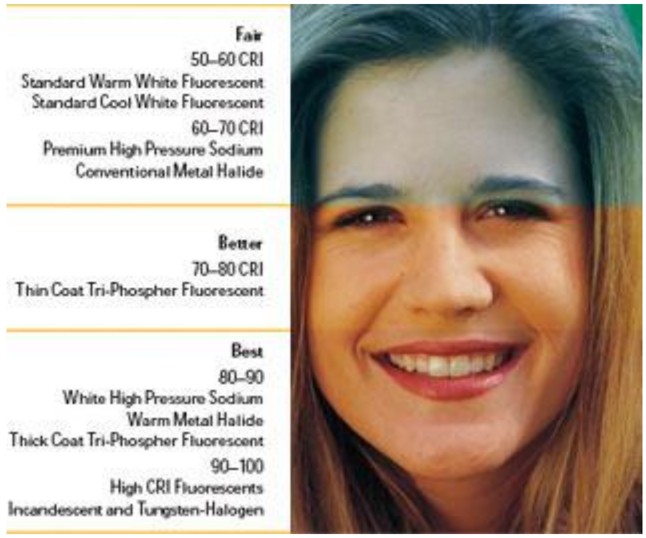


Figure 6.3 – Effect of CRI on skin tone (US Environmental Protection Agency)

6.4 LED

LED, solid state, lighting technology is rapidly improving. It delivers a very directional beam of light at a very low wattage. While the efficacy of the individual LEDs may not be significantly higher than other, more conventional sources, the efficiency of the entire lamp and luminaire combination is very high because nearly all of the light produced is directed out of the luminaire. LED lamps have a lifetime of 50,000 to as much as 100,000 hours depending on manufacturing quality. They work well for indicator lights, and façade wall washing in addition to accenting architecture in various rich colors. As LED lamp efficiency improves, LED lamps could be used for general interior illumination.

6.5 Compact Fluorescent

Compact fluorescent (CFL) sources have advantages over incandescent sources in that they have longer life and much greater efficacy. Compact fluorescent lamps have average lifetimes from 10,000-15,000 hours, depending on manufacturing quality and operating conditions. Due to the bulky size and shape of these lamps, they do not perform well as highly directional sources such as floodlights. They work very well for decorative luminaires that create a soft glow or for lighting surfaces or façades. For situations where emergency lighting is required, their instant-on capability makes them a good choice.

6.6 Linear Fluorescent

Linear fluorescent lamps have become the primary lamp for general interior lighting since their market introduction in the late 1930’s. Linear fluorescent lamps continue to be widely used for new construction and retrofits. Until the

1980s, most installations used T12 lamps, 4ft or 8ft long, with magnetic ballasts. Slimmer T5 and T8 lamps with higher efficiency electronic ballasts are now the standard in linear fluorescent lighting. Lamp and ballast manufacturers continue to improve linear fluorescent light output, dimming capabilities, efficacy, operating life, and color rendition. For example, 28W and 25W T8 fluorescent lamps have been introduced that use less energy than their 32W counterparts. Similarly, luminaire manufacturers continue to make advances in efficiency and optical control of linear fluorescent fixtures.

Fluorescent lamps are identified by a standardized code that provides information about operating characteristics and physical dimensions. Manufacturers' codes, found on the lamps and in catalogs, may vary slightly, however all major lamp manufacturers base their codes on the identification system provided below:

Example: F32T8/CW

"F" - fluorescent

"32" - rated nominal wattage of lamp

"T" – shape of lamp; this lamp is shaped like a tube

"8" - diameter in eighths of an inch; this lamp is 8/8 (1) inch in diameter

"CW" - light color from the lamp; this lamp is a cool white lamp

Other designations, such as “RS” for rapid-start, or “HO” for High Output, may be included in the product code. Catalogs from the lamp manufacturer will indicate any additional options given in the product code.

Lamp–ballast systems are characterized by the lamp starting method. The method and frequency of lamp starting are important because the coating on lamp cathodes is diminished with each starting cycle, resulting eventually in lamp failure. Dimming ballasts may require a certain type of lamp starting method for proper operation. For general interior lighting, the three most common lamp circuit/ballast types are:

Rapid-start – The rapid-start ballast provides low voltage to heat the lamp cathodes before applying higher starting voltage, and it continues to provide cathode heating voltage during normal lamp operation. Preheating the lamp cathodes decreases the required starting voltage and cathode wear, allowing for more starting cycles and/or extending lamp life. Dimmable fluorescent systems use the rapid-start method because the current for heating the cathodes is maintained while the lamp current is controlled by the dimming control. A disadvantage to rapid-start systems is that the cathode heating filament remains on at all times. In a non-dimmable system, the cathode heat does not provide any additional benefits after the lamp has been started, which decreases efficiency.

Instant-start – The instant-start ballast provides a high initial voltage to start the lamp without preheating the cathodes, as in a rapid-start lamp. Once current starts flowing through the lamps, the lamps illuminate at close to their full brightness. After a successful start, the instant-start ballast will immediately regulate the voltage and current down to the normal operating levels. This starting method degrades the lamp cathodes more quickly than do rapid-start systems; however, eliminating the power draw for cathode heating typically makes instant-start systems more energy efficient than rapid-start systems. Most instant-start systems are not dimmable.

Programmed start – Ballasts incorporating programmed-start capabilities avoid many of the pitfalls of the other two starting methods. Programmed start ballasts are now the most popular because of the advantages over rapid-start and instant-start methods. Programmed-start ballasts use cathode heating much like rapid-start systems, but ensure the cathodes are at their proper temperature before igniting the lamp. Traditional rapid-start methods can not guarantee that the cathodes are at their preferred temperatures prior to lamp ignition. Programmed start ballasts use a lower starting voltage to strike an arc compared to instant-start systems, which reduces lamp blackening and increases lamp life. Finally, once the arc in the lamp is established and the lamp is fully “on”, some programmed-start ballasts de-energize the cathode heating filament, which saves energy. Programmed-start systems are optimal for installations where the lamps will be switched on and off frequently, such as classrooms, offices, and conference rooms with occupancy sensors.

Fluorescent lamp–ballast systems can be “tuned” for light output and energy usage through specification of an appropriate ballast factor (BF), which in simplest terms is the percentage of rated lamp lumens (lm) that a particular lamp–ballast combination will produce. As an example, a lamp rated at 2800 lm (initial) operated on a ballast with a BF of 0.88 will produce 2464 lm, or 88% of its rated light output—with a corresponding reduction in energy usage. If higher light levels are needed, the same lamp can be operated using a ballast having a higher BF and higher system power draw.

When specifying lamp-ballast combinations, it is vital to specify all parameters of the lamp and ballast, including lamp type, physical dimensions, wattage, color temperature, CRI, ballast type and starting method, and ballast factor.

6.7 Lamps of Limited or Prohibited Use

High Pressure Sodium (HPS) lamps produce orange light and should not be used in general interior spaces due to the poor color rendition. HPS lamps may, however, be useful under certain conditions such as a greenhouse or other laboratory application.

Incandescent and halogen lamps should be used sparingly due to their low efficacy (lumens of light output per watt of electricity input) and short life. If incandescent or halogen lamps are used in limited cases, they should be dimmed to reduce energy usage and heat generation. However, dimming will result in bulb wall blackening. The lower operating temperatures of a dimmed lamp will cause the tungsten-iodine cycle to stop. The tungsten-iodine cycle prevents the filament from deteriorating, and if interrupted, will cause darkening of the lamp. Manufacturers claim that turning up the lamp to "full on" will clean the lamp. Extended dimming will increase lumen depreciation and reduce lamp life slightly. CFL or LED replacements for incandescent or halogen lamps are recommended for retrofit of existing installations using incandescent or halogen lamps.

APPENDIX A – WORKS CITED

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APPENDIX B – UTILITY INCENTIVES

The CSU partners with local utilities to develop strategic energy efficiency rebate and incentive programs for electricity and gas. There are essentially two types of programs, the CSU/IOU Energy Efficiency Partnership Program and individual incentive programs that campuses in municipal utility territories may have developed.

The contents of this appendix will consist of the following:

- Investor Owned Utility (IOU) Qualified LED Product Lists

- CSU/IOU Energy Efficiency Partnership Program; http://uccsuiouee.org
    - Program Processes and Background
    - Contact Information
    - Sample forms and templates used to apply for and recover incentives
    - Supplemental Utility Program Information

- Municipal (MUNI) Utility Information (hyperlinks)
    - LADWP; www.ladwp.com
        - Rebate and Incentive Programs: http://www.ladwp.com/ladwp/areaHomeIndex.jsp?contentId=LADWP_REBATES_SCID
        - Customer Service: http://www.ladwp.com/ladwp/csAreaHomeIndex.jsp?contentId=LADWP_CUSTSERV_SCID
    - SMUD; www.smud.org
        - Rebate and Incentive Programs: http://www.smud.org/en/rebates/Pages/index.aspx
        - Customer Service: http://www.smud.org/en/business/Pages/index.aspx
    - TID; www.tid.org
        - Rebate and Incentive Programs: http://www.tid.org/environment-conservation/energy-efficiency
        - Customer Service: http://www.tid.org/customer-service

Investor Owned Utility (IOU) Qualified LED Product Lists

PG&E:

www.pge.com/led

Both the Qualified LED Products list and Fixture Performance Specs are located on the right hand side of the page under Related Links (including how to submit new products for qualification).

SCE:

http://www.sce.com/business/ems/customized-solutions/tools-resources.htm

See Appendices E & F in the document located at the above hyperlink.

SDG&E:
http://www.sdge.com/business/rebatesincentives/programs/standardPerformanceContractsu.shtml

Refer to the last Appendix at the above hyperlink. The list is not as comprehensive as PG&E or SCE. SDG&E will accept products that are on any IOU's list.

2010-12 UC/CSU/IOU Partnership Program - FORM B: Retrofit Project Application Form

(Please complete blue-shaded cells)

Project Name:		**Contact Name:**		**Date:**	
Campus:		**Contact Phone:**		**Email:**	
Building Name:		**Building Type:**		**# Floors:**	
Age:		**Sq. Ft.**			
Tax ID:		**Utility:**		**Account Number:**	
Project Completion Date:					

Meas #	*Location*	*Measure Description*	*Effective Useful Life (yr)*	*Remaining Useful Life of Old HVAC Equipment (yr)*	*Number of Units*	*Installed Cost per Unit ($)*	*Subtotal Measure Cost ($)*
1							
2							
3							
4							
5							
						Total Measure Cost:	

If Remaining Useful Life of the existing HVAC equipment is less than 5 years, calculate savings vs. a Title 24 baseline.

Energy/On-Peak Demand Savings Summary

Meas #	*Electric*						*Gas*		
	Existing Equipment Usage (kWh/yr)	Installed Measure Usage (kWh/yr)	Energy Savings (kWh/yr)	Existing On-Peak Demand (kW)	Installed On-Peak Demand (kW)	On-Peak Demand Reduction (kW)	Existing Equipment Usage (therm/yr)	Installed Measure Usage (therm/yr)	Energy Savings (therm/yr)
1			-			-			-
2			-			-			-
3			-			-			-
4			-			-			-
5			-			-			-
		Total:	-		Total:	-		Total:	-

Project Summary

Energy Savings Total (kWh/yr):	-
Energy Savings Total (therm/yr):	-
On-Peak Demand Reduction Total:	-

Total Measure Cost	$ -
Requested Program Incentive	
Net Cost to University	$ -

2010-12 UC/CSU/IOU Partnership Program - Mandatory Project Schedule

Please fill in the white cells to create a preliminary project schedule. (Initial start date and durations for activities under campus responsibility)

A Partnership representative will assist you in developing and maintaining a detailed schedule in Primavera P6.

