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Sustainability "How-To Guide" Series

Lighting Solutions

Bill Conley
CFM, CFMJ, LEED AP, IFMA Fellow
Managing Director
Pacific Building Care

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—Bill Conley

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ABOUT THE AUTHOR

Bill Conley

CFM, CFMJ, LEED AP, IFMA Fellow

Bill Conley is a CFM and CFMJ, a LEED AP and an IFMA Fellow. His experience in facility management extends over 30 years. He has managed facilities for VeriFone, Hewlett-Packard and SCAN Health Plan, and has served as a consultant through his own company, CFM2. Conley is currently Managing Director of the LEED®/Sustainability Development Group for Pacific Building Care (PBC). PBC operates in Central and Southern California, Phoenix, Arizona, and Denver, Colorado. Part of his duties includes spearheading a lighting retrofit service for commercial real estate in those regions.

FORWARD

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The IFMA Association's ISC is charged with developing and implementing strategic and tactical sustainability initiatives. A current initiative involves working with the IFMA Foundation on the development of a series of "How-To Guides" that will help educate facility management professionals and others with similar interests in a wide variety of topics associated with sustainability and the built environment.

The general objectives of these "How-To Guides" are as follows:

1. To provide data associated with a wide range of subjects related to sustainability, energy savings and the built environment
2. To provide practical information associated with how to implement the steps being recommended
3. To present a business case and return-on-investment (ROI) analysis, wherever possible, justifying each green initiative being discussed
4. To provide information on how to sell management on the implementation of the sustainability technology under discussion
5. To provide case studies of successful examples of implementing each green initiative
6. To provide references and additional resources (e.g., Web sites, articles, glossary) where readers can go for additional information
7. To work with other associations for the purpose of sharing and promoting sustainability content

The guides are reviewed by an editorial board, an advisory board and, in most cases, by invited external reviewers. Once the guides are completed, they are distributed via the IFMA Foundation's Web site www.ifmafoundation.org free of charge.

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IFMA Foundation

1 E. Greenway Plaza, Suite 1100
Houston, TX 77046-0194
Phone: 713-623-4362

www.ifmafoundation.org

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'Expand knowledge of the built environment, in a changing world, through scholarships, education and research'

The Vision Statement of the IFMA Foundation

1 EXECUTIVE SUMMARY

There are many factors that drive sustainability. Tenants and occupants are starting to demand greener, cleaner buildings. Legislation is starting to mandate energy efficiency and a curtailment of greenhouse gas emissions. Code requirements dealing with lighting density and light trespass dictate operational sustainability. Corporate directives are manifest in many decisions to go green; senior executives are beginning to realize the cost benefits of sustainable operations and the subsequent increase in building valuation and of being publicly recognized as a good corporate citizen.

Lighting associated with commercial buildings accounts for close to 71 percent of overall lighting electricity used in the United States. It is the largest cost component of a commercial property's electricity bill and a significant portion of the total energy bill. With good design, lighting energy use in most buildings can be cut at least in half while maintaining or improving lighting quality. Lighting electricity savings equates to an increase in net operating income (NOI) that drives favorable cap rates.

Updating an existing lighting system with the latest technology will make it more energy efficient while yielding cost savings. The aesthetic quality of a facility's environment will be enhanced and productivity increased without sacrificing lighting system performance. A lighting retrofit has the best return on investment (ROI) of any energy-efficient technology with typical payback periods between 14 and 18 months. Once the payback is realized, the savings will continue, creating a sound investment in the future. It must be understood, too, that energy savings should be monitored on a consumption level, not a dollar level. Energy costs fluctuate; the amount of energy saved is the true telling measure.

Newer lighting technology also leads to decreased demand on heating, ventilating and air conditioning (HVAC) systems. Lighting is the largest source of waste heat, also called heat gain, inside commercial buildings. In fact, for every 3 watts of lighting load reduction, you reduce the air conditioning load by 1 watt. Lighting also affects the power quality of a 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. Upgrading with higher-efficiency lighting systems can free up valuable electrical capacity.

Artificial lighting consumes a significant part of all electrical energy consumed worldwide. In commercial buildings and offices, from 35 to 50 percent of total energy consumed is due to lighting. Most importantly, for some buildings over 90 percent of lighting energy consumed can be an unnecessary expense through over illumination or misapplication of lamp types. The cost of that lighting can be substantial. A single 100W incandescent light bulb used just six hours a day, with a utility cost of $0.10/kWh, can cost over $25 (US dollars) per year.

Artificial lighting consumes a significant part of all electrical energy consumed worldwide. In commercial buildings and offices, 35 to 50 percent of total energy consumed is by lighting.

