LIGHTING

Overview

Lighting consumes 25 – 30% of energy in commercial buildings, and is a primary source of heat gain and waste heat. Excess heat and energy can be reduced by implementing an energy-efficient lighting system. Upgraded lighting systems can also improve lighting quality to increase occupant comfort and productivity.

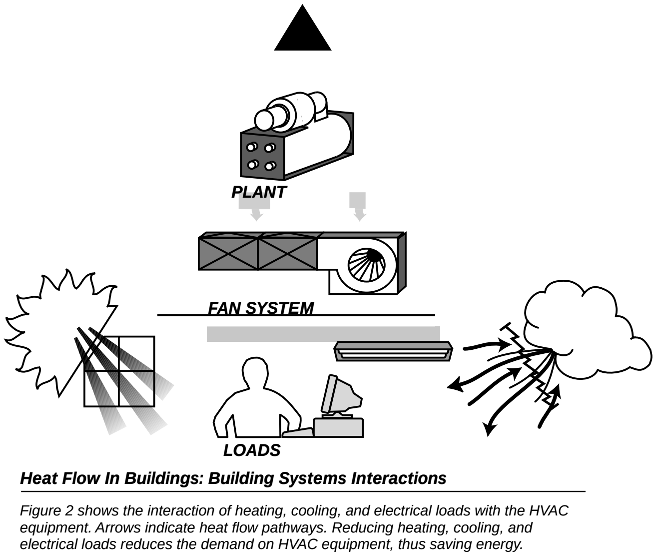
Figure 1 illustrates how heat from the lighting system effects cooling loads in the building. Comprehensive lighting upgrades create opportunities to improve the efficiency of electrical distribution and HVAC systems by reducing these loads. The additional energy savings from lighting upgrades are discussed in subsequent stages of the upgrade process.

Benefits of a comprehensive lighting upgrade:

- Highly profitable energy savings and low-risk investment.
- Maximize energy savings opportunities for subsequent building systems upgrades.
- Successful lighting upgrades can increase management and occupant acceptance of other energy-efficiency projects.

This chapter will identify opportunities and strategies to improve the efficiency of lighting systems. "Best Ways to Save" and "Take Action" are checklists to perform a quality lighting upgrade and maximize energy savings.

Figure 1: Heat Flow In Buildings



Best Ways to Save

- Design **light quantity** and **quality** for the task and occupants' needs.
- Maximize **lamp and ballast efficiency**.
- Maximize **system efficiency**, not just the components.
- Use **automatic controls** to turn lights off or dim lights in daylit spaces.
- Establish maintenance schedule for **group relamping and fixture cleaning**.
- Use **ENERGY STAR Labeled exit signs**.
- Establish responsible **disposal practices**.

Take Action!

- Develop an implementation plan and budget for lighting upgrade projects.
- Communicate project objectives and process to occupants.
- Perform trial installations to assess light levels, occupants acceptance, and energy use.

The Importance of Lighting

Lighting and The Environment

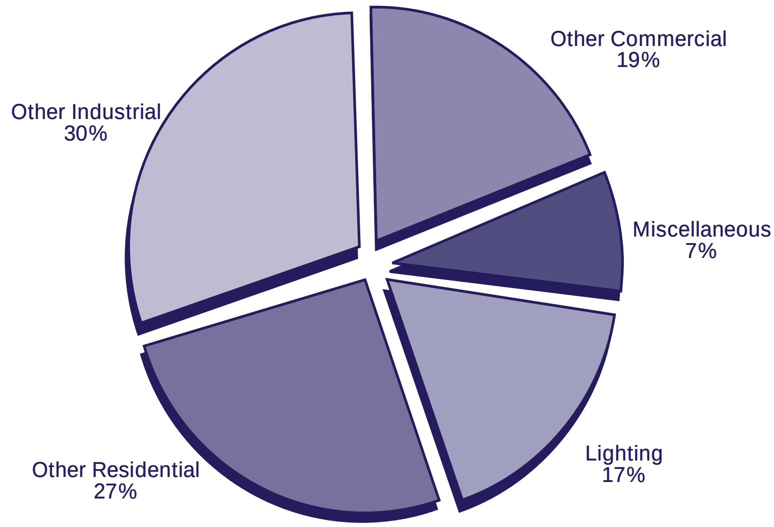
Lighting consumes a tremendous amount of energy and financial resources. Lighting accounts for approximately 17 percent of all electricity sold in the United States (see Figure 2, E SOURCE 1994, *Lighting Technology Atlas*, Ch. 4).

ENERGY STAR estimates that if efficient lighting were used in all locations where it has been shown to be profitable throughout the country, the nation's demand for electricity would be cut by more than 10 percent. This could save nearly $17 billion in ratepayer bills and result in the following annual pollution reductions:

- 202 million metric tons of carbon dioxide, the primary cause of global climate change. This would be the equivalent of taking 15 million cars off the road.
- More than 1.3 million metric tons of sulfur dioxide, which contributes to acid rain.
- 600,000 metric tons of nitrogen oxides, which contribute to smog.

Table 1 illustrates potential lighting energy savings.

Figure 2: Lighting Share Of All Electric Energy Use



Source: E SOURCE 1994, *Lighting Technology Atlas*, Ch. 4.

Table 1: Potential Lighting Energy Savings

Lamps and Ballasts	20 to 40 %
New Fixtures	30 to 50 %
Task/Ambient Lighting	40 to 60 %
Outside Lighting	30 to 50 %

Green Lights lighting upgrades save 48 percent of a building's lighting energy use on average.

Source: EPA Green Lights Program.

Lighting And Your Business

Lighting is also a significant expense in operating buildings. Lighting is the largest cost component of a commercial building's electricity bill (see Figure 3) and a significant portion of its total energy bill.

