LIGHTING HANDBOOK AND RETROFIT GUIDE

US FOREST SERVICE

INTRODUCTION AND ACKNOWLEDGEMENTS

Welcome to the Lighting Handbook and Retrofit Guide

This guide was developed in partnership with Lawrence Berkeley National Laboratory, the California Lighting Technology Center at the University of California, Davis, the Forest Service Missoula Technology and Development Center, and many dedicated Forest Service staff members.

Evidence of the impact human activities are having on the environment proves it is imperative to take action in saving energy and resources. Given that lighting is a significant portion of our energy consumption, now is the right time to put forth effort in making positive changes to the way we consume energy to light our world.

This lighting handbook and retrofit guide aims to assist in the process of developing high-performance, energy efficient, quality lighting retrofits for the Forest Service community. During the development of this guide, field evaluations were made to a wide range of Forest Service facilities in an effort to identify the most applicable recommendations. We thank those who welcomed us to their facilities.

This guide covers both commercial and residential spaces in an effort to include the many types of facilities within the U.S. Forest Service. The recommendations can be applied to existing owned facilities, leased facilities (when applicable), and future owned or leased facilities.

How to use this handbook and guide

This handbook and guide is intended to connect users to resources and information related to energy efficient lighting. Within the electronic interface of this handbook, there are links that bridge directly to other chapters, as well as to outside resources. Sections of this guide can be printed, but we ask that resources be conserved and for readers to take advantage of the electronic format.

This handbook and guide will cover the benefits of conducting lighting retrofits, recommendations to focus on, a specifications guide to ensure what you want is what you get, and a guide to recycling. In an effort to cover industry-specific information for a wide audience, we have included a lighting basics reference appendix: ***Back to Basics***. Notice that on the footer of each page throughout the publication, ***Back to Basics*** is available as a direct link to the reference section, for further explanations of lighting terminology used in this handbook and guide. Bookmarks are also available, which can be accessed by selecting View>Navigation tabs>Bookmarks in the main menu.

We believe this handbook and guide will greatly help the exploration of lighting and how to approach a lighting retrofit. Enjoy!

Example Call Out Box

Located throughout this guide are many call out boxes, like this one. These provide more detailed information about the main body text.

Technical terms within the text are linked to the reference guide, ***Back to Basics***. Some text with online addresses are linked to outside resources. All links can be identified when the cursor changes to .

First edition completed in January 2008.

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Real benefits in saving energy

There are many benefits to updating light fixtures in residential and commercial spaces. First, it will save energy, reduce maintenance and labor costs over the life of the source and fixture (a.k.a. luminaire), and improve lighting quality. The benefit of saving energy not only lowers the operating costs, but it also reduces greenhouse gas emissions, preserving our natural resources. Now those are big savings!

In addition to saving energy, this guide also explains how to look for ways to lower maintenance costs and increase efficiency by minimizing inconsistencies in lighting technologies. In turn, this will provide a greater understanding and insight to making valuable retrofits in the future.

Conducting a lighting retrofit will provide the potential for more efficient and longer life technologies. According to ***Flex Your Power***, a California based organization that provides resources for energy efficiency and conservation, replacing just five of the most frequently used lamps in residential spaces with ***ENERGY STAR*** qualified compact fluorescent lamps (CFLs) can save more than 75% each year in lighting energy costs. Fluorescents offer such dramatic savings because they are 3 to 4 times more efficient and last up to 10 times longer than standard incandescent lamps. This means more reliability, better security, and reduced maintenance costs. It is safe to say that electric lighting is used almost everywhere in residential and commercial spaces, but the exact electrical costs attributed to lighting are often drastically underestimated. As a nation, the United States spends about one-quarter of the total electricity budget on lighting, or more than $37 billion annually. Converting to energy efficient technologies that are available today will help cut lighting costs at least 30% to 60% while enhancing lighting quality and reducing environmental impacts.

In addition to saving energy, time, and maintenance costs from the use of CFLs, the amount of hazardous materials and greenhouse gases that enter the environment will be reduced. The main hazardous material associated with fluourescent lighting is mercury. According to ***ENERGY STAR***, CFLs contain a very small amount of mercury sealed within the glass tubing – an average of 5 milligrams – about the amount that would cover the tip of a ballpoint pen. By comparison, older thermometers contain about 500 milligrams. Mercury is an essential component of CFLs that allows the lamp to be an efficient light source. There is absolutely no hazard when the lamps are intact and used properly, however, if a fluorescent lamp breaks, a small amount of mercury vapor will be released (see the ***Burned Out?*** section for what to do if a fluorescent lamp breaks). Many manufacturers have taken significant steps to reduce mercury in fluorescent lighting products. Even though incandescent lamps do not contain mercury, they do require increased wattage and in turn, more electricity.

Decreasing electrical consumption by utilizing CFLs or other energy efficient sources is the first step to reducing power plant emissions known as greenhouse gases. According to the ***U.S. Environmental Protection Agency (EPA)***, greenhouse gas emissions are gases that trap heat in the earth's atmosphere. Some greenhouse gases are naturally emitted

What is ENERGY STAR?

ENERGY STAR is a voluntary product labeling program run by the U.S. Department of Energy and the U.S. Environmental Protection Agency. The label helps consumers identify energy efficient products, from lamps, luminaires, and lighting fixtures to appliances, air conditioners, and other products.

Replacement products that meet certain minimum performance requirements are granted the right to carry the ENERGY STAR label. The specifications for CFLs and residential light fixtures set performance levels for energy efficiency in terms of light output per watt of electricity consumed, rated lifetime, color rendering ability, ballast performance, and product warranty.

ENERGY STAR lighting products carry a two-year warranty, which is double the industry standard. They can be found at most home shopping centers, lighting showrooms, and specialty stores.

For more information visit ***www.energystar.gov***.

energy CHANGE FOR THE BETTER WITH ENERGY STAR

into the atmosphere, but many are created and emitted solely through human activities. One such gas that is emitted as a result of human activities in addition to being caused naturally is carbon dioxide. Most over-production of this gas is from the burning of fossil fuels (e.g. oil, natural gas, and coal), solid waste, trees and wood products, and as a result of other chemical reactions (e.g., manufacture of cement). Reducing energy consumption and harmful materials that enter the environment is an effective way to decrease human impact on the planet. Refer to the callout box below, ***What is a Carbon Footprint?*** for resources about the harmful impacts of carbon output caused by human activities, and how to be a part of the effort to stop climate change.

Recycling should be a very important role in the life of fluorescent lighting because it can reduce the amount of mercury and harmful gases entering the environment. If recycled properly, nearly 100% of the materials in CFLs can be reused and kept out of the environment. It is just as important to recycle as it is to use energy efficient lamps. Putting fluorescent lamps in conventional waste systems is not a safe method of disposal for people or the environment. See the ***Burned Out?*** section for resources on how and where to manage efficient lamp materials.

What is a Carbon Footprint?

According to ***Wikipedia***, one definition of carbon footprint is the total amount of carbon dioxide attributable to the actions of an individual (mainly through their energy use) over a period of time. The term comes from the idea that a footprint is what has been left behind as a result of the individual's activities. The following links have been provided for more details about the carbon footprint concept and to calculate estimates of individual carbon output:

Carbon Footprint
Calculate Your Impact
Greenhouse Gas Equivalencies Calculator
Personal CO_2 Emissions Calculator

According to ***www.nature.org***, switching to CFLs will decrease carbon footprint and fight climate change. This easy switch will save 100 pounds of carbon emissions for each incandescent lamp replaced over its average lifetime. For more information on making changes in the home and workplace, visit ***www.nature.org's*** list of ***Easy Things You Can Do To Help Our Climate***.

The benefits of updated lighting goes beyond saving energy and reducing hazardous waste. Updating lighting fixtures and/or sources should also improve overall lighting quality. Improving the quality of lighting in facilities and offices can improve work environments and employee satisfaction. There is increasing evidence through lighting industry research correlating how a space is lit to workplace satisfaction. For more information on industry research and lighting's direct link to productivity, see the article, ***Lighting Strategies*** by Craig DiLouie.

There are many benefits to saving energy and the benefits as discussed above can be measured on many different scales. Energy saving actions taken today may benefit the environment for future generations. We hope this guide is a useful and valuable resource in discovering the changes that can be made at work or at home to save energy, reduce maintenance, and improve lighting quality.

Quick Facts

There is a wealth of information about lighting available on the Web, but searching for accurate and thorough information may be challenging. There is a new online resource available, ***The Lighting Portal***, aimed at addressing the need for energy efficiency awareness and the exchange of information related to energy efficient lighting.

The Lighting Portal Forum allows users to ask questions and participate in discussion boards on many topics revolving around lighting energy efficiency (e.g. the latest technologies, retrofit questions, installation issues, lighting fundamentals and approaches). ***The Lighting Portal*** also includes links to many other lighting related resources and to manufacturers with latest energy efficient technologies. It is accessible at ***www.thelightingportal.ucdavis.edu***.

Quick Facts

Mercury is an element found naturally in the environment. Mercury emissions in the air can come from both natural and man-made sources. Coal-fired power plants are the largest man-made source because mercury that naturally exists in coal is released into the air when coal is burned to make electricity. To find out more information on mercury in the environment and recycling view the ***Burned Out?*** section.

WHAT'S IN A LIGHT?

AN INTRODUCTION TO TODAY'S LIGHTING TERMS

There are many new lighting and control technologies to choose from. This section covers some of the common technologies available and is a general introduction that will be discussed in the ***Retrofit Strategies*** section. For more thorough technical information and more related terms and technologies, refer to the ***Back to Basics*** section.

Common lighting terms:

Watt: The unit of measure for power.

Kilowatt Hour (kW h): The unit of measure for energy consumed over a period of time.

Recessed downlights and surface mount fluorescent luminaires in a conference room.