No.	Project Activities / Milestones	Duration (Days)	Start Date	Finish Date	Detailed Explanation
	Phase I: Definition/Scope				
1	START PROJECT				Initial milestone representing decision to pursue a given project and start project-specific effort
2	Develop Scope and Savings Projections				Develop energy savings projections, project budget, and schedule. Complete when Project is defined enough to prepare a defensible application.
3	Prepare Application				Finalize and submit Retrofit Project Form B to UCOP/CSUCO for review
	SUBMIT APPLICATION				Milestone representing date IOU receives project application
	Phase II: Review				
4	IOU Review	30			IOU (or technical consultant) Performs a site visit and due diligence
5	Management Team Approval	7			Partnership Management Team approves reviewed project
7	Execute Project Agreement	14			Campus must sign and return agreement for IOU to commit incentive funding
	Phase III: Design/Plan				
8	Design Process				Includes procurement of Design Engineer/Contractor/Implementor if necessary (may occur in parallel to IOU review)
	Phase IV: Implementation				
10	Construction				May begin once Project Agreement is executed
11	Punch List/Commissioning				Final commissioning of equipment and punch list items
12	Notify IOU of Finished Contstruction/Implementation				Prepare and Submit Project Completion Form (Form E)
	Phase V: Verification & Payment				
13	IOU Inspection & Verification	30			IOU (or techinical consultant) performs post-installation site inpsection and verification
14	IOU Send Incentive Payment	7			IOU records project as "Paid" and books savings
15	Campus Receive Incentive Payment	7			Campus Receives Payment

= Campus Responsibility
= IOU Responsibility

2010-12 UC/CSU/IOU Partnership Program

FORM B: Retrofit Project Application Form

Additional Project Information

Project Manager: ____________

Energy Manager: ____________

Engineering Consultant: ____________

Contractor/Implementer: ____________

Contact Mailing Address: ____________

____

____

Project Site Address: ____________

____

____

Financing

(Mark only one line with an "X")

CSU Projects

Will financing from CSU Chancellor's Office be requested for this project? Yes ____ No ____

UC Projects

Will financing from UC Office of the President be requested for this project? Yes ____ No ____

NOTE: All UC projects must be assigned an SEP ID, even those not receiving UCOP funding

Include SEP #(s) below :

Meas #	Measure Description	SEP #
1		
2		
3		
4		
5		

2010-2012 UC/CSU/IOU Energy Efficiency Partnership Program

FORM C: MBCx Project Application Form

One Application Per Building

Please fill in all green boxes. If more room is required, use Additional Information tab.

System	
Campus	
Building Name	
Campus Contact	
Email	
Phone	
Consultant Contact	
Email	
Phone	
Date Application Prepared	

A. Building Description

Building Function

Building Area (GSF) — Please use REVOGSF80 (UC) or equivalent CSU definition of space if available

Number of Floors — Year Constructed

Fume Hood Count — Typical Operating Hours per Week

Percent of building area requiring 100% outside air ventilation (e.g. laboratories)

Please explain why this building is a good candidate for MBCx. For example, is this building known as a "problem building" or an "energy hog" and why?

(to AutoFit the row height to the text, click inside of the text cell, then hit 'Enter')

How does the energy use index of this building compare with other buildings on campus and other buildings serving a similar function? (UC campuses see Form C.1)

(to AutoFit the row height to the text, click inside of the text cell, then hit 'Enter')

B. Central System Equipment Inventory

Please identify control systems.

	DDC	Mix of DDC, Pneumatic, Other	Pneumatic or Other
Air Handlers:	☐	☐	☐
Zone Controls:	☐	☐	☐
Chillers and Boilers (if in bldg):	☐	☐	☐

C. Building Metering/Monitoring/Management Inventory

Select the appropriate status for each of the following meter types in the building. Hot Water, Steam and Chilled Water meters only apply to buildings which receive these energy sources from a *separate* building or central plant. The MBCx program **requires** that each energy source entering a building (and exiting, for central plants) be metered.

	Building does not receive this energy source.	Meter exists and is *already* tied into campus EIS.	Meter exists and will *be* tied into campus EIS.	New meter will be installed and tied into campus EIS
Electricity:	☐	☐	☐	☐
Natural Gas:	☐	☐	☐	☐
Hot Water:	☐	☐	☐	☐
Steam:	☐	☐	☐	☐
Chilled Water:	☐	☐	☐	☐

Please identify the existing and/or proposed energy information system(s) (EIS) and how it will interface with meters and equipment (meters should automatically communicate interval energy use to a front end storage device). Also identify the storage capacity (the MBCx program requires the EIS to be able to store and manipulate data for at least 10 years).

(to AutoFit the row height to the text, click inside of the text cell, then hit 'Enter')

The MBCx program requires that commissioning agents train campus operators in the revised sequences of operations and usage of newly implemented energy management strategies. Please acknowledge this requirement by checking the box below.

Training and documentation of commissioned systems will be provided to campus operators: ☐

D. Estimated Building Energy Use

Please enter the quantity of energy entering the building. Indicate in the second cell how this is measured or estimated.

Building Use Index

Annual Electricity Use

kWh/yr — kWh/yr-sq.ft.

On-Peak Electric Demand

kW — W/sq.ft.

Annual Natural Gas Use

therm/yr — therm/yr-sq.ft.

Does this building serve other buildings with hot water, steam, chilled water or electricity?

If yes, explain how this energy will be metered:

(to AutoFit the row height to the text, click inside of the text cell, then hit 'Enter')

E. Estimated Energy Delivered to the Building from a Separate Plant

Please enter the quantity of energy delivered to the building from a separate plant. For example, if the building receives chilled water, hot water or steam from a separate plant, enter the quantity here. Please also indicate in the second cell how this is measured or estimated. If the building generates its own chilled water, hot water or steam with the electricity and gas use reported above, do not enter the energy use in these cells.

Plant Use Index

Annual Steam Use *(choose units)* — therm/yr-sq.ft

Annual Hot Water Use

Million Btu/yr — therm/yr-sq.ft.

Annual Chilled Water Use (Electric Chillers)

kWh/yr-sq.ft.

Annual Chilled Water Use (Steam Chillers)

therm/yr-sq.ft.

F. Total Estimated Utility Energy Use

This section calculates the total current annual utility energy use. This includes use directly at the building and energy delivered to the building from a separate plant. If applicable, this estimate assumes a marginal boiler efficiency of 80%, a marginal chiller efficiency of 0.8 kW/ton, and a marginal steam chiller rate of 10 lb. steam per ton-hr.

Total Energy Use Index

Annual Electricity Use

- kWh/yr — kWh/yr-sq.ft.

On-Peak Electric Demand (Refer to "On-Peak Electric Demand (kW)" worksheet for program definition.)

- kW — W/sq.ft.

Annual Gas Use

- therm/yr — therm/yr-sq.ft.

G. Projected Utility Energy Savings

Enter the projected annual utility energy savings, including savings from the building as well as savings from the separate plant, if applicable.

Projected Annual Electricity Savings

kWh/yr

0% Percent of total electricity use projected to be saved.

Electric savings are expeced to fall within the following range:
- 5% without potential modifications identified;
- 10% with likely measures identified;
- 15% for particularly inefficient operations already identified.

On-Peak Electric Demand

kW

0% Percent of total summer on-peak demand projected to be saved.

If either the annual or on-peak electric savings fall outside of the anticipated 5-15% range, explain:

(to AutoFit the row height to the text, click inside of the text cell, then hit 'Enter')

Projected Annual Gas Savings

therm/yr

0% Percent of total gas use projected to be saved.

Thermal savings are expeced to fall within the following range:
- 10% without potential modifications identified;
- 20% with likely measures identified;
- 30% for particularly inefficient operations already identified.

If annual thermal savings fall outside of the anticipated 10-30% range, explain:

(to AutoFit the row height to the text, click inside of the text cell, then hit 'Enter')

Notes

(to AutoFit the row height to the text, click inside of the text cell, then hit 'Enter')

2010-2012 UC/CSU/IOU Energy Efficiency Partnership Program

FORM C: MBCx Project Application Form

One Application Per Central Plant

Please fill in all green boxes. If more room is required, use Additional Information tab.

System	
Campus	
Building Name	
Campus Contact	
Email	
Phone	
Consultant Contact	
Email	
Phone	
Date Application Prepared	

A. Central Plant Description

Bldg Area Served by Plant (GSF)		Please use REVOGSF80 (UC) or equivalent CSU definition of space if available
Year Constructed		

Please describe in general how this central plant is used (e.g. typical operating hours, types of buildings served).

(to AutoFit the row height to the text, click inside of the text cell, then hit 'Enter')

Please explain why this plant is a good candidate for MBCx. For example, is this building known as a "problem building" or an "energy hog" and why?

(to AutoFit the row height to the text, click inside of the text cell, then hit 'Enter')

B. Central Plant Equipment Inventory

Please describe the types and capacities of chillers, boilers, co-generation and thermal energy storage systems in the central plant.

(to AutoFit the row height to the text, click inside of the text cell, then hit 'Enter')

C. Central Plant Metering/Monitoring/Management Inventory

Select the appropriate status for each of the following meter types in the central plant. The MBCx program **requires** that each energy source entering and exiting a central plant be metered.

	Plant does not receive or deliver this energy source.	Meter exists and is already tied into campus EIS.	Meter exists and will be tied into campus EIS.	New meter will be installed and tied into campus EIS
Electricity:	☐	☐	☐	☐
Natural Gas:	☐	☐	☐	☐
Hot Water:	☐	☐	☐	☐
Steam:	☐	☐	☐	☐
Chilled Water:	☐	☐	☐	☐

Please identify the existing and/or proposed energy information system(s) (EIS) and how it will interface with meters and equipment (meters should automatically communicate interval energy use to a front-end storage device). Also identify the storage capacity (the MBCx program requires the EIS to be able to store and manipulate data for at least 10 years).

(to AutoFit the row height to the text, click inside of the text cell, then hit 'Enter')

The MBCx program requires that commissioning agents train campus operators in the revised sequences of operations and usage of newly implemented energy management strategies. Please acknowledge this requirement by checking the box below.

Training and documentation of commissioned systems will be provided to campus operators: ☐

D. Estimated Central Plant Energy Use

Please enter the quantity of energy entering the plant. Indicate in the second cell how this is measured or estimated.

Plant Use Index

Annual Electricity Use

	kWh/yr			kWh/yr-sq.ft.

On-Peak Electric Demand

	kW			W/sq.ft.

Annual Natural Gas Use

	therm/yr			therm/yr-sq.ft.

Please enter the quantity of energy leaving the plant. Indicate in the second cell how this is measured or estimated.

Annual Steam Use *(choose units)*

Annual Hot Water Use

	Million Btu/yr	

Annual Chilled Water Use (Electric Chiller)

Annual Chilled Water Use (Steam Chillers)

E. Projected Utility Energy Savings

Enter the projected annual utility energy savings.

Projected Annual Electricity Savings

	kWh/yr
0%	Percent of total electricity use projected to be saved.

Electric savings are expeced to fall within the following range:
2% without potential modifications identified;
5% with likely measures identified;
10% for particularly inefficient operations already identified.

On-Peak Electric Demand

	kW
0%	Percent of total summer on-peak demand projected to be saved.

If either the annual or on-peak electric savings fall outside of the anticipated 2-10% range, explain:

(to AutoFit the row height to the text, click inside of the text cell, then hit 'Enter')

Projected Annual Gas Savings

	therm/yr
0%	Percent of total gas use projected to be saved.

Thermal savings are expeced to fall within the following range:
2% without potential modifications identified;
5% with likely measures identified;
10% for particularly inefficient operations already identified.