Lighting and Your Building

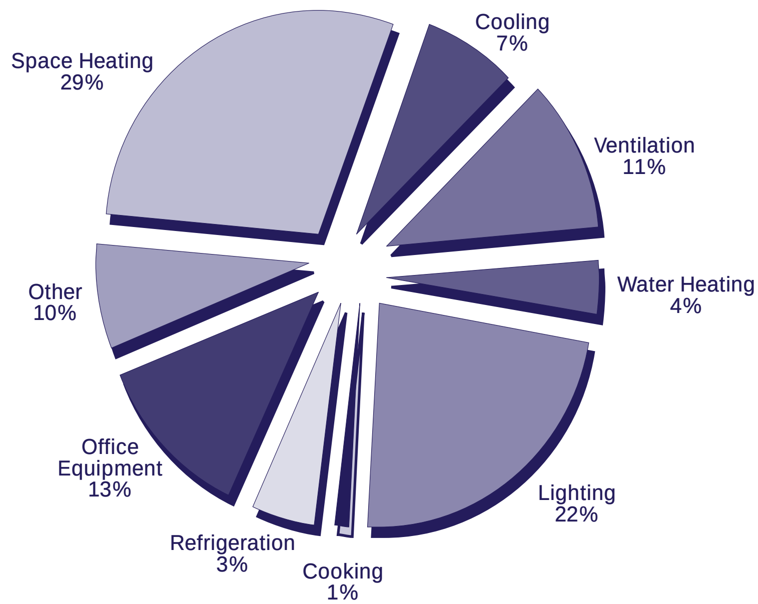
Reduce Heat Gain

In addition to visible light, all lighting systems produce heat. Lighting is typically the largest source of waste heat, often called "heat gain," inside commercial buildings. Improving lighting efficiency reduces heat gain, which affects your buildings in two ways.

Waste heat is a useful supplement when the building requires heat, it must be removed by the HVAC system when the building needs to be cooled. The impact of this tradeoff—the penalty for increased heating costs versus the bonus for reduced cooling costs—depends on your building type, its geographic location, and its HVAC system. Although heating costs may rise, they will rarely exceed the resultant cooling savings, even in buildings in northern climates that use electric resistance heat.

By reducing internal heat gain, efficient lighting also reduces your building's cooling requirements. Consequently, your existing cooling system may be able to serve future

Figure 3: Lighting Share Of Office Building Electricity Use



Source: U.S. Department of Energy, Energy Information Administration, *Energy End Use Intensities in Commercial Buildings*, Sept. 1994. DOE/EIA–05555(94)/2.

added loads, or may be appropriate for "rightsizing". Given the large impact lighting upgrades can have on your HVAC system requirements and the high cost of cooling equipment, you should always quantify HVAC and lighting interactions. There are simplified methods available for calculating the impacts of lighting upgrades on heating and cooling systems. (See EPRI *Lighting Bulletin*, no. 6, April 1994.)

Improve Power Quality

Lighting also affects the power quality of your building's electrical distribution system. Poor power quality is a concern because it wastes energy, reduces electrical capacity, and can harm equipment and the electrical distribution system itself.

Upgrading to lighting equipment with clean power quality (high power factor and low harmonic distortion) can improve the power quality in your building's electrical system. Furthermore, upgrading with higher efficiency and higher power factor lighting equipment can also free up valuable electrical capacity. This benefit alone may justify the cost of a lighting upgrade.

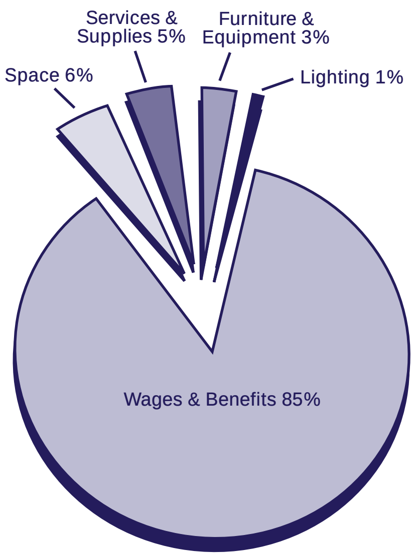
Lighting and People

A lighting upgrade is an investment not only in reducing electricity consumption but also in improving the performance of the building in supporting its occupants. A building's lighting directly affects the comfort, mood, productivity, health, and safety of its occupants. Moreover, as the most visible building system, it also directly affects the aesthetics and image of the building and your business. Successful lighting upgrades take into account the impact of energy performance choices on the building occupants and seek to marry efficiency with improved lighting quality and architectural aesthetics wherever possible.

Productivity

The relationship of lighting to task performance and visibility is well understood. Improved lighting enhances visual comfort, reduces eye fatigue, and improves performance on visual tasks. Well-designed lighting is likely to improve performance, increase productivity, and reduce absenteeism. Because costs associated with your employees greatly outweigh the other building costs (see Figure 4), any lighting changes that improve your occupants' workspaces are worth investigating.

Figure 4: Annual Operating Costs Per Square Foot, Typical Office Space



Source: *Lighting Management Handbook.*

Safety

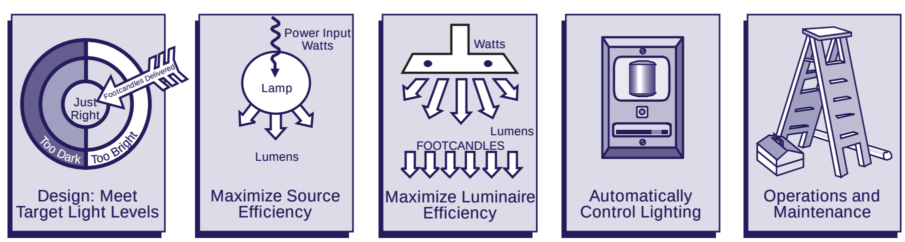
Lighting also contributes to the safety of occupants and the security of buildings. Emergency lighting must be available during power outages, and minimum levels of light must be available at night when most lighting is turned off. In addition, safety codes require exit signs to highlight escape routes during fires or other emergencies. Outside lighting and indoor night lighting deters crime by exposing intruders' movements and permitting occupants to move safely through the building or to cars.

Although such effects are difficult to quantify, comfort, mood, productivity, health, safety, and other impacts on people should be considered as part of every lighting upgrade.

Maximizing Efficiency and Quality

A comprehensive lighting upgrade achieves your qualitative lighting objectives while maximizing efficiency and profitability. With rewards beyond the sum of its parts, this process integrates equipment replacement with deliberate design, operation, maintenance, and disposal practices. This whole-system approach takes what is frequently regarded as a complex system of individual decisions and unites them into a strategic approach that ensures that each opportunity is addressed and balanced with other objectives (see Figure 5).