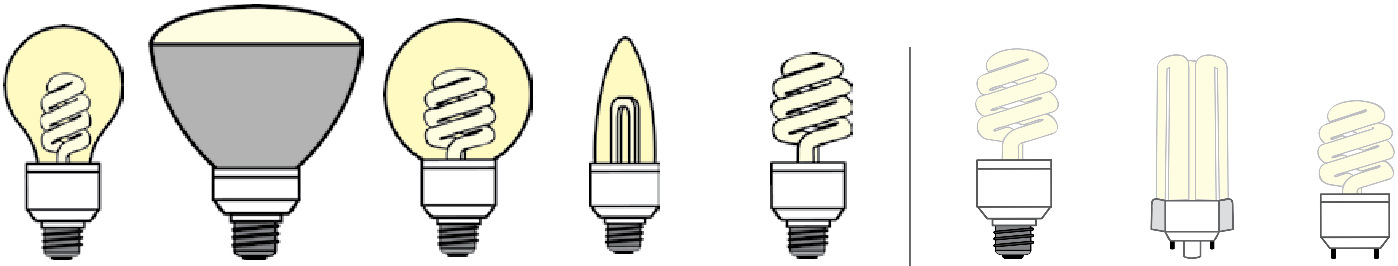
Luminaire: A complete portable or permanent lighting package consisting of a lamp(s) and ballast(s), together with the parts designed to distribute the light, to position and protect the lamp(s), and to connect the lamps to the power supply. These parts include: reflectors, housing, lenses, etc.

Types of luminaires:

- **Recessed:** Luminaires mounted above the ceiling or behind the wall, with the opening flush with the ceiling or wall.
- **Surface mount:** Luminaires mounted directly on the ceiling or wall.
- **Pendent:** Luminaires hung from the ceiling or roof by stems, chain, cable, or conduit.
- **Chandelier:** Luminaires also suspended from the ceiling, but are branched, decorative light fixtures that hold a multiple number of lamps.
- **Task:** Luminaires that direct light to a specific surface or area to provide illumination for a visual task.
- **Track:** Luminaires secured to an electrified raceway. The track itself can be mounted on or below ceilings or walls, horizontally or vertically, with flexible positioning for the aiming of light.
- **Pole and post top:** Luminaires generally mounted on the top of poles used for the illumination of buildings, roadways, walkways, and parking lots. Post top luminaires mounted on short poles are called bollards.
- **Undercabinet:** Luminaires usually mounted under kitchen and office wall cabinets.

Components of a luminaire:

- **Light sources:** A general term used to describe anything that delivers light into a space (i.e. incandescent, florescent or LED).
- **Lamp:** Interchangeable term for "light bulb" or "light source." The illustrations on the following page are examples of the different lamp shapes available for compact fluorescent lamp (CFL) technology. For more information on specific lamp shapes and lamp technologies refer to the ***Back to Basics*** section.
- **Ballast:** Component that provides the required voltage to start a discharge lamp (e.g. fluorescent or high intensity discharge lamps), then limits and regulates the amount of current supplied to the lamp during operation.



- **Lens:** A transmissive covering on a luminaire that diffuses, concentrates, or redirects light.
- **Sockets:** Components that mechanically and electrically connect the lamp to the luminaire.
    - **Screw base:** The most common threaded socket on the market. A standard screw base socket is a Type-A (arbitrary lamp) socket. There are also Type-B and C, which are smaller. The mogul socket screw base is a larger socket made for high intensity discharge lamps.
    - **Pin-based:** A socket in which the lamp's base consists of two or more electrical pins, rather than a screw base, and snaps into a luminaire socket. It is typical for a pin-based socket to be designed for a specific lamp type.
    - **GU-24:** A new socket design geared towards compact fluorescent lamps (CFL) that incorporates the ease of using a screw base socket without the option of installing a less efficient source. Similar to a screw base CFL a GU-24 CFL includes an integrated ballast, but with a "twist and lock" socket connection.

Lighting controls are a broad category of technologies that in general control the lighting in the area based on various inputs. Lighting controls include occupancy/vacancy sensors, motion sensors, photocontrollers, and timers.

- **Occupancy/vacancy Sensor:** A lighting control system that turns lighting on or off in interior spaces as a function of occupancy. Typically a manual on/off switching device that uses a motion detector to determine room occupancy and automatically sends a message to the relay pack to turn off luminaires when the space is unoccupied.
- **Motion sensor:** A lighting control system that turns lighting on or off in outdoor applications based on motion detection. Most motion sensors are auto on/off based on a moving object's presence or lack thereof.
- **Dimmer:** A device used to control the intensity of light emitted from a luminaire by controlling the voltage or current.
- **Commissioning:** The act of customizing any type of controller to a specific application, photosensor to a desired light level, occupancy sensor's sensitivity, range and time outs, and timer's time on/off.
- **Photocontroller:** A light sensitive control system that automatically turns off or turns down lighting by automatically sending a message to a control pack to turn off the lamp(s) when there is an adequate ambient light level (e.g. the photosensor will override any other control(s) to turn the luminaire on from dawn to dusk).
- **Photosensor:** The component of a photocontroller that senses the amount of light present.

Candlepower distribution: A graphical representation of the light spread and intensity showing how a particular a lamp performs in a specific luminaire.


Dual circuit wall based occupancy sensor with integrated LED night light.

In an effort to encompass many different types and sizes of spaces, certain generalizations were assumed. The generalizations do not take into account the occupancy rate, current age, conditions or amount of technologies installed, and/or the electricity rate for the potential space. Refer to the individual recommendations to help determine the best retrofit opportunity for the targeted space.

Below are energy efficient retrofit strategies that are ranked by the best bang for the buck. Within each strategy are specific applications and case study examples.

1. Replace incandescent

A good first step to reducing lighting energy use is to replace all incandescent light sources. Incandescent lighting is very popular, but it is also very inefficient, as most energy is converted into heat rather than light. In fact, only 5% of the energy used in incandescent lights is converted into visible light. The other 95% of the energy is directly converted to heat!


Screw base CFL PAR lamp

Replacing the lamp versus replacing the luminaire

In general, it is better to replace incandescent luminaires with luminaires that are designed for more efficient lamps (e.g. fluorescent, LED) rather than changing the lamp(s) within the existing luminaires. Utilizing luminaires not designed for specific light sources may result in poor optics and poor thermal conditions. For example, when installing screw-in compact fluorescent lamps (CFLs) into incandescent downlights, the heat trapped in the can may cause ballast malfunction, reduced light output, and a reduction in the expected lamp life. In addition to heat, more of a CFLs' light may be trapped in the downlight than an incandescent lamps' light, as the luminaires' optics are not designed for such sources. Thus, it may not effectively direct as much of the light out of the can. Also, the distribution of light from the luminaire will be compromised, as the optics of the luminaire will be altered by the different type and size of lamp.

In addition to the performance concerns, it is important to keep in mind the long term energy goals; as easy as it is to unscrew and replace incandescent lamps with more efficient screw-in lamps, it is just as easy to revert back, reversing the energy saving efforts.

While replacing incandescent lamps with more efficient screw-in lamps, like a CFL, may not be the ideal solution in some applications due the issues detailed above, it may be more cost effective and better than doing nothing at all.

The following is a list of typical incandescent luminaires that are ideal candidates for fluorescent lamp or luminaire retrofits. The luminaires are not listed in any particular order, but when evaluating which technology to retrofit, first choose the largest number of luminaires with the highest occupancy density to have the biggest impact.

Track luminaire

For the least amount of labor and initial investment when retrofitting line voltage track luminaires, replace incandescent A or PAR lamps with CFLs. CFLs come in many styles, including lamps with reflectors to give a similar distribution and look of incandescent PAR lamps. To determine what lamp is best for track luminaires, see the ***Quick Reference Lighting Guide*** section.

When retrofitting incandescent lamps with CFLs in track luminaires with dimming controls, keep in mind that typical screw-in CFLs are not compatible with incandescent dimmers. There are some dimmable screw-in CFLs on the market today, but even these systems may not always dim as continuously as incandescent lamps. To truly dim fluorescent light sources, consider replacing the luminaire with dedicated fluorescent track luminaires designed for dimming. Electronic ballast technology of dedicated fluorescent luminaires has greatly improved allowing for dimming that is comparable to incandescent technology.

Low voltage track systems may be difficult to retrofit; consider replacing the entire luminaire with a metal halide, fluorescent or LED luminaire. If installing a new luminaire is not an option, consider installing a dimmer to save energy from dimming.

Surface-mount luminaires

Surface-mount incandescent luminaires in commercial applications (like the one pictured to the right) are good candidates for retrofitting with screw-in CFLs. A limited amount of labor is required for installation and there is easy access to the luminaire for maintenance.

Surface-mount incandescents like this one, installed in a garage, are good retrofit opportunities.

In most applications, where tasks are being performed it may be better to opt for replacing surface-mount incandescent luminaires with linear fluorescent luminaires as there will be less shadowing and more usable light to the task plane. In high ceiling, or “high bay” applications, linear fluorescent luminaires will distribute more light throughout the space with the energy efficiency of fluorescent technology.

Some linear fluorescent luminaires are available with integrated occupancy sensing. This will add some initial cost, but may increase energy savings by reducing the number of lamps on during unoccupied times (e.g. with a 6-lamp luminaire, only 2 lamps are on during unoccupied times). The usage patterns for the intended installation space should be evaluated to ensure adequate energy savings when considering fluorescent luminaires with integrated occupancy sensing.

Downlights or “cans”

It is common today to have tens to hundreds of incandescent downlight luminaires installed in commercial and residential spaces.

In commercial applications, it may be appropriate to replace standard incandescent downlights with dedicated fluorescent downlights especially when the luminaire is installed in T-bar ceilings. T-bar ceilings allow for less labor due to easier access for installation and maintenance.

Top right: Dedicated fluorescent downlight.

Bottom right: Screw base CFL retrofit into an existing incandescent fixture.

On the other hand, residential downlights installed in drywall ceilings require significant labor to replace, and the economics for low-operating hours and increased labor may not support full luminaire retrofits. In this case, consider retrofitting incandescent luminaires with screw-in PAR or BR CFLs that are rated for downlight applications.