If annual thermal savings fall outside of the anticipated 2-10% range, explain:

(to AutoFit the row height to the text, click inside of the text cell, then hit 'Enter')

Notes

(to AutoFit the row height to the text, click inside of the text cell, then hit 'Enter')

2010-2012 UC/CSU/IOU Energy Efficiency Partnership Program

FORM C: MBCx Budget Proposal and Incentive

System	
Campus	
Building	
Building Area (GSF)	

Cost Category	In House Costs	Contractor Cost	Total Cost
Monitoring: Install or Upgrade Front End Data System (if required)			$ -
Monitoring: Implement Building Level Monitoring			$ -
Monitoring: Implement Equipment Level Monitoring			$ -
Subtotal Monitoring	$ -	$ -	$ -
Commissioning Measure Identification			$ -
Commissioning Measure Implementation			$ -
Subtotal Commissioning	$ -	$ -	$ -
Total MBCx Project Cost	$ -	$ -	$ -
Incentive Requested by University *			$ -
Funding from University			$ -

* Incentive is capped at 80% of project cost.

2010-12 UC/CSU/IOU Partnership Program - Mandatory Project Schedule

Please fill in the white cells to create a preliminary project schedule. (Initial start date and durations for activities under campus responsibility)

A Partnership representative will assist you in developing and maintaining a detailed schedule in Primavera P6.

No.	Process Component	Duration (Days)	Start Date	Finish Date	Detailed Explanation
	Phase I: Definition/Scope				
1	START PROJECT				Initial milestone representing decision to pursue a given project and start project-specific effort
2	Develop Scope and Savings Projections				Develop energy savings projections, project budget, and schedule (may include procurement of Cx Agent)
3	Prepare Application				Finalize and submit MBCx Project Form C to UCOP/CSUCO for review
4	SUBMIT APPLICATION				Milestone representing date IOU receives project application
	Phase II: Review				
5	IOU Review	30			IOU reviews project application and energy savings projections
6	Management Team Approval	7			Partnership Management Team approves reviewed project
7	Execute Project Agreement	14			Campus must sign and return agreement for IOU to commit incentive funding
	Phase III: Design/Plan				
8	Procure and Install Meters				Purchase and install meters used to collect data for project, can occur in conjunction with IOU review
9	Collect Baseline Data				Minimum baseline collection period is 3 months (see MBCx Guidelines)
10	Prepare Baseline/Findings Report				See MBCx Guidelines for Baseline/Findings Report components
	Phase IV: Implementation				
11	Implementation of identified Measures				Implement low-cost measures identified in Baseline/Findings Report
12	Collect Post-Implementation Data				Minimum post-implementation data collection period is 3 months (see MBCx Guidelines)
13	Prepare Systems Manual, Final Report, & Form D				Final Report and Form D (MBCx Results Form) are required for incentive payment
14	Notify IOU of Finished Contstruction/Implementation				Submit Form E (Project Completion Form), Form D, and Final Report
	Phase V: Verification & Payment				
15	IOU Verification	30			IOU reviews and approves final savings claims
16	IOU Send Incentive Payment	7			IOU records project as "Paid" and books savings
17	Campus Receive Incentive Payment	7			Campus Receives Payment

= Campus Responsibility
= IOU Responsibility

MBCx Project Reporting Summary for Program Database

UC/CSU/IOU 2010-2012 Energy Efficiency Partnership Program

Return to mike_anderson@newcomb.cc. Call with questions to 415-896-0300.

Name of Campus Representative Completing this Form		
Contact Information for Campus Representative Completing this Form		
District and Campus		
Building or System Name		
Primary Building Function		
Gross Building Area (excluding parking lots and other unconditioned spaces)		GSF
Area of Building that requires 100% outside air ventilation		GSF
Number of laboratory fume hoods in the building		

What was the scope of the retrocommissioning project? Check all systems and building components that were addressed.

- ☐ Cooling plant
- ☐ Heating plant
- ☐ Air handling & distribution
- ☐ Terminal units
- ☐ Envelope
- ☐ Lighting
- ☐ Plug loads
- ☐ Other - Please describe below:

What energy uses were targeted?

- ☐ Electricity
- ☐ Natural gas
- ☐ Hot water
- ☐ Chilled water
- ☐ Steam
- ☐ Other - Please describe below:

What energy saving measures did you anticipate finding through the MBCx process?

Which of the following types of monitoring were implemented? Check all that apply.

Energy and Power Meters

- ☐ Whole building electricity meter
- ☐ Whole building gas meter
- ☐ Pump power (e.g. ammeter, kW meter)
- ☐ Fan power (e.g. ammeter, kW meter)
- ☐ Chiller power (e.g. ammeter, kW meter)
- ☐ Hot water BTU meter
- ☐ Chilled water BTU meter
- ☐ Steam BTU meter

Temperature and Pressure Sensors

- ☐ Hot water temperature(s)
- ☐ Chilled water temperature(s)
- ☐ Supply air temperature(s)
- ☐ Return air temperature(s)
- ☐ Outside air temperature
- ☐ Differential pressure(s)

Flow Meters

- ☐ Hot water flow meter
- ☐ Chilled water flow meter

Status Measurements

- ☐ Fan Status/Speed
- ☐ Pump Status/Speed

- ☐ Other - Please describe below:

Describe the data collected during the baseline measurement period. How were these data used to adjust the facility's annual historical energy use baseline?

What energy saving commissioning measures were implemented? When? (Use measure categories listed on Input Page 3.)

How was the annual energy savings calculated from the monitored data? (Select from pull-down menu.)

Please describe below:

What problems did the monitoring allow you to identify that may not have been identified otherwise?

List any retrofit projects identified as a result of the MBCx project.

List any non-energy benefits of the MBCx project, or other comments on the project.

MBCx Project Reporting Summary for Program Database
UC/CSU/IOU 2010-2012 Energy Efficiency Partnership Program

INSTRUCTIONS: Fill in ALL green fields. If a field does not apply, enter 'N/A'. If the facility's boiler and chiller marginal efficiencies are not known, use the standard marginal efficiencies nominally listed (and also available in the drop-down menus). For all peak demand inputs, refer to the 'On-Peak Demand (kW)' tab for the program definition. For the peak chilled water demand from electric chillers at a central plant, include only the portion of the demand that actively uses on-peak electricity; do not include any portion handled by a Thermal Energy Storage (TES) system. Where applicable, choose the units in which energy is being reported.

Building/Process Total Energy Use

A. Historical Baseline From Proposal

Building Electricity Use - *Do not include central plant use*		kWh/yr	
Peak Demand - *Do not include central plant use*		kW	
Building Natural Gas Use - *Do not include central plant use*		th/yr	
Steam from Central Plant			
Hot Water from Central Plant		Million Btu/yr	
Chilled Water from Central Plant			
Peak CHW Demand from Electric Chillers at Central Plant		tons	*(do not include any portion of the load handled by a TES system)*

B. Revised Baseline after Monitoring *(adjusted to TMY)*

Building Electricity Use - *Do not include central plant use*		kWh/yr	
Peak Demand - *Do not include central plant use*		kW	
Building Natural Gas Use - *Do not include central plant use*		th/yr	
Steam from Central Plant			
Hot Water from Central Plant		Million Btu/yr	
Chilled Water from Central Plant			
Peak CHW Demand from Electric Chillers at Central Plant		tons	*(do not include any portion of the load handled by a TES system)*

C. Energy Use after Initial MBCx Modifications *(adjusted to TMY)*

Building Electricity Use - *Do not include central plant use*		kWh/yr	
Peak Demand - *Do not include central plant use*		kW	
Building Natural Gas Use - *Do not include central plant use*		th/yr	
Steam from Central Plant			
Hot Water from Central Plant		Million Btu/yr	
Chilled Water from Central Plant			
Peak CHW Demand from Electric Chillers at Central Plant		tons	*(do not include any portion of the load handled by a TES system)*

Building/Process Energy Savings

D. Measured Savings from MBCx Project (B minus C from above.)

Building Electricity Savings *(Not including central plant use)*		kWh/yr
Peak Demand *(Not including central plant use)*		kW
Building Natural Gas Savings *(Not including central plant use)*		th/yr
Steam Savings from Central Plant		Million Btu/yr
Hot Water Savings from Central Plant		Million Btu/yr
Chilled Water Savings from Central Plant		ton-hr/yr
Peak CHW Demand Savings from Electric Chillers at Central Plant		tons

If this facility has only one chiller type, indicate below by entering "100%" in the appropriate cell. If both electric and steam chillers are in use, enter the percentage of CHW savings coming from each type. (This will not necessarily be the same as the percent of total CHW delivered by each chiller type.

	Electric Chiller	Steam Chiller
Percent CHW Savings from each Chiller Type:	100%	0%

Estimate the equivalent electricity and fuel savings at the central plant. Standard marginal efficiencies are nominally listed below for boilers and chillers. If more accurate marginal efficiencies are available, input that data. If marginal efficiencies are not available, use average efficiencies.

Fuel Savings at Central Plant from Saving Steam		th/yr of gas
Fuel Savings at Central Plant from Saving Hot Water		th/yr of gas
Electricity Savings at Central Plant from Saving Chilled Water		kWh/yr of electricity
Fuel Savings at Central Plant from Saving Chilled Water		th/yr of gas
Peak Demand Savings from Electric Chillers at Central Plant		kW

Boiler Efficiency	80%	Percent
Electric Chiller Efficiency	0.80	kW/ton
Steam Chiller Efficiency	10.00	lb-steam/ton-hr

Net Utility Savings Including Central Plant (if any)

E. Savings at the Meter

	Building Savings		+	Central Plant Savings		=	Total Savings	
Annual Electricity Savings	-	kWh/yr		-	kWh/yr		-	kWh/yr
Peak Demand Savings	-	kW		-	kW		-	kW
Annual Natural Gas Savings	-	th/yr		-	th/yr		-	th/yr

F. Actual Project Cost

	Contracted Out	In House Costs	Total Costs
Metering and Monitoring (Meters and installation, trending software, and training on meters and software):			$0
Baseline and Commissioning (Establishing baseline, commissioning activities, reporting and Cx training):			$0
Total Cost			$0

MBCx Project Reporting Summary for Program Database

UC/CSU/IOU 2010-2012 Energy Efficiency Partnership Program

INSTRUCTIONS: Fill in ALL green fields. If a field does not apply, 'N/A'. For all peak demand inputs, refer to the 'On-Peak Demand (kW)' tab for the program definition. Where applicable, choose the units in which energy is being reported.

Central Plant Total Energy Use

A. Historical Baseline From Proposal		
Inputs to Plant		
Plant Electricity Use		kWh/yr
Peak Demand		kW
Plant Natural Gas Use		th/yr
Outputs from Plant		
Steam from Central Plant		
Hot Water from Central Plant		Million Btu/yr
Chilled Water from Central Plant *(Electric Chiller)*		
Chilled Water from Central Plant *(Steam Chiller)*		
B. Revised Baseline after Monitoring *(adjusted to TMY)*		
Inputs to Plant		
Plant Electricity Use		kWh/yr
Peak Demand		kW
Plant Natural Gas Use		th/yr
Outputs from Plant		
Steam from Central Plant		
Hot Water from Central Plant		Million Btu/yr
Chilled Water from Central Plant *(Electric Chiller)*		
Chilled Water from Central Plant *(Steam Chiller)*		
C. Energy Use after Initial MBCx Modifications *(adjusted to TMY)*		
Inputs to Plant		
Plant Electricity Use		kWh/yr
Peak Demand		kW
Plant Natural Gas Use		th/yr
Outputs from Plant		
Steam from Central Plant		
Hot Water from Central Plant		Million Btu/yr
Chilled Water from Central Plant *(Electric Chiller)*		
Chilled Water from Central Plant *(Steam Chiller)*		

TMY output from the central plant post-MBCx should nominally be the same as the pre-MBCx output, unless plant changes have reduced the campus load (e.g. reduced distribution losses due to loop temperature re-set). If post-MBCx output varies from pre-MBCx output by more than 2%, please provide an explanation of the system modifications that have resulted in this difference in loads:

Central Plant Energy Savings

D. Measured Savings from MBCx Project (B minus C from above.)		
Plant Electricity Savings	-	kWh/yr
Peak Demand	-	kW
Plant Natural Gas Savings	-	th/yr

E. Actual Project Cost

	Contracted Out	In House Costs	Total Costs
Metering and Monitoring (Meters and installation, trending software, and training on meters and software):			$0
Baseline and Commissioning (Establishing baseline, commissioning activities, reporting and Cx training):			$0
Total Cost			$0

MBCx Project Reporting Summary for Program Database

UC/CSU/IOU 2010-2012 Energy Efficiency Partnership Program

0

0

Please enter the **number** of Component-Measures implemented in this project in the applicable green cell.