Figure 5: Comprehensive Lighting Upgrade Strateg



Avoid implementing only the easiest and quickest payback opportunities. While this may seem appealing, you will forgo quality-enhancing and savings opportunities that result from comprehensive upgrades. A simplified upgrade may yield faster payback, but you will sacrifice long term energy savings over the life of the system.

Table 2 illustrates the economic impacts of pursuing incrementally more aggressive upgrades while maintaining profitability and lighting quality and quantity. (See E Source, *Lighting Technology Atlas*, Chapter 3, for more detail.)

Lighting Design

Successful lighting design begins with an assessment of several design issues to meet the occupants' lighting needs, which depend on the tasks performed in the workspace. The lighting system should be designed to provide the quantity and quality of light responsive to those requirements. Chapter 10, "Quality of the Visual Environment," of the IESNA Lighting Handbook 9th edition, identifies several issues such as color, daylight availability, glare and, light distribution that should be considered. Retrofits that skip this assessment may perpetuate designs that have become inadequate because of workspace rearrangements or changing tasks (for example, paper-based to computer-based tasks).

Table 2: Performance Comparison of Fluorescent Retrofit Options

	Base case: T12 Lamps w/ magnetic ballasts Case 1	*"Energy saving" T12 lamps Case 2*	*T8 lamps, electronic ballasts Case 3*	*T8 lamps, electronic ballasts, reflector lens, + 50% delamping Case 4*	*Same as Case 4 + occupancy sensors Case 5*	*Same as Case 5 + maintenance Case 6*
Avg. maintained footcandles (fc)	28	25	30	27	27	27
Input watts per fixture	184	156.4	120	60	60	50
Total kW	2.208	1.877	1.440	0.720	0.720	0.600
Annual energy use (kWh)	8,832	7,507	5,760	2,880	1,800	1,500
Costs						
Energy savings (%)	N/A	15%	35%	67%	80%	83%
Annual operating cost for energy ($)	883.70	750.74	576.00	288.00	212.40	177.00
Upgrade cost ($)	N/A	312	1,440	1,620	1,970	1,970
Savings						
Energy savings (%)	N/A	15%	35%	67%	80%	83%
Operating cost savings (%)	N/A	15%	35%	67%	76%	80%
Simple payback (years)	N/A	2.4	4.7	2.7	2.9	2.8
Internal Rate of Return (10-year)	N/A	41%	17%	35%	32%	34%

Source: Adapted from E SOURCE, *Lighting Technology Atlas*, Table 3.1.

It is important to recognize that people do not see absolute levels of illuminance, the amount of light shining on a surface. They see differences in luminance or brightness—the amount of light reflected back from the surface. The fundamental relationship between lighting and occupant tasks makes it essential that the lighting, task, and surrounding area be evaluated together. Although lighting retrofits are generally limited to the lighting equipment, good design should evaluate and modify work environments where appropriate. For example, a lighting redesign may reorient computer monitors away from windows or increase the contrast between tasks and their backgrounds.

Room dimensions and finishes also affect the required light output and thus the energy consumption of all interior lighting systems. As much as one-third of the energy use of a lighting system depends upon the surrounding interior features, such as the ceiling height, windows, and color and reflectivity of room surfaces and furnishings. Where possible, the lighting designer should work with both the architect and interior designer to ensure that features that significantly enhance lighting levels, such as large windows and light-colored finishes, are utilized wherever possible. This helps minimize the required light output and therefore the energy consumption of the lighting system.

The same principals and guidance that apply to interior lighting are applicable to exterior lighting as well. Outdoor lighting that is designed and implemented properly should be cost effective, control light by directing it where needed; reduce glare and distribute illumination evenly; and reduce light trespass.

The Right Quantity of Light

A common misperception contributing to the proliferation of ineffective and inefficient lighting is that more light equals higher quality light. Lighting-level requirements have evolved with the changes in our workplaces and our knowledge of visual science. The Illuminating Engineering Society of North America (IESNA) has developed consensus-based guidelines to select appropriate illuminance levels for hundreds of indoor and outdoor activities. These recommendations, some of which are listed in Table 3, are starting points, suggesting a range of values based on design issues, locations, and tasks. Listed below are several design issues outlined by IESNA:

- Appearance of Space and Luminaires
- Color Appearance (and Color Contrast)
- Daylighting Integration and Control
- Direct Glare
- Flicker (and Strobe)
- Light Distribution on Surfaces
- Light Distribution on Task Plane (Uniformity)
- Luminances of Room Surfaces
- Modeling of Faces and Objects
- Point(s) of Interest
- Reflected Glare
- Shadows

- Source/Task/Eye Geometry
- Sparkle/Desirable Reflected Highlights
- Surface Characteristics
- System Control and Flexibility

Table 3: Recommended Light Levels (footcandles)

Average Reading and Writing	50 fc
Offices with Computer Screens	
Task Lighting	25 fc
Ambient Lighting	25 fc
Hallways	10 fc
Stockroom Storage	30 fc
Loading and Unloading	10 fc
High-Volume Retail	100 fc
Low-Volume Retail	30 fc
Roadway Lighting	.3 – 1.6 fc
Parking Lots	.8 – 3.6 fc
Building Entrance	5 fc

Source: *IESNA Lighting Handbook*.

It is important to note that these are **average maintained** target levels for the task and should not necessarily be applied uniformly as the ambient light level for the entire space. Lighting levels should be customized through the use of supplemental task lighting in areas requiring higher localized levels. Target lighting levels should be the sum of the ambient and task lighting levels. This task and ambient lighting design approach creates flexibility to accommodate individual tasks or worker requirements, creates visual interest, and can save considerable energy in comparison to a uniform ambient level approach.

The Right Quality of Light

Of equal importance to the quantity of light is the quality of light. The quality of light is dependent on both the properties of the light and how that light is delivered to the space. The fundamental quality issues include all of the IESNA “design issues“ listed above with special consideration given to:

- Glare
- Uniformity of luminance
- Color temperature and color rendition

The eye does not see absolute levels of illuminance; the amount of light shining on a surface. It sees differences in luminance, the amount of light reflected back from the surface. Eyestrain and fatigue are caused when the eye is forced to adapt continually to different luminances. Therefore, it is important not only to provide the right level of light but also to ensure that light is evenly distributed across the task area. Balancing light levels also ensures that task lighting levels will be adequate throughout the space. Uniformity on vertical surfaces should also be maintained to avoid a gloomy, cavelike atmosphere.