Nonetheless, there are a few negative consequences to using CFLs in incandescent downlights, regardless of whether in residential or commercial spaces. As mentioned in the *Replacing the lamp versus replacing the luminaire* paragraph on the previous page, considerable amounts of heat and light become trapped in the can of a downlight. Manufacturers of dedicated fluorescent downlights generally engineer their luminaires with optical systems that are designed to direct as much of the CFLs’ light out of

the luminaire as possible and thermal systems that protect thermally sensitive components. Choosing to replace incandescent downlights with fluorescent downlights will ensure energy savings and proper product performance and life.

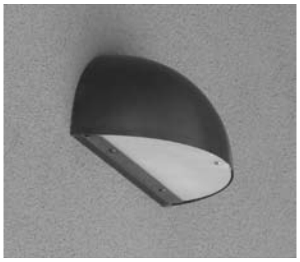
Another possible replacement for incandescent downlights are LED downlights. This new application of LEDs is now possible due to their recent increase in color quality and light output. The energy savings of LEDs are quite favorable, and the lamp life is much longer than incandescent, and even fluorescent technologies. There are different LED downlight products available with varying costs available today. Although the initial cost of purchasing LED products is comparatively high, the cost can be offset by the labor savings when installed in locations that are difficult to maintain and energy savings in areas that have significant burn hours. As more general illumination LED products become available in the market, it is foreseeable that this new technology will come down in price.

Portable luminaires

Portable luminaires, such as table lamps, are ideal retrofit applications for removing incandescent lamps and replacing with screw-in CFL's because most portable luminaires allow for adequate ventilation around the lamp. There are many dedicated portable fluorescent luminaires available as well as some emerging LED products. Halogen, another type of source found in portable luminaires such as torchieres, consume up to 3 times the energy of typical CFL torchieres, and in some instances have caused fires due to their high operating temperature. There are many CFL torchieres available that provide significant energy savings while retaining a similar distribution of light as the halogen equivalent.

Above: Shaper Lighting luminaire integrates motion and photocell controls for pathway applications.

Below: Dark sky friendly, full cut off wall pack.



Exterior luminaires

In exterior areas with incandescent luminaires, there are a few different energy saving retrofit options. Consider replacing incandescent lamps with screw-in CFLs. For additional energy savings, consider adding a photocontroller and occupancy sensor control pack to existing luminaires, or upgrade to luminaires with an integrated photocontroller and occupancy sensor. The photocontroller and occupancy sensor control pack will keep the lamp(s) off when either there is adequate ambient light present (e.g. dawn to dusk) or when there is no motion present. In applications where safety standards require a minimum light level throughout the night (e.g. applications with long burn hours that cannot utilize on/off controls), look for longer life and more efficient sources like LEDs or fluorescent technology.

When evaluating exterior lighting, light pollution is another important issue to consider. Light pollution is excess or obtrusive artificial light, often from city lights, that illuminates objects or creates glare outside of the intended target and often escapes into the night sky. Light pollution can be categorized as light trespass, over-illumination, glare, clutter, and sky glow. When replacing or installing new luminaires, specify products with full cut off angles (i.e. no light heading upwards from the luminaire) to ensure excess light is not polluting the night sky. For more information on dark sky compliance and about the International Dark Sky Association visit, ***www.darksky.org***.

Exit signs

Exit signs are a necessary and constant load; there are options available that can reduce their power consumption and increase their life. For the greatest potential savings in maintenance and power consumption, consider replacing incandescent, halogen, or fluorescent exit signs with LED

LED exit sign

exit signs or simply replace the lamp(s). In many cases, it may be faster and more cost effective to replace entire luminaires versus solely replacing the lamp(s). In addition, replacing luminaires may lead to increased performance and life. Another option to consider is cold cathode technology. Cold cathode luminaires may have a lower up front cost, but the LED luminaire will have longer life and lower operating wattage.

2. Turn luminaires off when not in use

One of the guaranteed ways to save energy is to turn off lights when not in use. Occupancy control systems are one of the most cost-effective lighting technologies that can be utilized when looking for energy saving solutions. Below are a couple of specific solutions to keeping the lights off when not needed.

Low occupancy spaces with lights often left on

Communal low traffic spaces (e.g. copy rooms, break rooms, bathrooms) often waste considerable load energy compared to personal spaces such as offices because luminaires are continually left on. Consider installing occupancy sensors to mitigate lights being left on for long periods of time when not in use.

There are generally two installation options when considering occupancy sensors: stand alone sensors and sensors integrated into a switch or luminaire. Stand alone occupancy sensors can be wall-mounted, ceiling-mounted, or mounted in the corner of the room where the walls and ceiling meet. Ceiling mounted sensors generally offer better sensor coverage of the controlled space, but wall sensors are often easier to install, particularly in retrofit applications.

As a rule of thumb, occupancy sensors should only control luminaires in the space that is "visible" to the occupancy sensor, and occupancy sensors should be positioned to "view" all the space they are intended to control (e.g. furniture will not block the sensor, etc.). To control a large area, ensure that occupancy sensors can view the entire space; ceiling-mounted occupancy sensors may be the best approach for doing so. Ceiling-mounted occupancy sensors typically have a wider field of view; therefore are more reliable and incurs a premium for this technology versus wall-mounted sensors.

Switch integrated sensors are simply wall switches that have an occupancy sensor built into them. These sensors are generally as easy to install as a standard wall switch. A limitation to these systems is that they are only appropriate in applications where the switch box location allows the occupancy sensor to control the lighting in that space.

Fixture integrated sensing technologies are also increasing in popularity. Occupancy and/or photosensor photocontrollers are being integrated in interior and exterior luminaires such as porch and stairwell luminaires.

In addition to installation options, there are two main sensing technologies: passive infrared (PIR) and ultrasonic. A third type of occupancy sensing combines PIR and ultrasonic technologies to improve reliability. PIR sensors are ideal for smaller spaces with an open floor plan where the sensor can view the space, whereas ultrasonic sensors are best for spaces with obstructions (e.g. cubicle walls, bathroom stalls, stairwells) where the sensor may not be able to view the entire space.

Quick Facts

When installing occupancy sensors, be aware that most sensors will require commissioning. Commissioning entails dialing in the settings for a specific location and occupant.

Wall mounted occupancy sensor.

Bi-level stairwell luminaire by Lamar reduces light during standby periods. Visit their Web site at ***www.lamarlighting.com***.

For multiple workstations

In spaces with numerous workstations, multiple luminaires, and varying occupancy patterns, it may not be necessary for all of the luminaires to be on at one time. If all luminaires are controlled by one light switch, only two lighting environments are available: all on or all off. Consider rewiring the space to allow for dual or multi-level switching.

Segmenting the space into separately controlled zones allows the occupant(s) the option to turn on only the luminaries in the area over or near his/her workstation. An electrician will need to create sub circuits, run line, and add switches, but the savings and added flexibility of dual or multi-level switching may be a straightforward solution. A further step towards energy efficiency for this type of application would be to consider daylighting controls as detailed in retrofit strategy #4: ***Areas with ample daylight***.

3. Replace damaged and/or poor performing luminaires

Replacing older, less efficient, and/or damaged luminaires could result in substantial energy savings, especially in high use areas. Old, yellowing, or cracked lenses hinder light from exiting luminaires and could alter the distribution of light exiting the luminaires. Similarly, dirty luminaires are inefficient at directing the maximum amount of light out of luminaires, hence wasting light, energy, and money.

Above: Examples of yellowing, cracked lenses needing replacement.

Quick Facts

Old, yellowing, or cracked lenses prevent light from exiting the fixtures. Dirty fixtures are inefficient because they waste energy and therefore money. Consider replacing the fixture, or at a minimum clean the fixture and replace the lens. Proper fixture performance will ensure maximum efficiency of light exiting the fixture.

Fluorescent luminaires or lamp and ballast retrofits

Older fluorescent luminaires may have poor efficiency due to less efficient lamp and ballast technologies. Replacing old magnetic ballast T12 luminaires with new electronic ballast T8 luminaires, has the potential to save up to 50% in energy costs per year. Payback for investing with new luminaires will depend on usage patterns, energy rates, cost of the new luminaire, etc. For a real world comparison of potential energy savings, refer to the *Annual Energy Cost Savings Worksheet* (courtesy of Osram Sylvania) at the beginning of the next page.

Consider replacing the lamp(s) and ballast(s) when limited by the up-front costs of a luminaire retrofit. This is ideal if the luminaire components are in good condition, but the energy savings potential of a T8 luminaire is desired**. For information on specifying the appropriate lamp and ballast, refer to the ***Quick Reference Lighting Guide***.

Although the up-front costs of a lamp and ballast retrofit may be lower, the drawbacks include a lack of benefit from the increased performance of newer luminaires and potential increase in labor costs if repairing luminaires are needed.

When upgrading the lamps and ballast(s) for four lamp luminaires with new T8 lamps and ballast(s), the luminaires may need to be de-lamped (removing one or more of the lamps in a fixture) since more efficient T8 lamps may provide too much light for the space. De-lamping is one of the easiest and guaranteed ways to save energy. There is a point when a luminaire is past the point of reclaiming; evaluate the labor associated with replacing the necessary components versus total costs associated with replacing the luminaire.

Quick Facts

When picking lamps, keep in mind T12 & T8 lamps have the same pin pattern, while T5 and high output (H.O.) lamps do not. It is also important to note that the lamp and the ballast must be electrically compatible. Ballast labels clearly indicate compatibility with specific lamps.

Below from left: T8, T12 & T12 H.O.

**While T8s will fit in T12 sockets, the ballast will need to be replaced to ensure proper operation and lamp life.

Annual Energy Cost Savings Worksheet

Use this 3-part calculation to determine annual energy cost savings resulting from an upgrade of one lamp or system type throughout a facility. This annual cost savings figure may be compared with the cost of the upgrade to determine simple payback and rate of return (ROR). NOTE: For fluorescent or HID systems, substitute "lamp" with "system" or "fixture" so that ballast watts are included.