		Commissioning Measures Implemented																	
		Design, Installation, Retrofit, Replacement				Operations & Control									Maintenance				
		Design change	Installation modifications	Retrofit/equipment replacement	Other	Implement advanced reset	Start/Stop (environmentally determined)	Scheduling (occupancy determined)	Modify setpoint	Equipment staging	Modify sequence of operations	Loop tuning	Behavior modification/manual changes to operations	Other	Calibration	Mechanical fix	Heat transfer maintenance	Filtration maintenance	Other
Component being Commissioned		D1	D2	D3	D4	OC1	OC2	OC3	OC4	OC5	OC6	OC7	OC8	OC9	M1	M2	M3	M4	M5
HVAC (combined heating and cooling)	V																		
Cooling plant	C																		
Heating plant	H																		
Air handling & distribution	A																		
Terminal units	T																		
Lighting	L																		
Envelope	E																		
Plug loads	P																		
Facility-wide (e.g. EMCS or utility related)	F																		
Other	O																		

Data format from Evan Mills, Lawrence Berkeley National Laboratory

If "Other" is marked above, please list row (e.g. V, C, H, etc.) and column (D1, D2, etc.) and describe the Component or Measure.

Row	Column	Description

2010-12 UC/CSU/IOU Energy Efficiency Partnership Program

FORM E: Project Completion Form

Campus: use this form to notify the Partnership that you have completed a project and are ready to schedule IOU verification visit.

System:	
Campus:	
Name of Person Submitting Form:	
Title of Person Submitting Form:	
Date Form Prepared:	

Project Title (From Initial Application):	
Project ID Number (If Available):	
Type of Project (Pick One):	

FOR RETROFIT PROJECTS		
All Measures Installed?	☐ YES	☐ NO
Date Final Measure Operational:		

FOR MBCx PROJECTS		
Low-Cost/No-Cost Changes Implemented?	☐ YES	☐ NO
Post Implementation Summary Spreadsheet (Form D) Submitted?	☐ YES	☐ NO

PROJECT RESULTS	Proposed Savings Values (From RPCP)	Estimated Post-Implementation Values
On-Peak Demand Reduction (kW)		
Energy Savings (kWh)		
Natural Gas Savings (Therms)		
Project Cost ($) with written backup		

Provide explanions for differences in proposed values in boxes below. Provide written backup for the project costs, breaking down by measure, including the major items, materials and labor.

Please explain any "NO" answers above and note any differences from initially proposed project:

Additional Comments:

Please email the completed Form to NAM, appropriate IOU representative and University representative.

PG&E: Dave Hather (dth2@pge.com)
SCE: Dick Sterrett (SterrettConsulting@Gmail.com)
SCG: Jason Lewis (jlewis2@semprautilities.com)
SDG&E: Linh-Chi Hua (LHua@semprautilities.com)

NAM: Andrew Meiman (andrew_meiman@newcomb.cc)

APPENDIX C – ADDITIONAL RESOURCES

This appendix will contain additional resources for lighting design and best practices in the form of case studies from the PIER Lighting Technology Program as well as Best Practice Award Winners from the Annual California Higher Education Sustainability Conference.

Public Interest Energy Research Program | IOU Partnership Draft-Case Study

Integrated Office Lighting System (IOLS)

PIER Buildings Program | Research Powers the Future | www.energy.ca.gov/research

Energy and Carbon Savings Opportunity

Better light, more savings, less maintenance, while maintaining appropriate light levels

The Integrated Office Lighting System (IOLS) is a system approach to reducing the billions of kilowatt hours (kWh) consumed annually by office lighting. Title 24 energy code of 2005 stipulates a maximum power density of 1.2 W/ft² for office lighting. The majority of the lighting is provided by overhead troffers or pendents. Appropriately achieving a significant energy savings requires the overhead lighting load to be reduced without allowing user comfort to suffer. This is made possible by incorporating high quality, efficient task lighting. One possible component of the IOLS approach is the Personal Lighting System (PLS), an LED task light that was developed jointly by Finelite, Inc. and California Lighting Technology Center (CLTC).

The PLS consists of a family of adjustable high-quality LED desk and under-cabinet lights connected to a single power module that is controlled by an occupancy sensor. Users can specify the appropriate number size and combination of these task lights for their specific office layout and work style. Combined with the right ambient system, this approach can reduce power density to 0.6 W/ft² or less.

Product Overview

Energy Savings:

Typically achieves 50% annual energy savings
Over 15 years, one system can yield savings of 7,500 kWh

Operation/Maintenance:

Cost effective replacement for all office environments; LED task lights are designed to last five times longer than standard office luminaires

Available Fixture Manufacturer:

Various task lighting manufacturers may be utilized
PLS task lights available from Finelite, Inc.

Market:

Commercial and residential offices

Project Design Guides:

- New construction product specification available
- LEED® Fact Sheets
- http://pierpartnershipdemonstrations.com/

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Completed Field Demonstrations

The IOLS was demonstrated in three different locations over a six-month period. In most demonstrations, the IOLS eliminated existing fluorescent under-cabinet lights and reduced ambient lighting by up to 50%.

Lessons Learned:

- Additional savings can be realized by incorporating daylight harvesting and bi-level controls into the IOLS
- Achieving maximum savings within Title 24 specifications requires zonal occupancy controls for overhead lighting
- Average task plane illuminance was either maintained or improved after the IOLS retrofit
- Paybacks for new construction may be equivalent, in some cases, to retrofit scenarios since existing offices are usually well above Title 24 power density requirements.

IOU Partnership:

The University of California/California State University (UC/CSU) and Investor-Owned Utility (IOU) Partnership Program has identified incentives for the IOLS of approximately $60 to $80 per work space. For more information please visit: www.uccsuiouee.org.

Before RETROFIT / 80watts

After RETROFIT/ 13.65watts

Top: Before and after of IOLS system at a Sacramento branch of the DMV
Bottom: Post-retrofit maintains equivalent light levels (two T8 lamps + PLS)

Equipment & Installation Costs

Retrofit:

A typical IOLS retrofit required de-lamping (~$25 per office) or fixture replacement ($70-$150 per office). Various types of high quality task lighting products can range from $100-$350 per office. Ambient lighting system in the table below is assumed to have A/B switching.

New Construction:

Payback in new construction is often close to retrofit due to the fact that many retrofit situations have a high power density while new construction must be no higher than Title 24 specifications. The incremental savings potential is less in new construction. However, new construction tends to have lower initial cost than retrofit. Ambient lighting in the table below is assumed to have bi-level functionality.

Economic and Environmental Impacts (with IOU incentives)

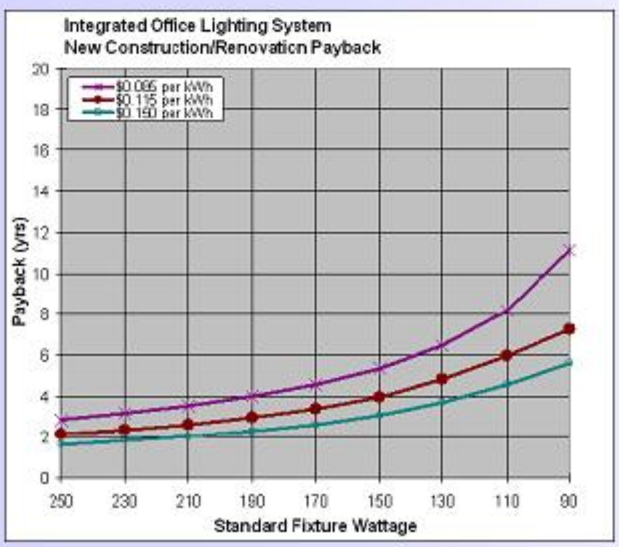
Base Case	Normal Power Density	IOLS Power Density	Material	Labor (Avg.)	Simple Payback ($0.115 per kWh)	Life Cycle Cost Savings*	Life Cycle CO_2 Savings per system
Retrofit: Two 3 lamp T8 Recessed Troffers, T8 under-cabinet task lighting	~2.0 W/ft²	0.6 W/ft²	$100-$500	$100	2-10 years	~$50-150 per workspace	~3,800 lbs
New Construction: Two 2 lamp T8 Troffers, T8 under-cabinet task lights	1.2 W/ft²	0.6 W/ft²	$0-$200	$0	0-3 years	~$250-500 per workspace	~2,700 lbs

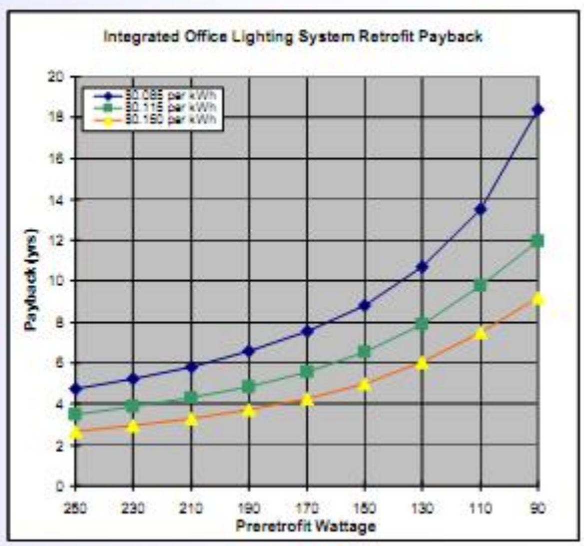
* Assume a 15-year fixture life and $0.115 energy cost per kWh. Savings are Net Present Value of total Life Cycle Costs compared to base case.

Study Results

Demonstration Site	Office Type	Lighting Retrofit	# of Offices	Energy Savings	Simple Payback (yrs)
Department of Motor Vehicles	Open-cubicle	Reduce ambient	11	20%	4
		Under-cabinet to PLS	11	83%	
GE Supply	Open-cubicle	Replace ambient	35	57%	7
		Under-cabinet to PLS	35	55%	
Bateson Building	Open-cubicle	Reduce ambient	18	27%	6
		Under-cabinet to PLS	18	86%	

Bateson Building, Sacramento, CA





Payback nomographs without IOU incentives.

IOLS workspace with LED desk lamps, daylight harvesting, and reduced overhead lighting, United Stationers

Considerations

Ease of Installation:

Typical installation time for IOLS is less than an hour; a plug-and-play fixture. Ambient lighting reduction can usually be completed by facility staff.

Attractiveness:

All campus users noted much improved light quality at their individual workstations.

Issues/Concerns:

High cost of some types of overhead fixtures replacements and task lighting leads to longer payback.

Conclusion

Cost Effectiveness:

Cost effective for retrofit, remodeling and new construction applications. Best retrofit paybacks are for replacing incandescent or T12 fluorescent fixtures.

Potential Impact:

Drastically reduced average fixture wattage. Huge energy savings for new construction and retrofit applications. Attractive option for both partitioned and private office space.

Applicability:

Primarily commercial office applications. May be used in home office environments, document research areas and similar task orientated work environments.

Considerations:

Improved lighting quality, easy to install, creates a personal workspace in open office areas.

Availability

The task fixtures are currently available from Finelite, Inc. and include multiple options such as wattage and mounting type. There are multiple fixture types in the series.