IESNA recommends as good design practice an average **luminance ratio** of no more than 3 to 1 for close objects and 10 to 1 for distant objects and outdoor applications (*IESNA Lighting Handbook*, Sect. 11—Office Lighting). In other words, the difference in light level between the task area and the background should be less than a factor of three. While some designers use illuminance variation as an organizing theme, such as defining hallways leading to open offices, or as a highlighting strategy, such as in retail and merchandising locations, large footcandle variations within a workspace should be avoided.

Glare is the most important quality factor. Glare results when luminance levels or the differences in luminance levels are too high, and objects appear too bright. Because glare creates discomfort, loss of visual performance, and impaired visibility, it should be minimized wherever possible.

The two types of glare you will encounter are direct glare and reflected glare. **Direct glare** occurs when light from a bright object enters the eye directly. It can be controlled through the use of luminaire lenses, louvers, and window blinds, all of which block the direct viewing of sources.

Reflected glare is produced when reflected light creates a shining or veiling reflection, which reduces or washes out task contrast. This commonly occurs on shiny, light-colored surfaces and computer screens. Although veiling reflections are more difficult to control, they can be minimized by moving the light source, reorienting the task, and installing reflectors, lenses, or louvers on luminaires. Good general practices to minimize glare include the use of lower ambient light levels, task lighting, indirect lighting, and luminaires with a high **visual comfort probability** (VCP) rating. The VCP index provides an indication of the percentage of people in a given space that would find the glare from a fixture to be acceptable. You should ensure a minimum VCP rating of 70 for commercial interiors and 80 for computer areas.

The color mix of a light source is described by the terms **color rendering** and **color temperature**. The ability of a light source to accurately reveal the true colors of objects is measured by its color rendering index (CRI), which ranges between 0 and 100 (see Table 4). Lamps with a higher CRI make people and objects appear more natural and bright. Because high CRI lamps improve visual clarity and aesthetics, use the highest CRI lamps economically practical.

The color temperature of lamps, measured in degrees Kelvin (° K), refers to the relative warmth or coolness of their light color. The higher the color temperature, the cooler the light source. Lamps with a color temperature of 3500° K are generally considered neutral (see Figure 6).

Table 4: Typical CRI Values For Selected Light Sources

Source	*Typical CRI Value*
Incandescent/Halogen	98+
Fluorescent	
Cool White T12	62
Warm White T12	53
High Lumen T12	73–85
T8	75–98
T10	80–85
Compact	80–85
Mercury Vapor (clear/coated)	15/50
Metal Halide (clear/coated)	65/70
High-Pressure Sodium	
Standard	22
Deluxe	65
White HPS	85
Low-Pressure Sodium	0

While color temperature is largely an architectural choice, it also relates to design lighting levels. While warmer sources, with a temperature below 3500° K, are generally preferred in lower illuminance environments, cooler sources, with a temperature above 3500° K, are preferred in higher illuminance environments.

Maximize Source Efficiency

Too often, lighting retrofits start and finish with the objective of pairing lamps with ballasts to turn electricity into visible light most efficiently. While the majority of energy savings potential often resides here, pursuit of high efficiency alone may lead to compromises in light quality and controllability and higher system installation and maintenance costs. Lamp and ballast specification should seek to optimize efficiency while maintaining a balance with these other considerations.

Figure 6: Color Temperatures of Various Light Sources

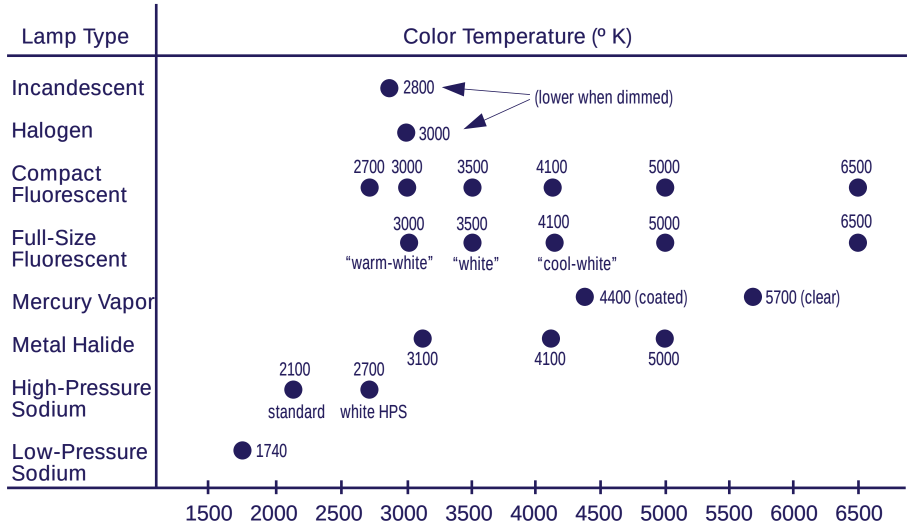


Table 5: Lamp Characteristics

	Standard Incandescent	*Full-Size Fluorescent*	*Mercury Vapor*	*Metal Halide*	*High-Pressure Sodium*
Wattages	3–1,500	4–215	40–1,250	32–2,000	35–1,000
System Efficacy (lm/W)	4–24	49–89	19–43	38–86	22–115
Average Rated Life (hrs)	750–2,000	7,500–24,000	24,000+	6,000–20,000	16,000–24,000
Color Rendering Index	98+	49–85	15–50	65–70	22–85
Life Cycle Cost	High	Low	Moderate	Moderate	Low
Source Optics	Point	Diffuse	Point	Point	Point
Start-to-Full Brightness	Immediate	0–5 Seconds	3–9 Minutes	3–5 Minutes	3–4 Minutes
Restrike Time	Immediate	Immediate	10–20 Minutes	4–20 Minutes	1 Minute
Lumen Maintenance	Good/ Excellent	Fair/ Excellent	Poor/Fair	Good	Good/ Excellent

While a wide range of light sources are available, the predominant types used in commercial and industrial spaces are fluorescent and high-intensity discharge (HID). Historically, fluorescent lighting has been used for high-quality, general-purpose indoor diffuse lighting. HID has been used for industrial and outside lighting. However, technical advances and a flood of new products have increased the use of HID in interiors.