1. Compute the total power (kilowatts kW) saved by upgrading older lamps

Original Lamp Wattage		Replacement Lamp Wattage		Watts Saved per Lamp		# of Lamps to Replace		Total Watts Saved		Total Kilowatts Saved
________ W	–	________ W	=	W	x	________ lamps	=	W	÷ 1000 =	kW

2. Compute the total energy (kilowatt hours, kWh) saved annually by performing this upgrade

Total Kilowatts Saved		Hours of Use per Day		Days of Use per Week		Weeks of Use per Year		Total kWh Saved per Year
________ kW	x	________ hrs/day	x	________ days/wk	X	________ wks/yr	=	kWh/yr

3. Compute the total energy cost savings per year

Total kWh Saved per Year		Your Energy Cost per kWh (typically $0.10)		Total Energy Cost Savings per Year
________ kW/yr	x	$ ________	=	$

Simple Payback = **Initial Cost of Lighting Upgrade** / **Total Energy Cost Savings per Year** = years

Rate of Return (ROR) = **100** / **Simple Payback** = %

Quick Facts

There are additional associated energy savings when comparing the mechanical air conditioning costs of a space lit with higher wattage incandescent versus lower wattage fluorescent lighting technologies. The true energy savings (and comparable CO_2) may be higher in particular spaces than represented in the Annual Energy Cost Saving Worksheet to the left.

Luminaires in large open office spaces

Traditionally, office spaces have relied on ceiling mounted luminaires for both task and ambient lighting. The target illuminance levels have been dictated by task requirements, which is the equivalent of providing task lighting throughout the work plane. Ceiling-mounted luminaires tend to be too far away from the work plane, which make them inefficient for providing task light.

Task luminaires offer significantly more efficient and effective ways of delivering task lighting than ceiling mounted luminaires. Moreover, task lighting luminaires offer individual user control of where, when, and how much light is needed, a feature greatly desired and appreciated by end users.

Separating task and ambient lighting systems can result in significant energy and lifecycle cost benefits. This can be achieved by reducing the light levels produced by the ambient system (e.g. ceiling-mounted luminaires) to significantly lower levels and providing secondary luminaires for task lighting. Moreover, task lighting systems can be equipped with occupancy sensors and dimming controls, which can increase energy savings even further.

In new and renovated office environments, there are several ways of implementing the separation of ambient and task lighting systems.

In new construction: Ambient lighting systems can be designed for a low target illuminance with the addition of task lighting dimming controls. This will allow variation of the work plane illuminance from the ambient system based on end users' preference and/or the contribution of the task lights to the ambient illumination. Low target levels of ambient illumination result in greater initial and maintained operating cost savings because of the employment of fewer luminaires providing ambient lighting.

Parabolic fluorescent fixture

RETROFIT STRATEGIES

IN DEPTH DISCUSSION ON RETROFITTING SPACES

In retrofit scenarios: Most existing ceiling mounted systems can be retrofitted via de-lamping, re-lamping, and/or by adding dimming controls to allow for lower ambient light levels and task luminaires to be integrated into each workstation. Each option has advantages and disadvantages with respect to cost, energy, and luminous performance. Decisions should be made on a case-by-case basis.

De-lamping, re-lamping or replacing luminaires should be done systematically to ensure the ambient light level remains even and uniform throughout the space. If parabolic troffers are the primary source for ambient lighting, they should not be de-lamped, as this type of luminaire is designed to create a specific distribution with the intended number of lamps. De-lamping will compromise the distribution of light out of the luminaire from the remaining lamps. Instead, consider re-lamping with lower wattage lamps (e.g. energy savers).

When re-lamping, some ballasts are designed to operate a specific number of lamps and removing one or more of the lamps will keep the remaining lamps from operating. De-lamping one set of lamps and ballasts from multi-ballasted luminaires will ensure that at least half of the lamps can remain on. Most single-ballasted luminaires may not be optimal for de-lamping, whereas most multi-ballasted luminaires are.

LED task luminaire from the PLS system by Finelite.

Dual-workstation Task Ambient Luminaire unit with two-way task lighting for shared work surfaces by Tambient.

The following are examples of new task luminaires that can be utilized in task/ambient lighting designs:

Personal Lighting System (PLS) by Finelite: This breakthrough LED system consumes about half the energy of the most efficient fluorescent task luminaires. The components (task luminaires and undercabinet fixtures) can be combined in multiple arrangements to distribute light exactly where the user wants it and saves installation time and cost.

Task Ambient Luminaires by Tambient: At less than 0.75 W/sq. ft., Tambient's Task Ambient Luminaires mount to open office panel systems and work surfaces. They provide task and ambient lighting using a single lamp. This eliminates the need for task luminaires and ceiling luminaires, establishes comfortable luminance ratios, and saves energy.

Exterior high pressure sodium luminaires

It may be appropriate in some exterior applications to replace old, poor color rendering, higher wattage high-pressure sodium (HPS) luminaires with less efficient, smaller wattage metal halide lamps. Metal halide sources render color better, which may be more appropriate for luminaires where visual acuity is important.

Attaining potential energy savings from replacing existing HPS lamps with smaller wattage metal halide lamps can be achieved in one of two ways: replace the entire luminaire or only the existing lamp and ballast. Benefits and drawbacks apply to any lamp or luminaire retrofit. Refer to the related discussion in the first topic of ***Retrofit Strategies***.

High-bay luminaires

Old, high-bay luminaires usually operate with high intensity discharge (HID) lamps. Typically, fluorescent technologies offer improved lumen maintenance, controllability, and color rendering over old HID technologies. For high-bay applications, consider replacing HID high-bay luminaires with linear fluorescent high-bay luminaires. Not all fluorescent luminaires are a one-to-one replacement with high wattage HID luminaires. Compare the initial and maintained lumen output of both technologies to ensure similar light output.

Conversely, HID technology is making advancements with utilizing electronic ballasts. Electronic ballasted HID luminaires offer similar features of controllability with dimming and occupancy sensing that is often available with fluorescent technologies. If the application requires enclosed luminaires, keep in mind fluorescent sources are temperature sensitive and do not perform as well in enclosed environments due to high operating temperatures. Some fluorescent luminaires have been designed for enclosed environments with thermal management in mind.

4. Utilize daylighting/reduce electric lighting

In interior office spaces without daylighting

Single story, interior office spaces with high usage may be ideal for retrofitting with tubular daylighting devices (TDDs). TDDs (e.g. Solatube) provide an opportunity to reduce electric lighting by delivering daylight into interior office spaces that would otherwise have little to no access to daylight. Additional benefits for installing TTDs include the opportunity to increase the quality of light and energy savings.

In areas with ample daylight

In spaces where daylight provides ample lighting for a portion of the day, consider control systems that turn lamps on/off and/or dim in response to the amount of daylight present. Daylighting is typically classified as either top lit (with skylights or TDDs), sidelit (windows), or a combination of the two. Each daylighting approach has unique characteristics, and therefore requires unique controls.

There are two daylighting control scenarios: open loop control and a closed loop control systems. Since commissioning is often needed with daylighting controls, contact local contractors to discuss advantages and disadvantages of each of these scenarios.

Quick Facts

HID exterior luminaires are available with bi-level controls and occupancy sensors. This allows for even illumination; and lacks the dark spots that are often created by motion sensored luminaires. This approach, when using full cut-off luminaires, allows for energy savings without sacrificing security and is more night sky friendly than traditional luminaires left on all night. These controls come in retrofit kits for existing luminaires as well as new luminaires. Applications include pathways, parking lot luminaires, and wall pack luminaires.

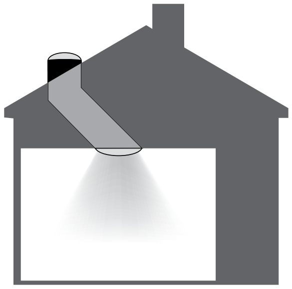


Diagram of a tubular daylighting device.

QUICK REFERENCE LIGHTING GUIDE

KNOW WHAT TO SPECIFY NOW

Now more than ever, there is a huge variety of products on the market and specifying the right product to the contractor or sales agent is crucial. The following information may help sort through the vast selection of technologies and ensure the most appropriate product is specified.

Quick Facts

All fluorescent lamps are labeled with a code that provides information about operating characteristics and physical dimensions. Note that manufacturers' labels will vary; instructions on how to read a specific product label can often be found in the product catalog.

Example of a high-output, rapid-start lamp: F48T12/WW/HO

"F"	The lamp type is fluorescent
"48"	The nominal length in inches
"T"	Tubular lamp shape
"12"	Diameter in eighths of an inch
"WW"	Color; this is a warm white lamp
"HO"	This is a high output lamp

Lamps

» **Wattage:** Determine internal guideline for standard lamp wattage(s) to ensure facility uniformity and consistency with existing stock of lamps.

» **Ballast:** Two general types: magnetic and electronic. Within electronic ballasts, there are generic electronic and high performance electronic ballasts. There is a relatively low premium (approx. 5–10%) when purchasing a high performance electronic ballast versus a generic electronic ballast, but with their approximate 5% energy savings, a 2 year simple payback is possible.

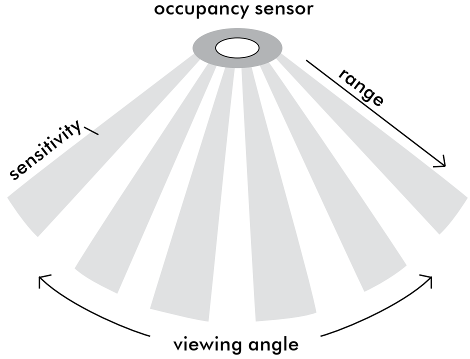
» **Thermally managed luminaires:** Particularly important for recessed luminaires. Ask product representatives for data or documentation of adequate performance while operating in the ambient temperature range of the anticipated installation.