About PIER

This project was conducted by the California Energy Commission's Public Interest Energy Research (PIER) Program. PIER supports public interest energy research and development that helps improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

For more information see www.energy.ca.gov/research

Arnold Schwarzenegger, ***Governor***
California Energy Commission
Chair: Jackalyne Pfannenstiel *Vice Chair:* James D. Boyd
Commissioners: Arthur H. Rosenfeld, John L. Geesman, Karen Douglas

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Public Interest Energy Research Program *IOU Partnership Draft-Case Study*

Integrated Classroom Lighting System (ICLS)

'"Our instructors and students really enjoy the new systems. We are planning more ICLS installation around campus."

Victor Lai—Energy Manager, San Francisco State University

PIER Buildings Program **Research Powers the Future** **www.energy.ca.gov/research**

Energy and Carbon Savings Opportunity

High lighting quality, flexibility, energy savings, cost-competitive

Many classrooms provide mediocre lighting quality and have high energy costs. Although high-efficiency systems are available, they require a piecemeal approach when including automatic controls for occupancy and dimming. Specifying control components individually greatly increases design time and cost. Additionally, each component carries an individual warranty, causing confusion and potential delayed repair time if performance problems occur.

The Integrated Classroom Lighting System (ICLS) combines high quality lighting, increased flexibility, daylighting, and energy efficiency into an affordable, easy to use, and easy to maintain single-source solution. By increasing lighting quality and distribution with suspended indirect fixtures, the ICLS is able to achieve a lower power density than standard classroom systems. With fewer fixtures, fewer lamps, and fewer ballasts, operational and maintenance costs are reduced. This also means installation costs are often less than costs for traditional classroom fixtures. All this, in addition to improved user controls, means the ICLS can benefit many applications.

Product Overview

Energy Savings:

Typically 30-50% below Title 24 due to reduced lamp quantity, teacher controls, and occupancy sensors

Operation/Maintenance:

Easier access to lamps and ballasts than standard fixtures
Manufacturer is single warranty source

Manufacturer:

Finelite, Inc., www.finelite.com

Market:

K-12 and college classrooms, conference rooms, offices

Project Design Guides:

- New construction product specification available.
- LEED Fact Sheets
- http://pierpartnershipdemonstrations.com/

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Field Demonstration CSU Stanislaus and San Francisco State University

The ICLS demonstrations at CSU Stanislaus and San Francisco State University (SFSU) featured a range of options that can be included in the classroom package. Further demonstrations were conducted at CSU San Marcos in spring of 2006 and at Sonoma State University in summer of 2006.

Lessons Learned:

- HVAC ducting can cause installation delays and increase costs
- Ceiling type affects method of anchoring hanging hardware (i.e. simple cast concrete ceiling vs. post-tension concrete ceiling)
- Specific attention should be paid to ceiling mounted video projectors and interference with main fixtures and whiteboard fixture

IOU Partnership:

The University of California/California State University (UC/CSU) and Investor-Owned Utility (IOU) Partnership Program has identified incentives for this technology that could range from $100 to $600 per system. For more information please visit: www.uccsuiouee.org.

Top: Business Bldg. Room 125 at SFSU before retrofit.
Bottom: Business Bldg. Room 130 at SFSU after retrofit.

Installation Costs

Retrofit: Contractors without experience installing suspended-indirect fixtures may charge more than they would for installing recessed fixtures. Efficient installation may also be affected by items such as ceiling tile replacement and HVAC rerouting. Labor costs are assumed to be $3500 in the retrofit portion of the table below.

New Construction: Costs are often equal to or lower than those needed to install more conventional fixtures and thus assumed to be $0 in the table below.. Depending on available options chosen, ICLS material costs may be lower than standard fixtures as well. The entire table below is based on an ICLS system that includes two 28-foot fixture rows plus an 16-foot whiteboard fixture, integrated occupancy sensor, wall switches, and teacher controls.

Economic and Environmental Impacts (with IOU incentives)

	Retrofit			New Construction/Renovation			
Base Case	Material (avg.)	Simple Pay-back ($0.115 per kWh)	Life Cycle Cost Savings	Material	Simple Pay-back ($0.115 per kWh)	Life Cycle Cost Savings	Life Cycle CO_2 Savings per system
Classroom with 30 3-lamp T12 troffers	$4,992 (dimming)	~7.2 yrs	~$2,000	$0 -$500	-	-	~46,000 lbs
Classroom with 30 3-lamp T8 troffers		~11 yrs	~$0		~0 yr	$7,000	~27,000 lbs
Classroom with 30 3-lamp T12 troffers	$3,840 (no dim-ming)	~6 yrs	~$2,800		-	-	~44,000 lbs
Classroom with 30 3-lamp T8 troffers (A/B switching)		~8.5 yrs	~$500		~0 yr	$5,000	~30,000 lbs

* Assume a 15 year fixture life and $0.115 energy cost per kWh. Savings are Net Present Value of total Life Cycle Costs compared to base case.

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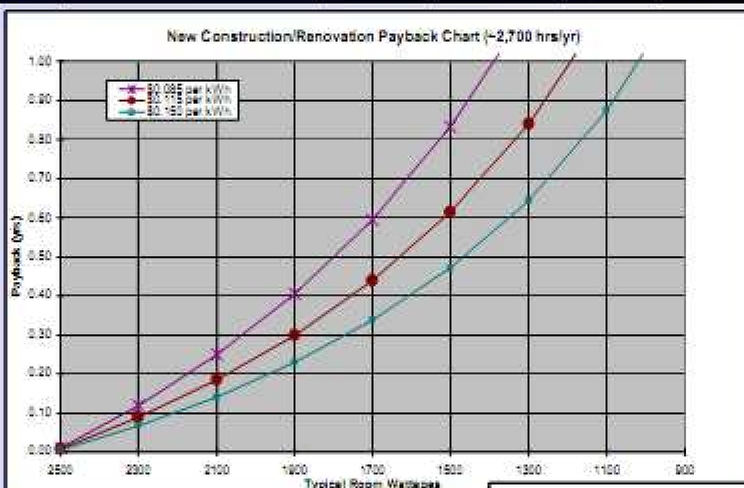
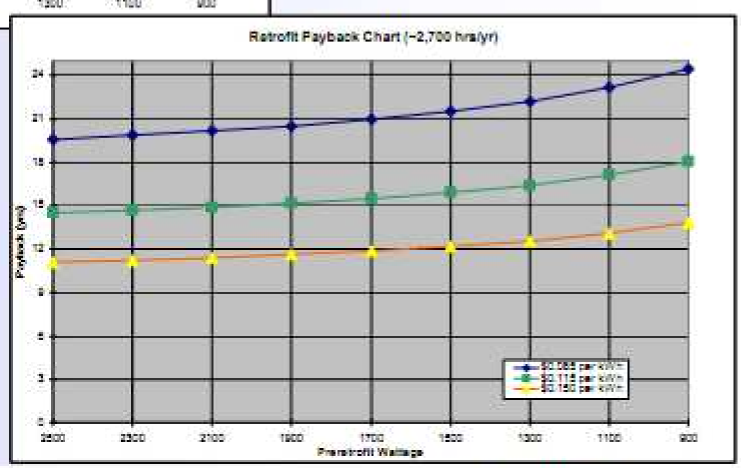
Study Results

SFSU Thornton Hall (Rooms 327 & 329)	Watts/room	Watts/ft²	Annual kWh	Energy Cost $/yr	Retrofit Cost $/room	New Construction Cost $/room
Pre-retrofit (24 troffers-34W T12)	1,728	1.71	4,752	$546.48		
ICLS Series 10 (Two 24' rows)	876	0.87	1,752	$201.48	$5,300	$4,500
Savings	852	0.85	3,000	$345.00		
CSU Stanislaus Bizzini Hall (Rooms 114 & 117)						
Pre-retrofit (22 troffers-32W T8)	2,523	2.34	5,046	$580.29		
ICLS Series 10 (Two 28' row)	840	0.78	1,680	$193.20	$5,500	$4,700
Savings	1,683	1.56	3,366	$387.09		
CSU Stanislaus Classroom Annex (Rooms 101 & 102)						
Pre-retrofit (12 troffers-34W T12)	1,728	2.03	4,752	$546.48		
ICLS Series 15 (Two 20' rows and one 16' row)	840	0.99	1,680	$193.20	$5,500	$4,700
Savings	888	1.04	3,072	$353.28		



Payback nomographs without incentives;

Lower wattage standard systems may be lower in cost compared to an ICLS depending on options. Higher wattage scenarios often yield very high savings potential. In many high wattage cases ICLS costs may be equivalent to or less than typical systems and would thus have an instant payback.



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Public Interest Energy Research Program *IOU Partnership Draft-Case Study*

Business Bldg. Room 125 with Series 10 fixtures at SFSU immediately after retrofit

Considerations

Ease of Installation:
Older buildings tended to have remnants of p revious retrofits which encumbered the wiring process. Ceiling tiles needed to be replaced in some classrooms.

Attractiveness:
Instructors and students noted better light quality, less glare, and better A/V mode.

Issues/Concerns:
Interference between ceiling mounted projectors and whiteboard fixture. For retrofitting lower wattage applications (with long paybacks), ICLS provides biggest benefit in improved lighting levels, more user controls, and reduced installation/maintenance costs.

Conclusion

Cost Effectiveness:
Desirable as a retrofit technology, cost effective in high wattage retrofit projects, new construction applications, or complete building renovations.

Potential Impact:
Huge potential impact for new construction, fixture type dramatically reduces power density.

Applicability:
Designed for practically any type of classroom, training room, or conference room. Indirect lighting utilized in the ICLS is recommended by the Illumination Engineering Society of America (IESNA) in their RP-3 publication and by the Collaborative for High Performance Schools (CHPS).

Considerations:
Positive user responses regarding controls and attractiveness. Facilities personnel noted improved maintenance characteristics and energy savings.

Availability

The Integrated Classroom Lighting System (ICLS) is currently available from Finelite, Inc. Please see their website for more information of fixture series and other ICLS options.

About PIER

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APPENDIX D – GLOSSARY

Term	Definition
A-lamp	The incandescent lamp most commonly used in North American households. The "A" designation refers to the lamp's bulbous shape.
amalgam	An alloy of mercury with other metals. Some CFLs use a mercury amalgam rather than standard mercury. An amalgam keeps mercury pressure in the discharge near its optimal value as lamp temperature changes. Amalgam lamps can produce more than 90 percent of maximum light output over a wide temperature range, but they can take longer to reach their full light output when started.
ambient temperature	The temperature of the surrounding air that comes into contact with the lamp and ballast. Ambient temperature affects the light output and active power of fluorescent lamp/ballast systems. Each fluorescent lamp-ballast system has an optimum ambient temperature at which it produces maximum light output. Higher or lower temperatures reduce light output. For purposes of lamp/ballast tests, ambient temperature is measured at a point no more than 1 meter (3.3 feet) from the lamp and at the same height as the lamp.
amplitude	The maximum absolute value attained by a periodic wave.
ANSI code	American National Standards Institute (ANSI) code that indicates the electrical operating designation of the lamp, which must match that of the ballast.
apparent power	The product of root-mean-square (rms) voltage and rms current.
application	The use to which a lighting system will be put; for example, a lamp may be intended for indoor residential applications.
arc tube	An envelope, usually quartz or ceramic that contains the arc of a discharge light source.
average rated life	The number of hours at which half of a large group of product samples fail under standard test conditions. Rated life is a median value; any lamp or group of lamps may vary from the published rated life.
ballast	A device required by electric-discharge light sources such as fluorescent or HID lamps to regulate voltage and current supplied to the lamp during start and throughout operation.
ballast access	The opening through which the ballast in a luminaire can be installed or replaced, either through the aperture or from above the luminaire.
ballast efficacy factor (BEF)	Sometimes called ballast efficiency factor, ballast efficacy factor is the ratio of the ballast factor to the active power (in watts), usually expressed as a percent. It is used as a relative measurement of the system efficacy of the fluorescent lamp/ballast combination.
ballast factor (BF)	The ratio of the light output of a fluorescent lamp or lamps operated on a ballast to the light output of the lamp(s) operated on a standard (reference) ballast. Ballast factor depends on both the ballast and the lamp type; a single ballast can have several ballast factors depending on lamp type.
ballast rated life	The number of hours at which half of a group of ballasts fail under standard test conditions. Rated life is a median value of life expectancy; any ballast, or group of ballasts, may vary from the published rated life.
beam angle	The angle at which luminous intensity is 50 percent of the maximum intensity.
beam appearance	The description of a beam's image on a wall as determined by subjective visual evaluations.
beam appearance	The description of the beam's image on a wall as determined by subjective visual evaluations of each lamp. The descriptive categories used are smooth, cloud, two-contour, ripple, and variegated.
beam spread	The width of a light beam, expressed in degrees. The beam of light from a reflector-type lamp (PAR, R, ER, or MR) can be thought of as a cone. The beam spread is the angular width of the cone. Common beam spreads are known as spot, narrow, narrow flood, and flood.
bi-level switching	Control of light source intensity at two discrete levels in addition to off.
bin	To sort or classify light sources (such as light emitting diodes) into groups according to their luminous intensity or color appearance.
brownout circuitry	For exit signs, brownout circuitry is designed to switch the sign over to battery supply if the voltage of the utility-supplied power drops below a specified value. Brownout circuitry is an option for some signs.
bulb designation	An abbreviation of the shape and size of a lamp's outer envelope. The letter or letters indicate the shape and the numbers indicate the bulb's maximum diameter in eighths of an inch.