Although fluorescent sources are still limited by their inability to function in very hot or cold environments or as spotlights, advances in physical size, thermal performance, and light quality are allowing wider application in industrial, manufacturing, and residential environments. Likewise, in the past, HIDs have typically been limited by their high light output and their inability to render color accurately or to be switched on and off frequently or dimmed. Today, however, HID lamps are used indoors in some applications where light quality is critical and where dimming and lower light outputs are necessary. While practical limitations still exist, now, more than ever, specifiers need to research lamp capabilities and understand the tradeoffs between efficiency and performance. For example, linear T5 lamps, which have recently been introduced, are becoming popular in direct/indirect pendent mounted systems, cove lighting and retail display lighting. But should not be used in retrofit applications because of the following limitations.

- Available only in metric lengths
- Lamp holder design is different that T8 and T12
- Higher tube luminance, which will cause glare problems in existing lighting equipment.

Ballast selection is integral to lamp performance. All fluorescent and HID lamps require a ballast to provide the necessary starting voltage and regulate lamp current and power quality. Ballasts determine the lamp's light output, life, and control capabilities. Similar to advances in lamp technology, electronics advances have greatly expanded ballast capabilities and selection.

The three types of fluorescent ballasts are magnetic, electronic, and hybrid ballasts. Magnetic ballasts, also known as electromagnetic ballasts, have improved from the standard-efficiency, core-coil ballasts last made in 1989 to higher efficiency models. Electronic ballasts have been developed for almost all fluorescent lighting applications to replace their conventional magnetic counterparts directly. Electronic ballasts operate fluorescent lamps at a higher frequency, which improves system efficiency by about 30 percent when used in conjunction with T8 lamps to replace T12 lamps and standard magnetic ballasts. Electronic ballasts also offer these advantages:

- Less audible noise and virtually no lamp flicker.
- Dimming capability (with specific ballast models).
- Ability to power up to four lamps, increasing energy efficiency by an additional 8 percent, while reducing first cost and maintenance costs.

Hybrid ballasts, which combine features of magnetic and electronic ballasts, are also available. Although these ballasts offer the same efficiency benefits as electronic ballasts, they cannot power more than three lamps.

Instant-start circuitry offers an additional 5 percent efficiency compared with rapid-start electronic ballasts. However, if lamps are frequently switched on and off, additional lamp and maintenance costs may exceed energy savings.

Programmed-start ballasts offer increased lamp life compared to instant or rapid start ballasts. Programmed-start ballasts are designed to soft start the lamp, which decreases lamp cathode damage. These ballasts are an excellent choice when luminaires are switched on and off frequently, such as in spaces controlled by an occupancy sensor.

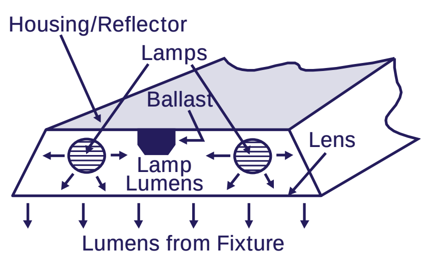
Selecting ballasts for HID lamps involves matching a ballast type to the electrical distribution system in your building to control the lamp light output when line voltage varies. The level of this control is then balanced against ballast losses, power factor, lamp life, and cost. Electronic ballasts are also available for most types of HID lamps, these ballasts are becoming more popular because of their smaller size, weight, decreased lamp color shifting, and increased compatibility with lighting controls Nominal efficiency improvements of only 5 to 7 percent make retrofits difficult to justify on energy savings alone. Linear reactor circuit ballasts have been developed which, when used with matched, pulse-start, metal halide lamps, can cut ballast losses in half and offer a 20-percent improvement in efficiency.

Maximize Luminaire Efficiency

A luminaire, or light fixture, is a system of components designed to direct light efficiently while providing a high level of visual comfort (see Figure 7).

Getting a large percentage of light to exit the fixture while controlling its distribution usually requires a compromise. Generally, the most efficient fixtures have the poorest visual comfort. Conversely, fixtures with excellent glare control are the least efficient.

Figure 7: Luminaire Components



When installing new fixtures, the lighting designer will determine the best compromise between fixture efficiency and visual performance and specify optimized fixtures that fit into the architectural design objectives. When retrofitting fixtures, however, lamps are repositioned, and reflectors and shielding materials are added to balance these objectives.

Reflectors are inserts designed to reduce the internal light loss in fixtures by using highly reflective surfaces to redirect light out of the fixture. They can be used in new fixtures or installed in existing fixtures as part of an energy savings retrofit strategy. In retrofits, reflectors improve fixture efficiency by improving the internal surface reflectance by up to 17 percent in new fixtures and more if fixture surfaces are old or deteriorating (see *Lighting Upgrade Technologies*, p. 10, EPA 430-B-95-008). By modifying the light distribution of the fixture, reflectors can also facilitate additional energy savings when reducing lighting levels through delamping or relamping.

Reflector performance is largely determined by specific design and installation rather than material selection. As reflector retrofits usually accompany a redesign of lighting quantity and quality in the space, evaluate changes in fixture appearance, target light levels, uniformity, and glare through trial installations.

Most indoor commercial fixtures use some type of diffuser, lens, or louver over the face of the fixture to block direct view of the lamp or to diffuse or redirect light. Although these shielding media improve visual comfort, each one has strengths and weaknesses with regard to visual performance, efficiency, and appearance (see Table 6).

In general, diffusers are simply semitranslucent plastic sheets that hide lamp images and diffuse light evenly across the face of the fixture. Because they spread light in all directions and absorb a large amount of light, diffusers are not only inefficient but also ineffective at controlling glare. By using clear plastic lenses with small prismatic surface patterns instead of diffusers, one can improve efficiency and the distribution of light.