» **Amalgam/non-amalgam:** Lamps containing amalgam produce higher light output across a wider temperature range. If the application is under 40 degrees Fahrenheit or over 90 degrees Fahrenheit, specify amalgam lamps. In applications where the temperature range is relatively small (e.g. indoor applications), amalgam lamps may not be necessary. Lamps with amalgam typically have a slower ramp-up period to full light output. Specify "quick start" lamps or simply non-amalgam lamps when ramp-up time is important.

Occupancy controls

» **View angle and range:** Consider the application of how far and wide the sensor should "see".

» **Sensitivity:** Consider the amount of tuning, for proper commissioning to meet occupant's needs.



Dimmers

Dimmer rating should be specified to meet source or load requirements. Types of dimmer ratings include:

» **Low voltage:** Rated for magnetic and electronic transformers, typically control halogen loads.

» **Line voltage:** A resistive dimmer, generally for incandescent loads. *Note that some new fluorescent electronic ballasts are being made to work with standard resistive dimmers.*

» **Inductive dimmers:** Required for most fluorescent dimming ballasts because of electronic ballast restrictions. Ensure the lighting system includes a compatible dimming ballast or transformer and compatible dimmer.

Quality Factors to Consider

- **ENERGY STAR:** The ***ENERGY STAR*** label guarantees a minimum standard of quality as well as energy performance. Most ***ENERGY STAR*** products require a color rendering index of greater than 80 and a color temperature of 2700–3000K or 4,500–6,000K, if not stated otherwise. ***ENERGY STAR*** also guarantees a minimum maintained light output and lamp life. For more information on ENERGY STAR product criteria, such as energy savings, lumen maintenance, lamp life, etc., refer to the ***ENERGY STAR*** Web site and the Key Product Criteria pages.
- **Warranty:** A longer warranty helps to protect the consumer from product failures and may also be an indicator of product quality and reliability.
- **Correlated Color Temperature (CCT):** CCT represents the relative appearance of the light source. The higher the temperature, the cooler the light appears and conversely the lower the temperature, the warmer the light appears. Typically, an acceptable range of CCTs for indoor environments is between 2500K and 5000K. Color temperature is the major mood-setting element; a warm color helps to create a “cozy” environment, while a cool color temperature is associated with a more daylit environment.
- **Color Rendering Index (CRI):** The CRI rating indicates how well an object’s color(s) are rendered by a light source. When color rendering is important, a source with a CRI of 80+ should be specified.

Avoid inconsistency in light appearance by specifying one standard color temperature.

THE RIGHT CFL

Now there is an ENERGY STAR CFL for every application!

	Pendent Fixtures	Table/Floor Lamps	Wall Sconces	Track Lighting	Ceiling Fixtures	Outdoor Exposed	Outdoor Covered	Ceiling Fans
Incandescent "A" Lamp	✓	✓					✓	✓
Bullet Lamp			✓				✓	✓
Globe Lamp	✓							✓
PAR Lamp						✓		
R Lamp				✓				
Tube/Universal Lamp		✓			✓			
Mini Spiral		✓	✓		✓		✓	✓

Source: ***www.energystar.gov***

BURNED OUT?

RECYCLING GUIDE FOR WHEN YOU'RE LEFT IN THE DARK

Earth 911
The Nation's Premier Environmental Resource

Where to recycle?

For proper recycling and disposal, take lamps and components to a local household hazardous waste collection center, or to a recycling event. To find a location in your area contact one of the following resources:

www.epa.gov/epaoswer/hazwaste/recycle/ecycling/donate.htm

www.recycle.com/statelinks.html
Earth 911.org or call
800 CLEAN-UP (253-2687).

When visiting ***Earth 911.org***, they will ask for the materials that need to be recycled, and the local zip code to find the nearest recycling centers. These Web sites include information for many types of recyclable material, including most household hazardous waste.

Interested in being a recycling role model?

Some regions do not have local regulations on recycling and some residents are taking proactive steps to educate their community and incite action. For example, Region 8 (Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming, and 27 sovereign tribal nations) is working with a local recycling agent to distribute prepaid recycling containers. For more information on local resources, contact your universal waste handler (e.g., storage facility, broker, etc.) or an authorized local recycling facility.

Thanks to the long-life benefits of fluorescent lighting, it is less often that one has to think about the disposal of these energy-saving light sources. When the time comes, what should be done with expired fluorescent lamps? This section explains how and why recycling fluorescent lamps is so important and provides valuable resources for further reference.

If a fluorescent lamp burns out, do not dispose of it in a regular waste bin or dumpster. Take caution when removing lamp(s) from the luminaire and, if possible, place in a cardboard or plastic container to protect it from breaking. This should provide enough protection until it can be transported to a local recycling center for proper disposal.

As mentioned in the ***Saving Watts and Beyond*** section, while there are small traces of mercury in fluorescent lamps, much more is being produced from power plants using fossil fuel combustion to create energy. According to Flex Your Power, fossil-fueled power plants are the largest man-made sources from which mercury enters the environment (58% of the total), emitting 0.04 milligrams of mercury per kilowatt-hour sold. Mercury is the only metal that is liquid at room temperature. Mercury is easily spread and broken down, allowing it to make its way into the environment. Currently, there are no known health hazards from being exposed to fluorescent lamps that operate as intended. If a lamp breaks, special caution should be taken. Follow the instructions in the *What to do if a fluorescent lamp breaks* call out box on the following page to minimize possible exposure to mercury.

Recycling fluorescent lamp components

If fluorescent lamps are properly recycled, nearly 100% of the materials can be reclaimed and reused. When fluorescent lamps are recycled, the glass, metal, mercury, phosphor powder, and other materials are sorted out for recycling. Up to 99.9% of the mercury can be recovered and is usable for other purposes according to ***World Wise***, an environmental consumer products company. The ballast can be recycled to reclaim valuable metals, such as copper and steel, thereby reducing the volume of solid waste sent to landfills.

States are stepping up to the recycling challenge

Some states have passed laws requiring proper disposal of common household items, including fluorescent lamps, while other states are not far behind. In California, Minnesota, Ohio, Illinois, Indiana, Michigan, and Wisconsin, it is unlawful for anyone to dispose of fluorescent lamps in regular trash bins. Please check with your local ***state environmental department*** to see what local regulations apply.

One of the regulations effective in California today requires all fluorescent lamps and HID lamps to be considered hazardous waste. Fluorescent lamps include CFLs, linear fluorescents, and even fluorescent lamps branded as low mercury, regardless of shape or size. HID lamps classified as hazardous waste include: metal halide lamps, sodium lamps, and mercury vapor lamps. All hazardous waste must be recycled, or disposed of at a household hazardous waste disposal facility, waste handler (like a storage facility or broker), or at an authorized recycling facility (CA Title 22, division 4.5, chapter 23, section 66273.8).

Regardless of state regulations, it is wise to take steps to be proactive in the recycling process to help lead the effort towards a healthier environment.

What to do if a fluorescent lamp breaks

Fluorescent lamps contain a very small amount of mercury sealed within the glass tubing. The Environmental Protection Agency recommends the following clean-up and disposal guidelines:

- Open a window and leave the room for 15 minutes or more.
- Put on rubber or latex gloves.
- Carefully scoop up the fragments and powder with stiff paper or cardboard and place in a sealed plastic bag.
- Wipe the area clean with damp paper towels or disposable wet wipes and place them in the plastic bag.
- Do not use a vacuum or broom to clean up the broken lamp on hard surfaces.
- Place all cleanup materials (including the rubber or latex gloves) in a second sealed plastic bag.
- Wash your hands after disposing of the bag.
- If a fluorescent bulb breaks on a rug or carpet, follow the steps above. After using stiff paper or cardboard to pick up as much material as possible, sticky tape (such as duct tape) can be used to pick up small pieces and powder. Place these materials and the paper or cardboard into two sealable plastic bags.
- If vacuuming is needed after all visible materials are removed, vacuum the area where the bulb was broken, remove the vacuum bag (or empty and wipe the canister) and put the bag or vacuum debris in two sealed plastic bags in the outdoor trash or a protected outdoor location for normal disposal.

Note: California prohibits normal trash disposal and requires that broken and unbroken lamps be taken to a local recycling center.

If you must wait for a hazardous waste collection day, store products safely with their original containers and labels. Keep out of the reach of children and pets.

When transporting containers to a household hazardous collection center:

- Place contents in a cardboard box and secure them so that they do not tip over. This will minimize shifting or sliding during sudden stops or turns.
- Transport container(s) in the back of a pick-up truck or in a car trunk. Ensure adequate ventilation if container must be transported in the passenger compartment.

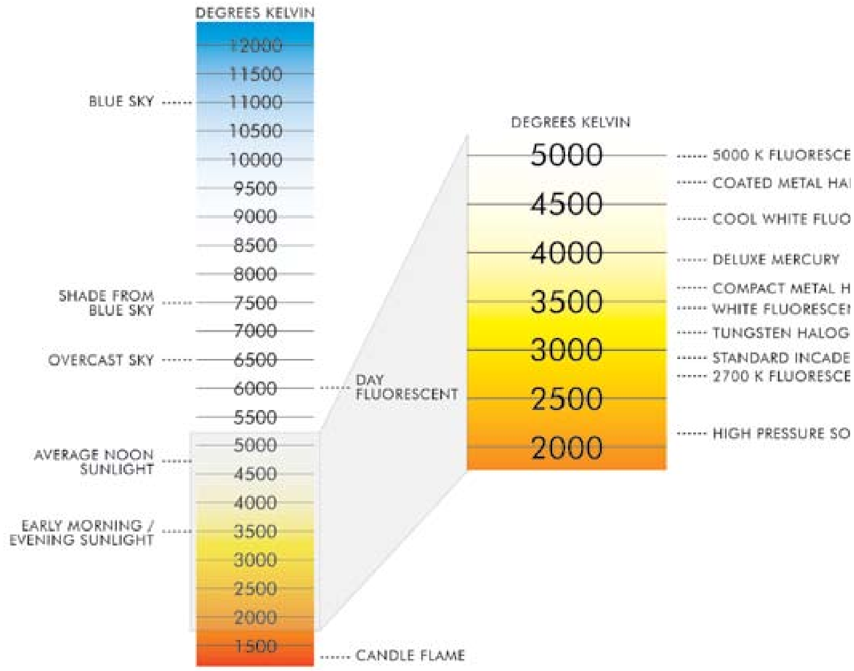
For more information, visit ***www.epa.gov/mercury/spills/index.htm***.