Term	Definition
bulb finish	The coating, if any, which is applied to the inside surface of the bulb. Finishes are either clear, phosphor coated, or diffuse.
candela	The Systeme International d'Unities (SI) of luminous intensity. One candela is one lumen per steradian. Formerly, candle.
capacitor	A device used in electric circuitry to temporarily store electrical charge in the form of an electrostatic field. In lighting, a capacitor is used to smooth out alternating current from the power supply.
cathode-disconnect ballast	An electromagnetic ballast that disconnects the electrode-heating circuit after the lamps are started. Cathode-disconnect ballasts operate lamps at 60 hertz; they are sometimes called "hybrid" or "low-frequency electronic" ballasts. They operate lamps at lower power than other magnetic ballasts that produce similar light output.
center beam candlepower (CBCP)	Center beam candlepower is the luminous intensity at the center of a beam, expressed in candelas (cd).
chromaticity	The dominant or complementary wavelength and purity aspects of the color taken together, or of the aspects specified by the chromaticity coordinates of the color taken together. It describes the properties of light related to hue and saturation, but not luminance (brightness).
CIE	Abbreviated as CIE from its French title Commission Internationale de l'Eclairage, the International Commission on Illumination is a technical, scientific, and cultural organization devoted to international cooperation and exchange of information among its member countries on matters relating to the science and art of lighting.
coefficient of utilization (CU)	Coefficient of utilization is the ratio of the luminous flux (lumens) received on a plane to the light output (lumens) of the lamps. Coefficient of utilization depends on luminaire efficiency, distribution of light from the luminaire, size and shape of the room, and reflectances of surfaces in the room. Specifiers use the coefficient of utilization to evaluate how effectively a luminaire delivers light to a workplane.
color appearance	The resultant color perception that includes the effects of spectrum, background contrast, chromatic adaptation, color constancy, brightness, size and saturation.
color consistency	The measure of how close in color appearance random samples of a lamp or source tend to be.
color matching	The action of making a color appear the same as a given color. Often used as a method of evaluating the ability of a light source to render colors faithfully.
color rendering	A general expression for the effect of a light source on the color appearance of objects in conscious or subconscious comparison with their color appearance under a reference light source.
color rendering index (CRI)	A rating index commonly used to represent how well a light source renders the colors of objects that it illuminates. For a CRI value of 100, the maximum value, the colors of objects can be expected to be seen as they would appear under an incandescent or daylight spectrum of the same correlated color temperature (CCT). Sources with CRI values less than 50 are generally regarded as rendering colors poorly, that is, colors may appear unnatural.
color rendering index (CRI)	A rating index commonly used to represent how well a light source renders the colors of objects that it illuminates. For a CRI value of 100, the maximum value, the colors of objects can be expected to be seen as they would appear under an incandescent or daylight spectrum of the same correlated color temperature (CCT). Sources with CRI values less than 50 are generally regarded as rendering colors poorly, that is, colors may appear unnatural.
color shift	The change in a lamp's correlated color temperature (CCT) at 40% of the lamp's rated life, in kelvin (K).
color stability	The ability of a lamp or light source to maintain its color rendering and color appearance properties over its life. The color properties of some discharge light sources may tend to shift over the life of the lamp.
color variation	Lamps of the same type made by the same manufacturer may exhibit a certain degree of variation in color, even when operated under the same conditions and seasoned for the same about of time.
compact fluorescent lamp (CFL)	A family of single-ended fluorescent-discharge light sources with small-diameter [16-millimeter (5/8-inch) or less] tubes.
compatible ballasts	An abbreviated list of common ballasts that will provide the necessary circuitry for a photosensor to operate correctly. Other ballasts may also be compatible; contact the photosensor manufacturer for details.

Term	Definition
constant-wattage autotransformer (CWA)	The most common type of ballast used for HID lamps, it maintains a constant power (wattage) supply to the lamp when system input voltage fluctuates.
continuous dimming	Control of a light source's intensity to practically any value within a given operating range.
continuously variable signal	A signal that communicates data that can have a theoretically unlimited number of possible values between two end points. Examples include voltage, temperature, and illuminance.
contrast	Also known as luminance contrast, it is the relationship between the luminances of an object and its immediate background.
control signal range	The range of the electrical signal (in volts) that a control device uses to signal the dimming level to a ballast.
correlated color temperature (CCT)	A specification for white light sources used to describe the dominant color tone along the dimension from warm (yellows and reds) to cool (blue). Lamps with a CCT rating below 3200 K are usually considered warm sources, whereas those with a CCT above 4000 K usually considered cool in appearance. Temperatures in between are considered neutral in appearance. Technically, CCT extends the practice of using temperature, in kelvins (K), for specifying the spectrum of light sources other than blackbody radiators. Incandescent lamps and daylight closely approximate the spectra of black body radiators at different temperatures and can be designated by the corresponding temperature of a blackbody radiator. The spectra of fluorescent and LED sources, however, differ substantially from black body radiators yet they can have a color appearance similar to a blackbody radiator of a particular temperature as given by CCT.
cosine distribution	A property of a light source such that its luminous intensity in a particular direction is proportional to the cosine of the angle from the normal to the source.
CPF	Campus Payment Form; Contract between campus and IOU that establishes ability for IOU to pay campus for energy efficiency project achievement
CSA	Canadian Standards Association.
current THD	A measure of the degree to which the current waveform deviates from sinusoidal, expressed as a percentage. See total harmonic distortion (THD).
cutoff angle	The angle of light distribution from a luminaire, measured upward from nadir, between the vertical axis and the first line at which the bare source (lamp) is not visible.
cutoff classification	The classification system of the Illuminating Engineering Society of North America (IESNA) that describes the light distribution of an outdoor luminaire. Cutoff classifications define the luminous intensity limits in two illumination zones that occur within the range of 80° to 180° above nadir. North America (IESNA) that describes the light distribution of an outdoor luminaire. Cutoff classifications define the luminous intensity limits in two illumination zones that occur within the range of 80° to 180° above nadir.
cutoff luminaire	IESNA classification that describes a luminaire having a light distribution in which the candela per 1000 lamp lumens does not numerically exceed 25 (2.5%) at or above an angle of 90° above nadir, and 100 (10%) at or above a vertical angle of 80° above nadir. This applies to all lateral angles around the luminaire.
diffuser material	Diffusers scatter the light from a luminaire in all directions. Most diffusers in commodity residential-grade luminaires are made of plastic, usually acrylic or polycarbonate. Other materials include glass and alabaster.
dimming ballast	A device that provides the ability to adjust light levels by reducing the lamp current. Most dimming ballasts are electronic.
direct digital control (DDC)	The technology used by the components of a distributed control system. Direct digital control modules exchange digitally encoded signals with each other, indicating the status of devices connected to the network and executing commands when appropriate. Each module contains a programmable microprocessor, hardware for at least one type of network connection, and some means of detecting or changing a device's status.
direct light	Light emitted by a luminaire in the general direction of the task to be illuminated. The term usually refers to light emitted in a downward direction.

Term	Definition
direct luminaire	A luminaire that emits light in the general direction of the task to be illuminated. The term usually refers to luminaires that emit light in a downward direction.
direct uplight	Light emitted upward by a luminaire.
disability glare	A type of glare that causes a loss of visibility from stray light being scattered within the eye.
discomfort glare	The sensation of annoyance or even pain induced by overly bright sources.
distributed control system	A control system in which the computing hardware and software are contained in a network of control modules or multi-circuit control panels physically distributed throughout the facility.
driver	For light emitting diodes, a device that regulates the voltage and current powering the source.
dynamic outdoor lighting	Outdoor lighting that varies light level or other characteristics automatically and precisely in response to factors such as vacancy or the type of use of an outdoor location.
efficacy	The ratio of the light output of a lamp (lumens) to its active power (watts), expressed as lumens per watt.
electrode preheat current	The current flowing through a lamp's electrodes to heat them during starting.
electrodes	The structure that serves as the electric terminals at each end of electric discharge lamps.
electromagnetic interference (EMI)	The interference of unwanted electromagnetic signals with desirable signals. Electromagnetic interference may be transmitted in two ways: radiated through space or conducted by wiring. The Federal Communications Commission (FCC) sets electromagnetic interference limits on fluorescent lighting systems in FCC Part 18.
electromagnetic wave	A wave composed of perpendicular electric and magnetic fields. The wave propagates in a direction perpendicular to both fields.
electronic ballast	A ballast that uses electronic components instead of a magnetic core and coil to operate fluorescent lamps. Electronic ballasts operate lamps at 20 to 60 kHz, which results in reduced flicker and noise and increased efficacy compared with ballasts that operate lamps at 60 Hz.
emergency options	Refers to options available when exit signs are operated on a non-utility power supply such as a generator, a central battery unit that operates several exit signs, or an individual rechargeable battery. Options include whether or not the exit sign increases the brightness of the light source if the utility-supplied power fails.
EUL	Effective Useful Life
ignitor	A device, either by itself or in association with other components, that generates voltage pulses to start discharge lamps.
illuminance	The amount of light (luminous flux) incident on a surface area. Illuminance is measured in footcandles (lumens/square foot) or lux (lumens/square meter). One footcandle equals 10.76 lux, although for convenience 10 lux commonly is used as the equivalent.
illuminance	The density of luminous flux incident upon a surface. Illuminance is measured in footcandles (lumens/square foot) or lux (lumens/square meter). One footcandle equals 10.76 lux.
illumination	The process of using light to see objects at a particular location.
impedance	A measure of the total opposition to current flow in an alternating current circuit. The unit of impedance is the ohm Ω.
incident angle	The angle between a ray of light reaching a surface and a line normal (perpendicular) to that surface.
indication	The process of using a light source as something to be seen as in signaling.
indirect lighting	Light arriving at a surface after reflecting from one or more surfaces (usually walls and/or ceilings) that are not part of the luminaire.
infrared radiation	Any radiant energy within the wavelength range of 770 to 106 nanometers is considered infrared energy. (1 nanometer = 1 billionth of a meter, or 1 X 10^{-9} m).
initial light output	A lamp's light output, in lumens, after 100 hours of seasoning.