Table 6: Shielding Media Options

Shielding Material	*Luminaire Efficiency Range (%)*	*VCP Range (%)*
Standard Clear Lens	60–80	50–70
Low-Glare Clear Lens	60–80	75–85
Deep-Cell Parabolic Louver	50–90	75–99
Translucent Diffuser	40–60	40–50
White Metal Louver	35–45	65–85
Small-Cell Parabolic Louver	40–65	99

Louver retrofits, depending on cell size and depth, can provide a better balance between superior light control and energy efficiency. Avoid small paracube louvers (cells less than 1 inch) whenever possible; although they provide excellent glare control, they are quite inefficient. Larger "deep cell" louvers provide high efficiency and excellent light control and are available for retrofit into many existing fixtures. New parabolic louvered fixtures are now designed to combine high efficiency (90 percent) with very high VCP ratings above 90. When retrofitting shielding media, evaluate changes in light output, distribution, and fixture appearance using trial installations.

The best type of lighting system for glare control and visual comfort is a direct/indirect pendent mounted system. By providing some up-light against the ceiling and a direct component to the work surface, direct/indirect lighting minimizes the extreme brightness between the ceiling surface and the fixture. Installing pendent mounted systems is usually only cost effective during complete renovations and new construction. However, these systems continue to come down in price and some contractors have experienced that the installed cost of a pendent mounted system is nearly the same as the installed cost of a new lay-in parabolic troffer, and their clients usually like the direct/indirect lighting system better.

Automatically Control Lighting

Reducing the connected load (wattage) of the lighting system represents only half of the potential for maximizing energy savings. The other half is minimizing the use of that load through automatic controls. Automatic controls switch or dim lighting based on time, occupancy, lighting-level strategies, or a combination of all three. In situations where lighting may be on longer than needed, left on in unoccupied areas, or used when sufficient daylight exists, you should consider installing automatic controls as a supplement or replacement for manual controls.

Time-Based Controls

The most basic controlling strategies involve time-based controls, best suited for spaces where lighting needs are predictable and predetermined. Time-based controls can be used in both indoor and outdoor situations. Common outdoor applications include automatically switching parking lot or security lighting based on the sunset and sunrise times. Typical indoor situations include switching lighting in production, manufacturing, and retail facilities that operate on fixed, predefined operating schedules. Time-based control systems for indoor lighting typically include a manual override option for situations when lighting is needed beyond the scheduled period. Simple equipment, such as mechanical and electronic timeclocks and electromechanical and electronic photocells, can be independent or part of a larger centralized energy-management system.

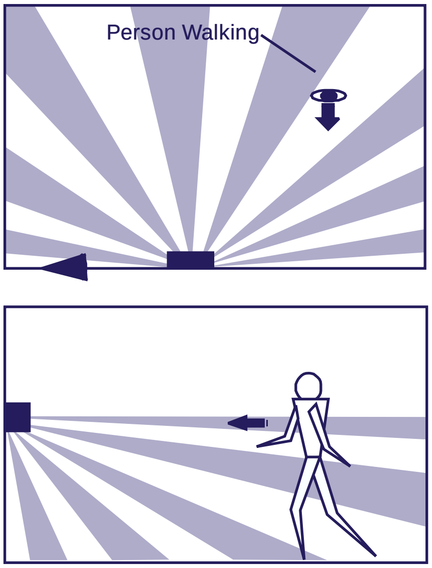
Occupancy-Based Controls

Occupancy-based strategies are best suited to spaces that have highly variable and unpredictable occupancy patterns. Occupancy or motion sensors are used to detect occupant motion, lighting the space only when it is occupied. For both initial and sustained success in using occupancy sensors, the sensor must be able to see the range of motion in the entire space while avoiding either on or off false triggering. This requires proper product selection, positioning, and testing.

Occupancy sensors should first be selected based on the range of body motion expected to occur throughout the entire lighted space. Controls for hallways, for example, need only be sensitive to a person walking down a narrow area, while sensors for offices need to detect smaller upper body motion, such as typing or reaching for a telephone. Once sensitivity and coverage area is established, sensors are selected from two predominant technology types.

Passive infrared sensors detect the motion of heat between vertical and horizontal fan pattern detection zones. This technology requires a direct line of sight and is more sensitive to lateral motion, but it requires larger motion as distance from the sensor increases. The coverage pattern and field of view can also be precisely controlled (see Figure 8). It typically finds its best application in smaller spaces with a direct line of sight, warehouses, and aisles.

Figure 8: Infrared Sensor Coverage Patterns



Ultrasonic sensors detect movement by sensing disturbances in high-frequency ultrasonic patterns. Because this technology emits ultrasonic waves that are reflected around the room surfaces, it does not require a direct line of sight, is more sensitive to motion toward and away from the sensor, and its sensitivity decreases relative to its distance from the sensor (see Figure 9). It also does not have a definable coverage pattern or field of view. These characteristics make it suitable for use in larger enclosed areas that may have cabinets, shelving, partitions, or other obstructions. If necessary, these technologies can also be combined into one product to improve detection and reduce the likelihood of false on or off triggering.

To achieve cost-effective, user-friendly occupancy sensor installations, both types of technologies need to be carefully commissioned at installation to make sure that their position, time delay, and sensitivity are properly adjusted for the space and tasks.

To ensure proper performance, the position of both wall- and ceiling-mounted sensors needs to be evaluated carefully. Ultrasonic sensors, for example will respond to strong air movement and need to be located away from ventilation diffusers. Infrared sensors should have their line of sight checked to ensure that it is not blocked by room furnishings. Both types of technologies should be positioned and adjusted so that their coverage area is not allowed to stray outside of the intended control area. See Table 7 for appropriate occupancy sensor applications.

All sensors have an adjustable time delay to prevent the lights from switching off when the space is occupied but there is little activity. Some infrared and all ultrasonic sensors also have an adjustable sensitivity setting. Customizing these settings to the application is necessary to balance energy savings with occupant satisfaction.