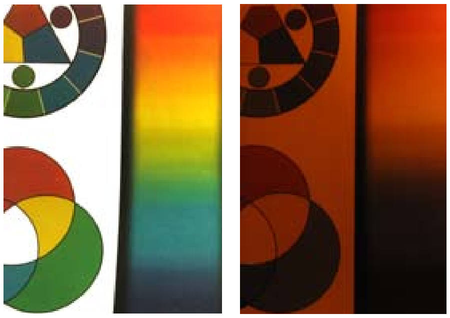
If contact with mercury occurs, call the State or the National Poison Control Center at 1-800-222-1222.

How light is measured

Correlated color temperature (CCT)

CCT is measured in Kelvin temperature, which is a reference to the color produced by blackbody emitters (such as stars) when they are heated to different Kelvin temperatures. As these emitters become hotter, they move from appearing orange to white to blue. In lighting, this can be confusing because light sources that are commonly referred to as "cool" are more blue and thus have a higher Kelvin temperature than "warm" — more orange light sources. Typically, an acceptable CCT range for indoor environments is between 2500K and 5000K. Warm lighting (which has a low CCT) helps to create a homey and cozy space, while cool lighting (with high CCT) is associated more with commercial environments. Refer to the typical correlated color temperature on the scale below.





High CRI Low CRI

Color Rendering Index (CRI)

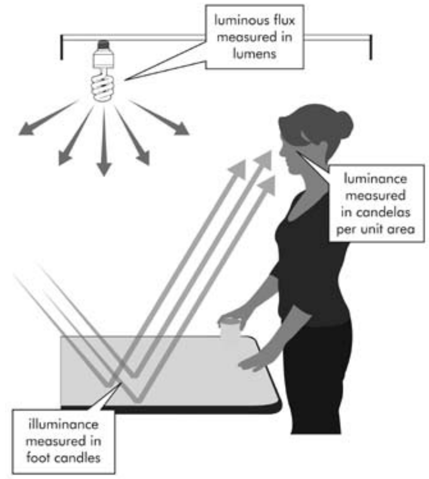
The CRI rating indicates how well an object's color(s) are rendered by a light source. It is a comparison of eight specific test colors between an "ideal" light source (incandescent or daylight) and the light source in question. The apparent shifting of these test colors is measured to give an average color rendering ability of a lamp. The greater the apparent shift, the lower the CRI. The CRI scale ranges from 0 (does not render colors well) to 100 (matched color rendition to that of the ideal source). If color rendering is less important, a CRI in the mid 70s may be less expensive and/or more efficient and may be sufficient. On the other hand, if color rendering is extremely important, it might be appropriate to sacrifice cost and/or efficiency for a CRI in the 90s. A CRI in the 80s is standard and should be specified for most applications.

Luminous Flux

Lumens are the unit of luminous flux, or visible light, produced by a light source. In a very simplistic model, a lamp receives power (Watts) and emits light (lumens).

Illuminance

The amount of visible light that falls on a surface is referred to as illuminance. Technically, the illuminance on a surface is the density of luminous flux falling or striking that surface. The units of illuminance are lumens per square foot or foot-candles (fc). The metric units for illuminance are lumens per square meter or lux. One fc is equal to 10.76 lux, although a 1 fc = 10 lux approximation is commonly made by lighting practitioners. Typical illuminance levels or foot-candles are recommended for different visual activities. Recommended number of foot-candles for a space refers to the average light level required for a particular task measured in the horizontal plane at desk height. Vertical foot-candles are illuminance on vertical surfaces, such as walls. Recommendations for illuminance levels can very greatly depending on location, types of tasks performed, etc. The following luminance levels are based on the Illuminating Engineering Society of North America recommended light level for a particular task or space.



Activity/Environment	Horizontal Footcandles	Vertical Footcandles
Corridors	3–10 fc	3–10 fc
Auditoriums	10–30 fc	3–5 fc
Conference & Meeting Rooms	30–50 fc	5–30 fc
Offices	30–50 fc	5–10 fc
Home Crafts and Hobbies	30–50 fc	5–10 fc
Industrial Assembly	30–100 fc	30–100 fc
Component Manufacturing	50–100 fc	50–100 fc
Retail Show Windows	300–1000 fc	500–1000 fc

The Federal Property Management Regulations, Energy Conservation (41 CFR 101-20.107) states that Forest Service Agencies shall have:

- between 10–1 foot-candles in non-work areas (like hallways, elevator entrances, etc.)
- 50 foot candles in work stations (like desks)
- 30 foot candles in work areas (office space)

Luminance

The amount of visible light coming off of a surface is referred to as luminance. The luminance of a source or surface is defined as the intensity of the source or surface in the direction of an observer divided by the area of the source or surface seen by the observer. This directionality is important to consider, as a source or surface often will have a luminance that varies depending on the angle in which it is viewed from. The units of luminance are candelas per square inch, or per square foot in the English (inch-pound) system and candelas per square meter in the metric (SI) system.

Candlepower Distribution

The graphical representation of the light spread and intensity of a lamp or luminaire.

Lighting terminology

Lamp/bulb/source

Lamp is the industry term used to describe a device that transforms electricity into light, also known as a light bulb and/or light source. Traditionally, lamps consist of a base, bulb, and light emitting device. The bulb is the glass enclosure which houses the light emitting device. The light emitting device varies depending on lamp type (e.g. the filament in a vacuum for incandescent lamps, cathode, anode, mercury and low-pressure noble gas for fluorescent sources, etc.). Light sources may also include any object that gives off its own natural light (e.g. the sun).

Fixture/luminaire

Technically, a fixture is a "fixed luminaire" but within the industry the terms fixture and luminaire are generally used interchangeably. A luminaire is a complete lighting unit consisting of a lamp(s), the parts designed to distribute the light (e.g. reflectors, lenses) and the parts to position and protect the lamps (sockets, housing), and the electrical parts required to generate the light (e.g. ballast or driver).

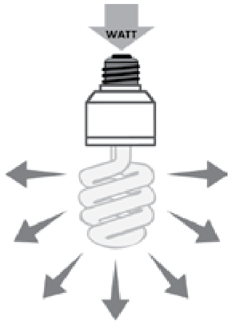
Electricity

Power (Watts)

Wattage is the unit of measurement for the amount of electrical power required or consumed by a fixture or appliance (voltage x amperage = Watts).

Energy (Watt-hours)

Energy is the amount of power that is used over a period of time. The most common unit used for energy is a kilowatt-hour (kW h). For example, a 100W lamp operated for 10 hours uses 1000 Watt-hours, or 1 kW h.



Efficacy model

Efficacy versus efficiency

Efficacy is a measure of how effectively a desired effect is achieved. For lighting, it is used to quantify how effectively lamps transform electrical power (Watts) into visible light (lumens). A lamp that consumes 100 Watts of power and produces 2000 lumens, would have an efficacy of 2000 lumen/100 Watts or 20 lumens per watt. On the other hand, efficiency is a ratio (often expressed as a percentage) of how much energy a system provides compared to the amount of energy supplied to it. In lighting, efficiency is generally applied to "luminaire efficiency" (see below).

Luminaire efficiency/optical efficiency

Luminaire efficiency, also known as optical efficiency, is a measure of how efficient the luminaire is at directing light (total lamp lumens) generated by a given light source out of the luminaire into a desired space (lumens out of the luminaire). Fixture efficiency is an important metric to consider because even if you are using a highly efficacious light source in a luminaire with a low efficiency, the overall energy efficiency may be low. For example, a CFL downlight might have a lamp efficacy of 70 lm/W, but if the luminaire efficiency is only 30–40%, the downlight may not be any more energy efficient than many incandescent downlights.

Fixture degradation

Fixture degradation is the concept of the performance of a fixture degrading over time. This can include yellowing of the lens, the dirtying of reflectors, and the general decay of the electrical system. Fixture degradation should be addressed because it can lead to decreased luminaire efficiency.

Lighting controls

Lighting controls is a term used to describe a broad category of technologies that are utilized to control lighting systems. They may also enhance overall system performance by improving energy efficiency and/or user amenity. Examples of lighting controls include occupancy sensors, photosensors, dimming controls, timers, and remote controls. Adding lighting controls allow occupants an added degree of freedom and potential for significant energy savings.

Visual comfort

Glare

Glare occurs when, within the field of vision, light that is brighter than the luminance to which the eyes are adapted causes discomfort and interferes with visibility. Glare can be caused by either direct or reflected light. Reflected glare is the result of bright reflections from polished or glossy surfaces. Direct glare occurs when the light travels directly from the source to the eye. Direct glare may be disomforting or disabling (defined below).

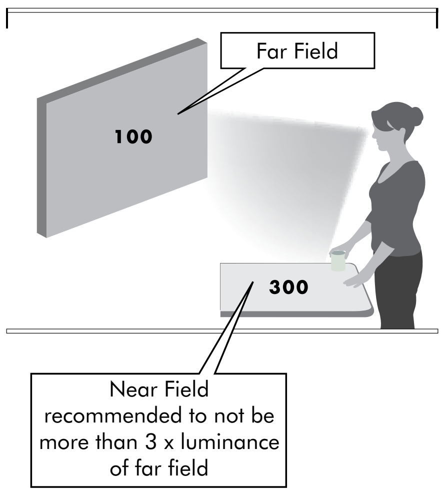
- **Disability glare:** The loss of visibility and visual performance from stray light.
- **Discomfort glare:** Stray light that results in discomfort; it may or may not directly result in reduced visibility or visual performance.

Luminance ratio

Luminance ratio is a ratio that is used to characterize absolute variation in surface brightness for a defined field of view. Very high luminance ratios within a workspace can compromise visibility and lead to eye strain.