Term	Definition
instant start	A method of starting fluorescent lamps in which the voltage that is applied across the electrodes to strike the electric arc is up to twice as high as it is with other starting methods. The higher voltage is necessary because the electrodes are not heated prior to starting. This method starts the lamps without flashing. It is more energy efficient than rapid or preheat starting, but results in greater wear on the electrodes during starting. The life of instant-start lamps that are switched on and off frequently may be reduced by as much as 25 percent relative to rapid-start operation. However, for longer burning cycles (such as 12 hours per start), there may be no difference in lamp life for different starting methods.
intensity (luminous intensity)	Total luminous flux within a given solid angle, in units of candelas, or lumens per steradian.
interoperability	The ability to communicate such information as temperature, illuminance levels, status of security devices, and occupancy among building systems and their controls.
IOU	Investor Owned Utility; PG&E, SCE, SCG, SDG&E
isotemperature	A set of coordinates within which all points have the same temperature. In a color space diagram, isotemperature lines represent lights with identical correlated color temperatures.
junction temperature	For light emitting diodes, the temperature of the light-emitting portion of the device (see PN junction), which is inversely correlated with its light output.
Kelvin	Color temperature is measured in degrees Kelvin, which indicates the hue of a specific type of light source. Higher temperatures indicate whiter, "cooler" colors, while lower temperatures indicate yellower, "warmer" colors.
lamp	A radiant light source.
lamp base position	The location of the lamp socket, either in the center of the top of the ballast or on the side of the ballast. Modular ballasts for circular compact fluorescent lamps (CFLs) have a lamp socket located at the end of a wiring harness.
lamp current	The current flowing between a lamp's electrodes during operation.
lamp efficacy	The ratio of the light output of a lamp (lumens) to its active power (watts), expressed as lumens per watt (LPW).
lamp electrode voltage	Voltage to the electrodes to operate a lamp.
lamp envelope	The shape of either the bare lamp or the capsule surrounding the lamp. Common shapes include quad, triple tube, four-tube, coiled tube, A-line, circular, square, globe, capsule (bullet), reflector, and decorative.
lamp life	The median life span of a very large number of lamps (also known as the average rated life). Half of the lamps in a sample are likely to fail before the rated lamp life, and half are likely to survive beyond the rated lamp life. For discharge light sources, such as fluorescent and HID lamps, lamp life depends on the number of starts and the duration of the operating cycle each time the lamp is started.
lamp life	The number of hours at which half of a large group of lamps have failed when operated under standard testing conditions.
lamp lumen depreciation (LLD)	The reduction in lamp light output that progressively occurs during lamp life.
lamp operating current	Current flowing through a lamp during normal operation.
lamp quantity and type	The number of lamps (in parentheses) used by the luminaire, followed by a generic designation indicating the type.
lamp rated life	The number of operating hours at which half of a large group of product samples are expected to fail. The rated life is a median value of life expectancy; individual lamp life may vary considerably from the published rated life and operating conditions (e.g., temperature, hours per start) may affect actual life because rated life is based on standard test conditions. In addition, the way a product fails can vary by technology. For example, incandescent lamps abruptly stop producing any light while LEDs are considered to have failed when their light output drops below a certain fraction of the initial level.
lamp shield type	The material used in a luminaire to shield the lamp from the environment. Lamp shields are required by Underwriters Laboratories for some lamp types.

Term	Definition
lamp starting current	Current flowing through a lamp during starting operation.
LCCA	Life Cycle Cost Analysis. Includes first cost, ongoing cost, effective useful life, and discount rate to determine net present value of a system relative to business as usual or other systems.
light loss	The reduced light output caused by a circuit-level power reducer expressed as a percentage of the light output without the circuit-level power reducer. (Full system output minus reduced output with a lighting-circuit power reducer divided by the full system output times 100.)
light pollution	An unwanted consequence of outdoor lighting that includes such effects as sky glow, light trespass, and glare.
light power density (LPD)	Sometimes referred to as power density. A measurement of the ratio of light output in an area and the electric power used to produce that light. LPD is determined by dividing the total light output by the total wattage consumed and is measured in lumens per watt.
light trespass	An undesirable condition in which exterior light is cast where it is not wanted.
line voltage	The voltage supplied by the electric power infrastructure, typically 110-120 VAC at 60 Hz for homes in North America.
load capacity	The maximum total power that can be connected to an occupancy sensor.
load shedding	The practice of turning off electrical devices during peak energy demand hours to reduce building energy use.
louver	A fixed shield, usually divided into small cells, that is attached to the face of a luminaire to reduce direct glare.
low battery voltage disconnect	Indicates whether or not an exit sign has a circuit that is designed to disconnect the battery after it is discharged. This circuit prevents damage to the battery. Lead acid and lead calcium batteries need this circuit, but nickel cadmium batteries do not.
low-voltage circuit protection	Protection for a ballast's low-voltage control circuit from high voltage spikes. Does not apply to high-voltage controls.
lumen (lm)	A unit measurement of the rate at which a lamp produces light. A lamp's light output rating expresses the total amount of light emitted in all directions per unit time. Ratings of initial light output provided by manufacturers express the total light output after 100 hours of operation.
lumen (lm)	A unit measurement of the rate at which a lamp produces light. A lamp's lumen output rating expresses the total amount of light the lamp emits in all directions per unit time.
lumen depreciation	The decrease in lumen output that occurs as a lamp is operated, until failure. Also referred to as lamp lumen depreciation (LLD).
lumen maintenance	The ability of a lamp to retain its light output over time. Greater lumen maintenance means a lamp will remain brighter longer. The opposite of lumen maintenance is lumen depreciation, which represents the reduction of lumen output over time. Lamp lumen depreciation factor (LLD) is commonly used as a multiplier to the initial lumen rating in illuminance calculations to compensate for the lumen depreciation. The LLD factor is a dimensionless value between 0 and 1.
lumen maintenance	The lumens produced by a light source at any given time during its operating life as a percentage of its lumens at the beginning of life.
luminaire	A complete lighting unit consisting of a lamp or lamps and the parts designed to distribute the light, to position and protect the lamp(s), and to connect the lamp(s) to the power supply. (Also referred to as fixture.)
luminaire angle	The vertical (altitude) angle used in luminaire photometry to express the direction of the light output being measured. Light coming straight down is at 0° (the nadir).
luminaire efficacy	The ratio of the measured light output of a luminaire to its active power, expressed in lumens per watt (LPW).
luminaire efficiency	The ratio, expressed as a percentage, of the light output of a luminaire to the light output of the luminaire's lamp(s). Luminaire efficiency accounts for the optical and thermal effects that occur within the luminaire under standard test conditions.
luminance	The photometric quantity most closely associated with the perception of brightness, measured in units of luminous intensity (candelas) per unit area (square feet or square meter).

Term	Definition
luminance contrast	Luminance contrast quantifies the relative brightness of an object against its background. It can range from zero and one. The closer the luminance contrast is to one, the greater the relative brightness of the object against its background.
luminous flux	Luminous radiant power, measured in lumens. The overall light output of a lamp or luminaire.
luminous intensity	The luminous flux on a small surface centered on and normal to the direction divided by the solid angle (in steradians) that the surface subtends at the source. Luminous intensity can be expressed in candelas or in lumens per steradian.
lux (lx)	A measure of illuminance in lumens per square meter. One lux equals 0.093 footcandle.
maximum ambient temperature	The maximum ambient temperature for which a compact fluorescent lamp (CFL) product is warranted to achieve rated life.
maximum ballast case temperature	The maximum temperature of the ballast case for which the manufacturer's life rating is valid.
maximum relative light output	Illuminance measured at a fixed distance from the lamps.
mean light output	Light output typically evaluated at 40% of rated lamp life. In combination with initial light output, mean light output may be used to estimate lamp lumen depreciation.
medium bi-pin	A type of connector commonly used on T-8 and T-12 fluorescent lamps. Two small pins protrude from the lamp ends, which are inserted into a socket in the fixture.
mercury vapor (MV) lamp	A high-intensity discharge lamp type that uses mercury as the primary light-producing element. Mercury vapor lamps produce light with a CCT from 3000 to 7000 K. Mercury vapor lamps with clear outer bulbs have CRI values from 15 to 25, whereas phosphor-coated lamps have CRI values from 40 to 55. Mercury vapor lamps are less efficacious than other HID lamp types, typically producing only 30 to 65 LPW, but they have longer lamp lives and lower initial costs than other HID lamp types.
metal halide (MH) lamp	A high-intensity discharge lamp type that uses mercury and several halide additives as light-producing elements. Metal halide lamps have better color properties than other HID lamp types because the different additives produce more visible wavelengths, resulting in a more complete spectrum. Metal halide lamps are available with CCTs from 2300 to 5400 K and with CRI values from 60 to 93. Efficacies of metal halide lamps typically range from 75 to 125 LPW.
metal halide lamp	A high-intensity discharge (HID) lamp that uses mercury and several halide additives as light-producing elements. Metal halide lamps have better color properties than other HID lamp types because the different additives produce light distributed over more visible wavelengths, resulting in a more complete spectrum. Metal halide lamps are available with CCTs from 2300 to 5400 K and with CRI values from 60 to 93. Efficacies of metal halide lamps typically range from 75 to 125 LPW.
metamers	Lights of the same color but of different spectral power distribution.
miniature bi-pin	A type of connector commonly used on T-5 lamps. Similar in design to but smaller than medium bi-pin connectors, it uses two small pins that protrude from the lamp ends and are inserted into a fixture socket.
minimum ambient temperature	The minimum temperature at which a compact fluorescent lamp (CFL) product is warranted to start.
minimum bulb wall temperature (MBWT)	The temperature of the coldest spot on a lamp's bulb wall. MBWT is determined by the ambient temperature, the heat generated within the luminaire, and the luminaire's heat dissipation effectiveness. The coldest spot on a lamp wall is where the mercury vapor tends to condense because pressure is lowest there.
minimum dimmed level	The lowest dimmed level achieved by a ballast, expressed as a percentage of that ballast's maximum light output.
minimum load requirement	The minimum power required for an occupancy sensor to operate properly.

Term	Definition
minimum required efficacy	The minimum lamp efficacy required by EPACT, expressed in lumens per watt (LPW).
minimum starting temperature	The minimum ambient temperature at which a ballast will reliably start fluorescent lamps.
monochromatic	For light, consisting of a single wavelength and having a very saturated color.
multitap	A passive distribution component composed of a directional coupler and a splitter with two or more output connections.
noncutoff luminaire	IESNA classification that describes a luminaire light distribution in which there is no candela limitation in the zone above maximum candela. (See also cutoff classification and cutoff angle.)
open-circuit voltage	The voltage applied across the output terminals of a ballast when no load is connected. Open-circuit voltage is the voltage applied across a lamp circuit to start the lamp. After starting, the voltage rapidly decreases and stabilizes at the operating voltage.
operating cycle	The frequency with which lamps are cycled on and off.
operating electrode voltage	The voltage that a ballast supplies to a lamp's electrodes.
operating position	The manufacturer-recommended operating position for a lamp.
operating voltage	The voltage a ballast supplies to a lamp's electrodes.
PAR lamp	An incandescent or tungsten-halogen incandescent lamp with a hard glass bulb and an interior reflecting surface, a precisely placed filament, and a lens to control beam spread. The lens is hermetically sealed to the reflector. Metal halide PAR-lamps are also now available.
pendant mounting	A suspension device between a mount and a luminaire.
phosphors	Materials used in a light source to produce or modify its spectral emission distribution. In fluorescent and high intensity discharge lamps, the phosphors fluoresce (emit visible light) when excited by ultraviolet radiation produced by mercury vapor inside the lamp when energized by an electric arc. In a light emitting diode, phosphors convert short-wavelength light or ultraviolet radiation produced by a semiconductor die into longer-wavelength light, usually with the goal of producing white illumination.
photopic	Vision mediated essentially or exclusively by the cones. It is generally associated with adaptation to a luminance of at least 3.4 cd/m^2.
photosensor	A device used to integrate an electric lighting system with a daylighting system so lights operate only when daylighting is insufficient.
PN junction	For light emitting diodes, the portion of the device where positive and negative charges combine to produce light.
polarized light	Light whose vibrations are oriented in (or around, for partially polarized light) a specific plane.
position factor	The light output of the lamp in a certain position divided by the light output of the lamp in the base-up position.
positive affect	Relatively mild shifts in current mood in a positive direction.
power	The power used by a device to produce useful work (also called input power or active power). In lighting, it is the system input power for a lamp and ballast or driver combination. Power is typically reported in the SI units of watts.
power factor (PF)	The ratio of active power (in watts) to apparent power (in rms volt-amperes), power factor is a measure of how effectively an electric load converts power into useful work. Power factor (PF) is calculated using the equation PF = (active power) / [(rms voltage) x (rms current)]. Phase displacement and current distortion both reduce power factor. A power factor of 0.9 or greater indicates a high power factor ballast.