Figure 9: Ultrasonic Sensor Coverage Patterns

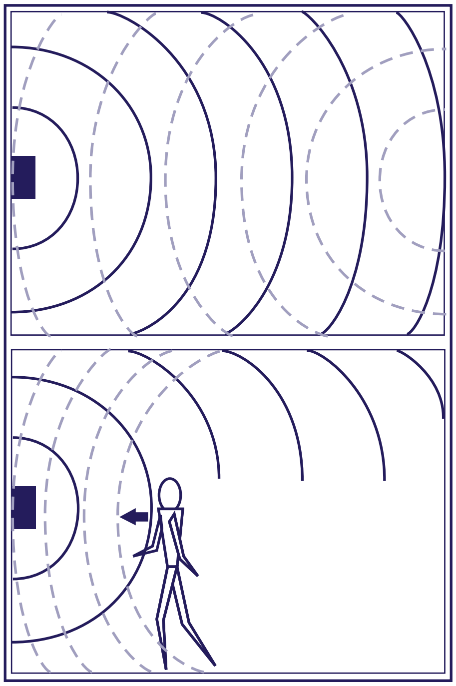


Table 7: Occupancy Sensor Applications

SensorPrivate Technology	Office Office	Large Open Office Plan	Partitioned Conference Plan	Room	Copy Restroom	Closets/ & Rooms	Hallways Warehouse Corridors	Aisles
Ultrasonic Wall Switch	3			3	3	3		
Ultrasonic Ceiling Mount	3	3	3	3	3	3		
Infrared Wall Mount		3			3		3	
Infrared Ceiling Mount	3	3	3	3		3		
Ultrasonic Narrow View							3	
Infrared High-Mount Narrow View							3	3
Corner-Mount Wide-View Technology		3		3				

Although increasing time delays will reduce the possibility of the lighting being switched off while the space is occupied, it will also reduce the energy savings. Setting the sensitivity too high may turn the lighting on when the room is unoccupied, wasting energy. Similarly, setting the sensitivity too low will create occupant complaints, as the lighting may turn off when the room is occupied. Evaluating the potential savings from an occupancy sensor installation should, and can, go beyond guesswork or speculation. Although sensors primarily affect energy use, they also affect energy demand, load on HVAC system, and lamp life. Evaluating the economic feasibility of an installation is best done by monitoring lighting and occupancy patterns. The use of inexpensive loggers will indicate the total amount of time the lights are on when the space is vacant, the time of day the savings take place, and the frequency of lamp cycling. This information will help you make an informed decision on the economic feasibility of potential occupancy-control opportunities.

Lighting Level-Based Controls

Lighting level-based strategies take advantage of any available daylight and supply only the necessary amount of electric light to provide target lighting levels. In addition to saving energy, lighting level controls can minimize overlighting and glare and help reduce electricity demand charges. The two main strategies for controlling perimeter fixtures in daylighted areas are **daylight switching** or **daylight dimming.**

Daylight switching involves switching fixtures off when the target lighting levels can be achieved by utilizing daylight. To avoid frequent cycling of the lamps and to minimize distraction to occupants, a time delay, provided by a deadband, is necessary. Several levels of switching are commonly used to provide for flexibility and a smooth transition between natural and electric lighting.

Daylight dimming involves continuously varying the electric lighting level to maintain a constant target level of illumination. Dimming systems save energy by dimming fluorescent lights down to as low as 10 to 20 percent of full output, with the added benefit of maintaining consistent lighting levels. Because HID sources cannot be frequently switched on and off, they are instead dimmed for time, occupancy, and lighting level-based control strategies.

Build In an Operations And Maintenance Plan

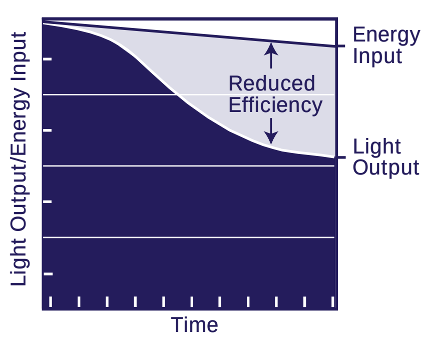
A lighting upgrade does not end with the installation of efficient equipment. Many cost-effective opportunities for reducing energy and maintenance costs and improving occupant satisfaction are frequently missed simply because operations and maintenance issues are ignored or addressed in an ad hoc fashion after the upgrade. The following decisions need to be integrated into your upgrade design from the beginning.

All lighting systems experience a decrease in light output and efficiency over time from three factors:

- Lamp light output decreases (lamp lumen depreciation).
- Dirt accumulates on fixtures (luminaire dirt depreciation).
- Lamps burn out.

Over time, these factors can degrade a system's efficiency by up to 60 percent (see Figure 10), wasting energy and maintenance costs and compromising safety, productivity, and building aesthetics. A planned maintenance program of group relamping and fixture cleaning at a scheduled interval minimizes this waste and maximizes system performance.

Figure 10: Efficiency Loss Over Time



Integrating a planned maintenance program into your lighting upgrade saves money in two ways. First, you will not have to overcompensate with higher initial lighting levels to ensure adequate lighting over time. The lighting system can be rightsized, saving on annual energy use and material first costs.

Second, while replacing lamps as they burn out on a spot basis may seem like a cost-effective practice, it actually wastes valuable labor. Group relamping times the replacement of lamps at their maximum economic value, generally at about 70 percent of their calendar life. Although it means replacing lamps before they expire, group relamping dramatically reduces the time spent replacing each lamp (not to mention the time spent responding to service calls and complaints), which can reduce your overall lighting maintenance budget by more than 25 percent. In addition, planned maintenance reduces the cost of lamps through bulk-purchase discounts, the storage space needs for replacement lamps, and disruptions in the workplace.

To sustain an efficient, high-performance lighting upgrade, assemble an operations and maintenance (O&M) manual. Use it as both the lighting management policy and a central operating reference for building management and maintenance staff. This manual should include the following information:

- Facility blueprints.
- Fixture and controls schedule.
- Equipment specifications, including product cut sheets.
- Equipment and service provider sources and contacts (include utility contacts).
- Fixture cleaning and relamping schedule with service tracking log.
- Procedures for relamping, reballasting, and cleaning fixtures.
- Procedures for the adjustment of photosensors and occupancy sensors.
- Procedures for proper lamp and ballast disposal.