Luminance ratio recommendations

The ***Illuminating Engineering Society of North America (IESNA)*** has developed recommendations for luminance ratios for office spaces. The basic recommended ratios for office spaces are divided into near field of view and far field of view. Near field of view can be considered any surface directly in view when a visual task is being performed. Far field of view can be considered as any surface that could come into view while using a space.

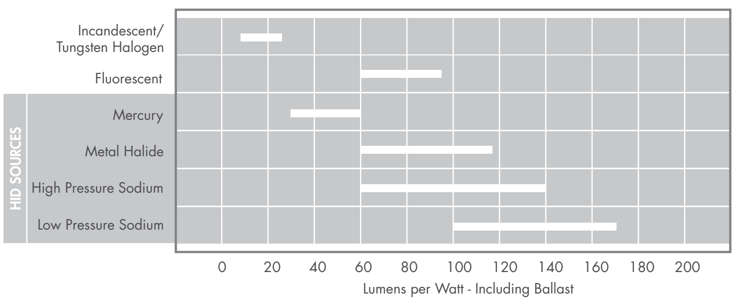


Lighting technologies

Source descriptions

The following section explains the different lighting technologies including the operation and common lamp shapes and applications for light sources that are more prevalent today.

The chart to the right depicts the difference in source efficacy. Note: LEDs are quickly advancing and the range could quickly become outdated. To date the average LED efficacy ranges between 20–40 lumens per Watt.



BACK TO BASICS

Lamp shapes

Regardless of the source, lamps are available in many different shapes. Here are the more common shapes:

– **Arbitrary or standard, (A):** Also called general service; the most common lamp shape available. This type of lamp distributes light in all directions (as opposed to reflector lamps which send light in a particular direction).

– **Bulbous reflector, (BR):** A type of reflector lamp with a blown outer glass, coated to reflect light to the front of the bulb. Designed to spread and direct light over a specific area and available in a variety of beam spreads.

– **Parabolic aluminized reflector, (PAR):** A type of reflector lamp, similar to BR lamps, designed to spread and direct light over a specific area. The outer bulb is formed of two pressed parts, a parabolic reflectorized bowl and a lens cover, that are sealed together. PAR lamps generally provide slightly better efficiency and optical control than BR lamps but cost slightly more.

– **Globe, (G):** A globe shaped transparent or semi-transparent glass that diffuses and redirects light.

Filament based sources

Incandescent and halogen are both filament-based, light sources that operate by a similar principle but have unique differences. In these lamps, current flows through a fine filament wire which is heated electrically to incandescence, causing it to glow.

Incandescent

Incandescent sources are classified as sources that produce light from a filament heated by an electric current to incandescence. Traditionally, incandescent lamps have been used indoors and outdoors in practically every application. Incandescent sources are known for their warm color appearance and high color rendering capability. Incandescent lamps are available in many different lamp shapes and sizes to fit almost any application. This is one of the least efficient sources available, and the most common type of lamp used in residential applications.

Close up of halogen quartz capsule.

Halogen

Sometimes called tungsten halogen or quartz halogen, this is another type of incandescent filament-based technology. This type of lamp uses halogen gas inside a small quartz capsule that encloses the filament. The halogen gas provides some protection for the filament which extends lamp life and allows halogen lamps to operate at a higher temperature. These higher operating temperatures slightly increase light output and efficacy over standard incandescent lamps, but have also caused fire and significant heat damage in certain cases. The halogen cycle also redirects filament particles back to the filament itself, which results in a longer lamp life than standard incandescents.

Halogen Infrared Reflecting (HIR) lamp

This is a type of halogen PAR lamp with a coating on the inside of the lamp. The coating not only absorbs UV but also re-directs heat (IR) back onto the filament. By re-directing the heat back to the filament, it allows for a slight increase in efficacy over standard halogen lamps.

Fluorescent

Fluorescent technology is a low pressure gas discharge source in which light is produced by the fluorescence of a phosphor coating when excited by ultraviolet (UV) radiation from a mercury arc. The phosphor coating on the inside of the glass tube transforms the UV radiation into visible light. A variety of phosphors can be utilized to provide fluorescent lamps in various color temperatures and with various color rendering qualities. Fluorescent lamps are available in many shapes, sizes, wattages and colors.

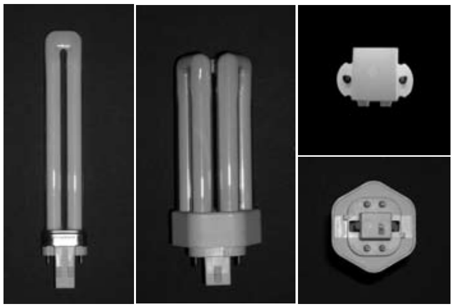
Ballasts are essential to the operation of fluorescent lamps. Ballasts are electrical devices that provide proper starting voltage to initiate the UV arc between the electrodes and then control current during operation.

Fluorescent lamp types

The following definitions are of different types of fluorescent lamp and ballast technology:

Preheat lamp and ballast

Preheat lamps use a bi-pin configuration. Preheat lamp and ballasts circuits are designed to heat the cathode using a variety of starter mechanisms before the high voltage is applied. The preheating takes a few seconds and then the ballast attempts to strike the lamp, if the lamp does not strike, the preheating process starts over. When using a starter that cannot recognize a lamp failure, it is important to remove the lamp as soon as possible or the ballast will continue to attempt to strike the lamp until the ballast and/or starter will fail. Indication of lamp failure is flickering of the lamp.



Above from left: 2 pin CFL, 4 pin CFL, 2 pin CFL base, 4 pin CFL base

Instant start lamp and ballast

Most instant start lamps use a single pin configuration. Instant start lamp and ballast circuits are designed to ignite upon the application of high voltage. The high voltage causes the electrodes to discharge electrons through field emission.

Rapid start lamp and ballast

Rapid start lamps require a bi-pin configuration. Normally the lamp electrodes are pre-heated continuously by a low voltage winding built into the ballast or a separate low voltage transformer.

Program start lamp and ballast

Program start lamps are normally a bi-pin configuration. The ballasts are electronic and briefly warm the electrodes before the high voltage is applied. Once the arc is struck the ballast stops the warming circuit.

Compact fluorescent lamp (CFL)

CFLs are a type of fluorescent lamp designed to fit into roughly the same space as incandescent lamps, but with the advantages of fluorescent sources. CFLs are available in three different base types with many different geometries, wattages and color temperatures.

Most CFLs for residential applications are designed to fit into standard Type-A (arbitrary lamp) screw base sockets. These are commonly known as screw-in or screw-base CFLs. Screw-in CFLs are also known as self-ballasted CFLs because the ballast is integrated into the lamp as a non-removable part. The ballast is enclosed in the plastic shell located in the base of the lamp.

On the other hand, pin-based CFLs have small plastic bases which do not contain integrated ballasts in the bases of the lamps. Pin-based CFLs are designed with 2 or 4 pins and are to be used with specially designed fluorescent luminaires that have the ballast remotely mounted to part of the luminaire.

Finally, there is a new type of CFL coming out on the market known as a GU-24 lamp. This lamp is geared towards utilizing both strengths of screw and pin based technology. There are a few different GU-24 lamp styles that are more shallow than traditional CFLs for decorative fixture applications. All GU-24 lamp styles will keep the same screw-in motion as a screw base CFL but with a modified twist and lock installation. Some styles will contain integrated ballasts while others will have separate detachable ballasts within the lamp configuration allowing for easier ballast replacements.

Explanation of lamp identification ordering abbreviations

All lamps are designated by a code that provides information about operating characteristics and physical dimensions. Note that manufacturers' codes may vary. Information on how to read lamp label ordering abbreviations is available in most product catalogs relative to a particular manufacturer. Two examples of lamp labels are listed below.

If looking to replace a burned out lamp with the same lamp, most fluorescents have the product label on the lamp.

Example 1:
F40T12/735/RS/ES

"F" This is a fluorescent lamp

"40" Indicates nominal wattage, although this is a 34W lamp*

"T" Tubular lamp shape

"12" Indicates diameter in eighths of an inch

"735" Color; the lamp has tri-phosphor, with a CRI over 70 and a CCT of 3500K

"RS" Mode of starting; the lamp is a rapid-start lamp. Note that preheat lamps do not have "RS" as a suffix.

"ES" This is an energy saving lamp, a generic designation; actual manufacturer designations may be "SS" for SuperSaver, "EW" for Econ-o-watt, "WM" for Watt-Miser or other variation.

*This is a 34W lamp, although the designation indicates a nominal wattage of 40 watts. The "ES" is the tip-off that this is an energy-saving version drawing 34 watts.

Example 2:
CF20EL/830/MED

"CF" This is a compact fluorescent lamp

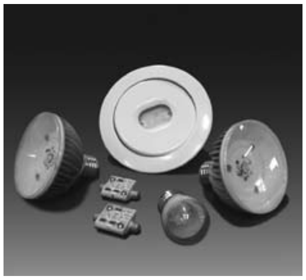
"20" indicates nominal wattage

"EL" Electronic ballast lamp

"830" Color; CRI over 80 and a CCT of 3000K

"MED" Medium screw base

Light emitting diode (LED)



Some examples of new LED products available. Some are designed for standard incandescent sockets while others are an entirely new luminaire system.

LED, or Light Emitting Diode, is one of the newest technologies in lighting today. LEDs are semiconductor light sources that emit light. Light output is dependent on the specific semiconductor's chemistry, size, color, and thermal environment. The color of the emitted light depends on the chemical composition of the semiconducting material used, and can be near-ultraviolet, visible, or infrared. Red LEDs are the most efficient at producing light in the visible spectrum. LEDs are monochromatic (one wavelength of visible spectrum) emitters. To make white light, there are two general approaches: color mixing or phosphors. Color mixing is typically denoted as RGB (Red-Green-Blue). The RGB LEDs are placed close together (typically with a diffusing lens) which combine to make white light. The other approach to making white light with LEDs requires a yellowish phosphor coating over the top of a blue LED. The resulting mix of blue and yellow light gives the appearance of white light.