Term	Definition
power line carrier (PLC)	A system that transmits high-frequency (50 to 500 kHz) analog or digital signals via the power lines of a building. These signals control devices such as luminaires or contain voice transmissions such as intercom messages. Some commercial and residential energy management systems also use power line carrier systems.
power quality	The degree to which current and voltage wave forms conform to a sinusoidal shape and are in synchronous phase with each other. Poor power quality results when the wave forms are distorted and/or out of phase and can interfere with data communications, cause inefficient operation or failure of other electrical equipment on the same supply line, and result in excessive current in electrical distribution lines.
power reduction efficiency factor	A measure of the efficiency of a power reducer, representing the reduced light output in percent from a lighting-circuit power reducer divided by the reduced active power in percent from a lighting circuit power reducer.
preheat	A method of starting fluorescent lamps in which the electrodes are heated before a switch opens to allow a starting voltage to be applied across the lamp. With preheat starting, the lamp flashes on and off for a few seconds before staying lit because several starting attempts may be necessary to establish the electric arc across the lamp electrodes. Often, the luminaire's start button must be held down until the lamp lights. Preheat ballasts are less energy efficient than rapid-start or instant-start ballasts.
preheat time	For rapid-start lamps, the time from the onset of lamp current to the lamp arc's striking, during which the lamp electrodes are heated to ease starting.
preheating time	Also referred to as preheat time and lamp preheat time. The length of time that a ballast heats a lamp's electrodes before initiating the lamp arc. Rapid start ballasts preheat a lamp before initiating the arc in order to ease starting. Too short or too l
primary	Any one of three lights in terms of which a color is specified by giving the amount of each required to match it by additive combination.
prismatic lens	An optical component of a luminaire that is used to distribute the emitted light. It is usually a sheet of plastic with a pattern of pyramid-shaped refracting prisms on one side. Most ceiling-mounted luminaires in commercial buildings use prismatic lenses.
programmed start	Refers to a type of rapid start ballast that optimizes the starting process by waiting until the lamp's electrodes have been heated to apply the starting voltage, thus easing the load to the electrode and extending lamp life. Standard rapid start ballasts heat the electrodes during the starting process to allow quicker starting without flicker.
pulse-width modulation	Operating a light source by very rapidly (faster than can be detected visually) switching it on and off to achieve intermediate values of average light output; the frequency and the duty cycle (percentage of time the source is switched on) are important parameters in the modulation.
R lamp	A common reflector lamp. An incandescent filament or electric discharge lamp in which the sides of the outer blown-glass bulb are coated with a reflecting material so as to direct the light. The light-transmitting region may be clear, frosted, or patterned.
rapid start	A method of starting fluorescent lamps in which the electrodes are heated prior to starting, using a starter that is an integral part of the ballast. Heating the electrodes before starting the lamps reduces the voltage required to strike the electric arc between the electrodes. A rapid-start system starts smoothly, without flashing.
rated average lamp life	Also referred to as lamp rated life. Lamps are tested in controlled settings and the point at which 50% of a given sample burns out is listed as the lamps' rated average lamp life.
rated lamp life	The number of hours at which half of a group of product samples fail. The rated life is a median value of life expectancy; any lamp or group of lamps may vary from the published rated life. Rated life is based on standard test conditions.
rated light output	The sum of the initial rated lamp lumens of the lamp(s) that were supplied with the luminaire.
rated light output from lamp(s)	The sum of the initial rated lamp lumens of the lamp(s) that were supplied with the luminaire.
rated lumen	Also referred to as rated light output from lamp in lumens. Lumen refers to a unit measurement of the rate at which a lamp produces light. A lamp's light output rating expresses the total amount of light emitted in all directions per unit time. Manufacturers rate their lamps' initial light output after 100 hours of operation.

Term	Definition
RE70	Designation referring to lamps that use rare-earth phosphors and have color-rendering index values of 70-79.
RE80	Designation referring to lamps that use rare-earth phosphors and have color-rendering index values of 80-89.
RE80 HLO, LL	An RE80 lamp with additional enhancements of high light output (HLO) and/or long life (LL).
RE90	Designation referring to lamps that use rare-earth phosphors and have color-rendering index values equal to or greater than 90.
reactive power	Power that creates no useful work. It results when current is not in phase with voltage. It is calculated using the equation reactive power = V x A x sin (q) where q is the phase displacement angle.
reflectance	A measure of the ability of an object to reflect or absorb light, expressed as a unitless value between 0 and 1. A perfectly dark object has a reflectance of 0, and a perfectly white object has a reflectance of 1.
relative system efficacy	The ratio of relative light output (RLO) to system active power. For each lamp type, relative system efficacy is normalized to the highest value at the maximum light output level, which is assigned a relative system efficacy value of 100%.
restrike time	The time required for a lamp to restrike, or start, and to return to 90% of its initial light output after the lamp is extinguished. Normally, HID lamps need to cool before they can be restarted.
rms current	Root-mean-square current, a value that quantifies the magnitude of a current that varies with time (as in ac circuits). Rms current is calculated as the square root of the squared values of current over one complete cycle. Rms current delivers the same power to a resistive load as an equivalent steady dc current.
root-mean-square (rms)	The effective average value of a periodic quantity such as an alternating current or voltage wave, calculated by averaging the squared values of the amplitude over one period and taking the square root of that average.
semiconductor	A material whose electrical conductivity is between that of a conductor and an insulator; the conductivity of most semiconductors is temperature dependent.
semicutoff luminaire	IESNA classification that describes a luminaire light distribution in which the candela per 1000 lamp lumens does not numerically exceed 50 (5%) at or above an angle of 90° above nadir, and 200 (20%) at or above a vertical angle of 80° above nadir. This applies to all lateral angles around the luminaire.
sensitivity adjustment	A trim potentiometer (sometimes called a "trim pot") or a set of dip switches used to refine the response function of a photosensor. Some photosensors include a remote trim pot that allows for adjustment at a distance from the photosensor housing.
shielding	Blocking an electric or magnetic field with a metallic substance. The incident field induces currents in the metallic substance, and these currents induce a field that opposes the incident field. Shielding reduces radiated electromagnetic waves. Electronic components, wires, lamps, and devices can all be shielded.
sky glow	Brightening of the sky caused by outdoor lighting and natural atmospheric and celestial factors.
skylight	A device similar to a window that is placed in a roof, allowing sunlight to enter a structure, thus reducing the need for electric lighting. Skylights can be used to reduce peak load demand by taking advantage of sunlight during the peak demand time of the day.
sound rating	Magnetic ballasts sometimes produce a humming noise caused by vibration of the magnetic core. Electronic ballasts operate at high frequencies and are usually less noisy. Ballasts are rated from “A” to “F” based on their noise levels. Ratings define the range of ambient sound levels in which people will not notice the ballast noise. The higher the rating, the more noise that will be required to mask the ballast hum.
spectral power distribution (SPD)	A representation of the radiant power emitted by a light source as a function of wavelength.
specular angle	The reflected angle of light striking a surface, which is equal to and in the same plane as the incident angle.
specular reflection	Light incident on a surface that is redirected at the specular angle. Glossy or shiny surfaces exhibit a high degree of specular reflection.
spill light	Light that falls outside of the area intended to be lighted.

Term	Definition
starting method	The method a ballast uses to start a lamp. For compact fluorescent lamps (CFLs), ballasts use one of three methods: preheat, instant start, or rapid start. Dimming electronic ballasts use one of these starting methods: rapid start, programmed start, or controlled rapid start.
starting time	The time it takes the lamp to start from the point at which voltage is applied to the lamp until stable operation.
starting voltage	The voltage applied across the lamp during starting.
supply voltage	The voltage, usually direct, applied by an external source to the circuit of an electrode.
system efficacy	Also referred to as relative system efficacy, system efficacy is a measurement of a system's ability to convert electricity into light. Measured in lumens per watt (LPW), system efficacy is the ratio of the light output (in lumens) to the active power (in watts).
time delay range	For motion sensors, the range of time that may be set for the interval between the last detected motion and the turning off of the lamps.
total harmonic distortion (THD)	A measure of the degree to which a sinusoidal wave shape is distorted by harmonics, with higher values of THD indicating greater distortion.
transformer	Transformers are electrical devices with no moving parts, which change distribution voltages to higher or lower levels. When used with incandescent or halogen lamps, they typically step 120-V distribution downward to 12V, although 5.5V and 24-V models are also offered.
tri-level switching	Control of light source intensity at three discrete levels in addition to off.
trim option	A decorative luminaire accessory.
tri-phosphor	A mixture of three phosphors to convert ultraviolet radiation to visible light in fluorescent lamps; each of the phosphors emits light that is blue, green or red in appearance with the combination producing white light.
tri-phosphors	Tri-phosphors are a blend of three narrow-band phosphors (red, blue, and green) that provide improved color rendition and higher light output versus some other types of phosphors.
ultraviolet	Any radiant energy within the wavelength range 100 to 400 nanometers is considered ultraviolet radiation (1 nanometer = 1 billionth of a meter, or 1×10^{-9} m).
uniformity	The degree of variation of illuminance over a given plane. Greater uniformity means less variation of illuminance. The uniformity ratio of illuminance is a measure of that variation expressed as either the ratio of the minimum to the maximum illuminance or the ratio of the minimum to the average illuminance.
uplight	Light directed upward at greater than 90° above nadir. The source of uplight can be from a combination of direct uplight and reflected light.
venting	Holes in the reflector assembly of a down light.
vertical illuminance	The average density of luminous flux incident on a vertical surface, measured in footcandles (fc) or lux (lx). One fc equals 10.76 lx.
visual performance	The quantitative assessment of the performance of a visual task, taking into consideration speed and accuracy.
voltage drop	The difference between the voltages at the transmitting and receiving ends of a feeder, main, or service.
voltage regulation	The change in output voltage that occurs when the load (at a specified power factor) is reduced from rated value to zero, with the primary impressed terminal voltage maintained constant.
wall-washing	The practice of illuminating vertical surfaces, such as walls. Wall-washer luminaries are designed to illuminate vertical surfaces.
warm-up time	The time it takes for a lamp to produce 90% of its initial light output when it is started, unless otherwise indicated.
wavelength	The distance between two corresponding points of a given wave. Wavelengths of light are measured in nanometers (1 nanometer = 1 billionth of a meter, or 1×10^{-9} m)
weight	The weight of a luminaire plus ballast (except for certain track luminaires with separately mounted ballasts, when the weight is that of the lamp and track head only). For modular compact fluorescent lamp (CFL) ballasts, the weight of the ballast without a lamp. For self-ballasted CFLs, "weight" indicates the total product weight.

Term	Definition
zenith	In the lighting discipline, zenith is the angle pointing directly upward from the luminaire, or 180°. Zenith is opposite nadir. In astronomical usage, zenith is the highest point in the sky, directly above the observation point.