Review the O&M manual with the staff responsible for lighting maintenance. Make training mandatory for all new maintenance personnel. Correct operation and maintenance should be built into job descriptions and should become part of all annual performance reviews.

Exterior Lighting

The three main considerations for exterior lighting are energy waste, glare, and light trespass. Energy waste and glare are discussed earlier in this chapter.

Light trespass, also known as spill light, is light that strays from its intended target and becomes an annoyance or nuisance. Maximizing the utilization of light output where and when it is needed will reduce light trespass. IES recommended light levels makes good economic sense and will minimize adverse environmental impacts associated with light trespass.

Strategies for Exterior Lighting

1. Use lighting fixture with directional control.
2. Direct and control light output to locations where it is needed.
3. Use time controls/dimmers to turn lights on and off and reduce light levels.
4. Design and install lighting to minimize glare.
5. Use the right amount of light for the task
6. Use energy efficient light sources and fixtures.

Environmental Effects

Exterior lighting can also have effects on the environment, excessive lighting near wildlife areas can adversely impact migrating bird life, nocturnal insects and other species. State and local ordinances have been established to protect natural wildlife from light pollution.

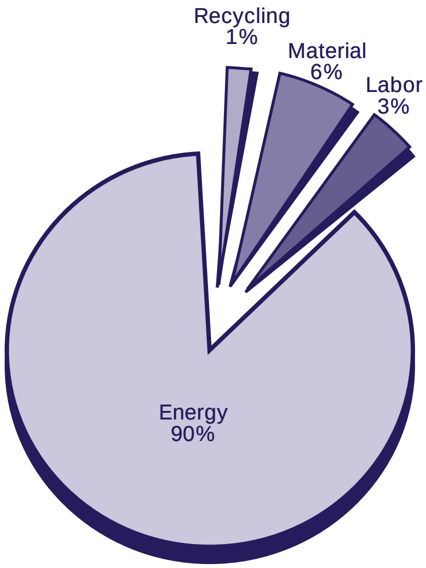
Ordinances and Community Standards

Outdoor lighting ordinances and codes encourage better quality lighting, which reduces glare, light trespass, and energy waste. Many codes are now including the concept of E-zones to distinguish between different types of lighting areas. For example, near national or state parks, wildlife refuges, or astronomical observatories lighting levels should be much lower than in city centers. The ordinances and community standards vary and local zoning departments should be contacted before implementing an outdoor lighting project.

Disposal

A lighting upgrade will most likely require the removal and disposal of lamps and ballasts. Group relamping every several years, and occasional spot relamping as necessary, will also create additional lamp waste. Some of this waste may be hazardous. As the waste generator, you must manage it according to applicable federal, state, and local requirements. While your specific requirements and your selected disposal options will determine the expense, it is important to note that disposal costs are rarely a "deal breaker" in a lighting upgrade. Typically, disposal costs constitute a very small percentage of the overall life-cycle costs of operating a lighting system (see Figure 11). Investigate and budget for these disposal costs both as a first cost during the upgrade and as an ongoing operation and maintenance expense.

Figure 11: Fluorescent Lamp Life Cycle Cost



Assumptions:

(2) T8 32-W lamps
62-W system wattage (w/electronic ballast)
Electricity at 7¢/kWh
Lamps at $2.65 each
Relamp labor at $1.50 each (group relamping)
Lamp life at 20,000
Lamp recycling at $0.50 each

Contact & Resource Information at a glance

Name	*Activity*	*Website/ Publications/Contact*
Resource Conservation and Recovery Act (RCRA)	Lamp Disposal	www.epa.gov/rcraonline/ Publication: Some Used Lamps are Universal Wastes RCRA Hotline 1.800.424.9346 (DC Metro Area 703.412.9810)
National Electrical Manufacturer's Association (NEMA)	Lamp Recycling	www.lamprecycle.org
Toxic Substances Control Act (TSCA)	Disposal of Ballasts with PCBs	www.epa.gov/pcb TSCA Hotline (202) 554-1401 E-mail tsca-hotline@epa.gov

Many lamps contain mercury, and are therefore considered hazardous waste under the Resource Conservation and Recovery Act (RCRA). In 1999, EPA added hazardous waste lamps to the universal waste program. Examples of common universal waste lamps include fluorescent, high intensity discharge, neon, mercury vapor, high pressure sodium, and metal halide lamps. Visit EPA's online RCRA Web site at www.epa.gov/rcraonline/ for more details. Recycling spent mercury-containing lamps is an alternative disposal method. The National Electrical Manufacturer's

Association (NEMA) encourages this practice and offers information on a website www.lamprecycle.org designed specifically to address lamp recycling issues.

The proper method for disposing of used ballasts depends on several factors, such as the type and condition of the ballasts. Generally, ballasts manufactured after 1978 contain the statement "No PCBs" and have not been found to contain PCBs. The disposal of Polychlorinated biphenyls (PCBs) is regulated under the Toxic Substances Control Act (TSCA). Information regarding the disposal of PCBs can be found on the PCB Home Page at www.epa.gov/pcb. Additional information can be obtained from the TSCA Hotline, which is reachable by phone at (202) 554-1401 or by e-mail at tsca-hotline@epa.gov. Other factors controlling the disposal of ballasts will depend on the regulations and recommendations in effect in the state(s) where you remove or discard them. Because disposal requirements vary from state to state, check with regional, state or local authorities for all applicable regulations in your area.

If you generated lighting material wastes, you are responsible for managing its disposal according to federal, state, and local laws or requirements.

Summary

Lighting has described opportunities for upgrading your building's lighting system at a profit. Keep the following strategies in mind as you upgrade your lighting system.

- Design **light quantity** and **quality** tailored to the task and occupants' needs.
- Maximize **lamp and ballast efficiency**.
- Maximize **fixture efficiency**.
- Use **automatic controls** to turn lights off or down when not needed.

  Reduce **light pollution** from exterior lighting
- Establish **operation, maintenance, and disposal** practices.

Next Steps

- Assess whether the existing lighting system meets occupant requirements.
- Communicate the lighting upgrade's objectives and process to all staff and occupants.
- Specify equipment that maximizes *system* efficiency, not just *component* efficiency.
- Perform trial installations to assess energy use and user acceptance.
- Move forward with lighting upgrades.