LEDs have been used for decades as indicators in most electronic equipment and more recently in exit signs and traffic signals. Recently, however, LED technology has been improving significantly and has begun to find niches in the general lighting market with the potential of considerable energy and maintenance savings. Rapid improvements in LED efficacy along with the development of white LED sources with very good color characteristics make LEDs a viable lighting source to consider in many applications.

High intensity discharge (HID) lamps

As gaseous discharge lamps, HID lamps operate similarly to fluorescent lamps. Typical HID lamps contain an electrode within an inner arc tube that is mounted on a supporting frame. The frame and support assembly are connected to a base, which provides the electrical contact. The entire assembly is surrounded by a hard glass outer jacket that has been exhausted of air to protect the arc tube and lamp components from contamination and oxidation.

The light-producing element of HID lamps is the electric arc discharge contained within the arc tube. However, while fluorescent lamps provide visible light by the fluorescence of phosphor coating along the tube wall, HID lamps, like most incandescent lamps, are point sources producing light from one general point. The efficacy and color characteristics of HIDs are dependent upon the materials present in the arc tube. The arc tube materials are how HID lamps are categorized (e.g. mercury vapor, metal halide, and high pressure sodium).

Mercury vapor (MV)

Mercury vapor is one type of HID technology in which a major portion of the light is produced by radiation from mercury operating at partial pressure. The outer glass envelope of mercury lamps are made of borosilicate hard glass, which is needed to withstand the high operating temperature. The outer glass shell absorbs much of the UV radiation emitted by the mercury arc. Some mercury vapor lamps have self extinguishing features to shut the lamp off if the outer glass bulb is broken, preventing ultraviolet radiation exposure.

MV lamps, due to their color rendering ability, may be used for lighting foliage where the color they produce enhances the greens of trees and shrubs. In general MV lamps are

an older technology that generally underperforms in efficacy and lamp life compared to metal halide or sodium lamps. Thus, in retrofit applications, mercury vapor lamps are often replaced with metal halide or high pressure sodium lamps.

Metal halide (MH)

Similar in construction to mercury lamps, MH lamps provide white light at higher efficacies and better lumen maintenance than mercury vapor sources. Metal halides present in the arc tube contribute to the improved lumen maintenance. MH lamps are commonly used for commercial, industrial, retail, sport, building façade, and high ceiling architectural purposes. High CRI metal halide PAR lamps are used in downlighting, accent, and display lighting in architectural and retail applications. MH is the most suitable HID source when good color rendition is required. MH technology is available in these three types of lamps:

» **Probe start metal halide lamps** contain a special “starting” electrode within the lamp to initiate the arc when the lamp is first lit. This generates a slight flicker when the lamp is first turned on.

» **Pulse start metal halide lamps** do not require a starting electrode and instead use a special starting circuit referred to as an igniter to generate a high-voltage pulse to the operating electrodes.

» **Ceramic metal halides** allow for an increase in color quality and are similar to the pulse start, except the arc tube is made of aluminum oxide instead of quartz.

High pressure sodium (HPS)

A type of HID lamp in which light is produced by radiation from sodium vapor operating at a partial pressure. The outer glass of a high pressure sodium lamp is made of borosilicate hard glass, which is needed to withstand the high operating temperature of the lamp. The arc discharge is produced by a mixture of xenon and sodium-mercury amalgam in the polycrystalline alumina arc tube. HPS lamps are available with clear and diffused coatings.

HPS lamps are widely used in outdoor and industrial applications where color appearance and color rendering are not critical. Their long life and high efficacy have made them popular for parking lots, street lighting, and exterior lighting.

Low pressure sodium (LPS)

Similar to high pressure sodium, low pressure sodium lamps produce light by radiation from sodium vapor operating at a partial pressure in the arc tube. This arc discharge produces a monochromatic “yellow” light at a color temperature of 1800K with zero CRI. Not only does the light appear yellow, but also any object whose color is not yellow appears yellow or grey under this source. LPS lamps have the highest efficacy of any lamp family, but because of their poor color characteristics, LPS lamps are of limited use. However, the simple LPS spectrum lends itself well to area lighting near astronomical observatories, where it can be easily filtered from telescope observations.

Luminaires

Components

- **Ballast:** The ballast serves two functions: it provides the required voltage to start a discharge lamp, then limits the amount of current supplied to the lamp during operation.
- **Socket:** The socket is a specific holder that makes both the electrical and mechanical connection between the lamp and fixture.
- **Lens:** A transmissive material that directs and/or diffuses light.

Types of luminaires

The following is standard terminology used to describe the different types of luminaires.

- **Recessed:** Recessed luminaires are mounted above the ceiling (or behind the wall), with the luminaire opening and associated light-control equipment flush with the ceiling or wall.
- **Surface-mount:** Surface-mount luminaires are mounted directly on the ceiling, wall, or ground.
- **Pendent:** Pendent luminaires hang from the ceiling or roof on a stem, chain, cable, or conduit. Light can be oriented down (direct lighting), upward (indirect lighting), or a combination of both (direct/indirect lighting).
- **Chandelier:** Chandeliers are also suspended from the ceiling similar to a pendent, but these decorative luminaires branch outward and utilize a multiple number of lamps.
- **Task:** These luminaires direct light to a specific surface or area to provide illumination for visual tasks.
- **Track:** Track-mounted luminaires are secured to an electrified raceway. The track itself can be mounted on or below ceilings, on walls horizontally or vertically, and has flexible positioning and focusing abilities of each track fixture.
- **Pole and post-top:** This type of luminaire is used for the illumination of buildings, roadways, walkways and parking lots. They are generally mounted on the top of poles; normally from 9 feet to 90 feet tall for roadways and parking lots, and 3 feet to 12 feet for walkways. Post-top luminaires mounted on short poles or posts are called “bollards,” and are used for very low mounting heights (3 to 4.5 feet).

Above, from top: Surface-mount, pendent, and track luminaires.

- **Under-cabinet:** These luminaires are usually mounted under kitchen and office wall cabinets, providing task-oriented lighting.
- **Tubular daylight device (TDD):** This alternative to electric luminaires delivers daylight into an interior space via a reflective tube that connects from the interior space to the building envelope.

Lighting controls

There are two general approaches when deciding how to control your lighting system: Energy Management Systems (EMS) or smaller zonal controls. The EMS gives the facility manager more control over energy usage and is more cost effective in new construction and/or medium to large building applications.

Occupancy sensors

The two most common occupancy sensor technologies are Passive Infrared (PIR) and ultrasonic. Both of these technologies have appropriate applications and are sometimes combined together to create a more reliable, but more costly technology. Below are descriptions and applications for the more common types of occupancy sensors:

» **Passive infrared (PIR):** PIR has a lower cost and requires a direct line of sight to detect thermal gradients. It does not respond to noise or vibration. PIR devices can be thought of as a kind of infrared "camera" that remembers the amount of infrared energy focused on its surface. If the amount of infrared energy focused on the sensor changes within a specified time period, the device will switch the state of the signal output. Manufacturers recommend careful placement of PIR products to prevent false signals. Mounting PIR controls in such a way that the sensor cannot "see" out of a window is suggested. Eventhough the infrared radiation wavelength to which the sensors are sensitive does not penetrate glass very well, a strong infrared source can cause a false (non-occupant caused) signal. A person moving on the other side of the glass, however, may not be "seen" by the PIR. Manufacturers also recommend that the PIR not be placed in such a position that heating, ventilation and air conditioning (HVAC) vents would blow hot or cold air onto the surface of the plastic which covers the housing's window. Although air has very low emissivity (i.e. emits very small amounts of infrared energy), the air blowing on the plastic window cover could change the plastic's temperature enough to send a false signal.

» **Ultrasonic:** Ultrasonic technology is higher in cost but does not require direct line of sight. The ultrasonic occupancy sensors send out a high frequency signal-wavelength and the sensor can detect motion by a change in frequency and wavelength of a wave. This technology allows for the sensor to see around corners but can be sensitive to mechanical devices and intense air movement.

Recommended applications:

Passive infrared (PIR):

- Private bathrooms
- Mechanical rooms
- Smaller storage rooms
- Electrical rooms
- Outdoor security lighting

Ultrasonic:

- Public bathrooms (with stalls)
- Larger storage rooms
- Offices
- Stairwells

Occupancy sensor installation: Ceiling versus wall-mounted

Occupancy sensors can be integrated into other technologies (e.g. wall switches, luminaires) or can be stand alone items mounted to ceilings, walls, etc. Occupancy sensors built into wall switches have integrated relays and offer reduced cost for most residential and small commercial applications.

Physical obstructions in a space may dictate that a ceiling-mounted occupancy sensor is sometimes appropriate. A ceiling-mounted occupancy sensor increases reliability by ensuring the field of view for the sensor is appropriate for the space. Ceiling-mounted occupancy sensors typically communicate to a remote relay pack for controlling the lighting load and require a low voltage power pack.


A ceiling-mounted occupancy sensor.

Occupancy sensors can function in two ways:

1. Automatic on/off: Upon detection of motion, the lights will automatically turn on and after a set time of no motion detection, automatically turn off.

2. Manual on/automatic off: Occupants are required to manually activate the lights via a switch, and after a set period of no motion detected, the sensor will automatically activate the relay pack to turn the lights off.

Timers

Timers are typically integrated into a centralized lighting control panel and can be programmed to turn lights on and off for specific hours of the day and specific days of the year. Below is a description of two more common types of controls:

- **Time out switches:** Lighting controls that automatically turn off luminaires after a pre-defined amount of time from when it was activated, independent of occupancy.
- **Timer on/off:** Lighting controls that automatically turn luminaires on or off at predetermined times of the day.

Daylighting controls

Daylighting controls are designed to adjust electric light levels in a space in response to daylight levels increasing and decreasing. Daylighting controls use either a dimming ballast communication output or a switching relay to adjust the electric light levels.