Lighting represents a critical component of energy use today, especially in large office buildings. High-efficiency lighting systems reduce glare, which helps to reduce eyestrain, boosting occupant productivity. Electronic ballasts do not flicker or hum like magnetic ballasts, improving the quality of the commercial facility environment. Proper lighting contributes to occupant comfort and productivity. Light levels need to be maintained at certain levels for particular surfaces. For example, the number of footcandles at the desktop level for proper work is different from the number of footcandles needed at the floor level to evacuate a building.

This guide has been written to explain the benefits of investigating and upgrading lighting systems in and around facilities. Based on extensive research, input from lighting specialists and general experience, it provides a broad description of options available to facility professionals to enhance the indoor quality of buildings while saving energy, dollars and manpower to maintain proper lighting.

Detailed findings in this guide will serve as a reference for standards and activities to help mitigate the costs and consumption of energy. It includes:

- Basic lighting concepts and terms
- Efforts on a global level to increase lighting efficiency
- Lamp and ballast types
- The benefits of occupancy sensors and natural light
- Future technology for lighting solutions
- Lighting upgrades

The guide concludes with two case studies of lighting retrofits and a glossary of lighting terms.

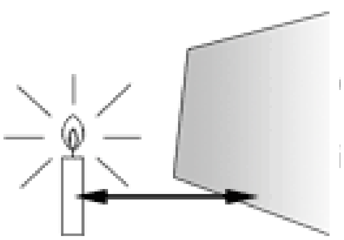


Figure 1: Recommended footcandle level for an office space

FOOTCANDLE (FC)

Footcandles are a quantitative measurement to describe the total amount of light that actually strikes a work surface, floor, wall or any single point of calculation. Footcandles are measured with an illuminance meter.

One footcandle is equivalent to the illuminance produced on 1 square foot (0.09 square meters) surface area by a source of one candle at a distance of 1 foot (0.3 meters). Horizontal footcandles measure the illumination striking a horizontal plane. The Illuminating Engineering Society (IES) has published a handbook with a comprehensive breakdown of appropriate footcandle levels.

LUX

The metric unit for illuminance. To convert footcandles to lux, multiply footcandles by 10.76.

ILLUMINANCE

The light intensity measured on a plane at a specific location, measured in footcandles (lux). Illuminance is measured using an illuminance meter. Using simple arithmetic and manufacturers' photometric data, illuminance can be predicted for a defined space.

Table 1: Footcandles per space requirements

Space	Footcandles	Lux
Open office	30	323
Private office	50	538
Printed tasks	30	323
Conference room	30	323
Videoconference room	50	538
Stairways/corridors	5	54
Lobby	10	108
Restrooms	5	54
Warehouse	30	323
Storage	10-30	108-323
Maintenance	50	538

2 INTRODUCTION

2.1 Background

Addressing lighting systems in a facility is one of the easiest ways to realize cost savings through energy efficiency and improve the quality of the indoor environment. A conversion from T12 lamps to high-performance T8 lamps could save up to 50 percent of energy consumption from lighting while providing better working conditions for building occupants. Based on a rate of $0.10 per kilowatt-hour (kWh), savings could average up to $0.17 a square foot ($1.85/square meter) (US dollars). Increases in productivity and higher employee morale from proper lighting will feed directly to a company's bottom line.

The critical success factors for a facility manager revolve around having satisfied customers, creating positive visibility to upper management and providing measurable and measured results in operations. Facility operations and projects should be planned and implemented so that they coincide with business issues and will always contribute to the bottom line, either directly or indirectly. Cost of ownership must be taken into consideration and attention must be paid to life cycle cost and life cycle assessment criteria. Every tool available to save money must be considered, reflecting constant efficiency improvements and continued cost savings.

In true FM fashion, the effect of any action must also be considered as a part of the whole. There are always ramifications of what is done and how particular services are integrated within a holistic view of operations. Operations and maintenance practices should utilize standards, be proactive and reflect strategic thinking. Facility professionals have a fiduciary responsibility to supply optimum efforts and solutions that will benefit both the company and its employees.

2.2 Lighting and Facility Management

All of these concerns tie the facility strategic plan to the organization's strategic plan, and are satisfied by sustainable operations and by comprehensive lighting solutions. One of the easiest ways to address energy efficiency in a facility is by implementing proper lighting solutions. This can be accomplished through lighting analysis, retrofit options and a holistic view of lighting in the workplace.

Not only are cost benefits and energy efficiency realized through these actions, occupant comfort, improved productivity and decreased absenteeism can be attributed directly to the quality of the indoor work environment, in which lighting plays a large part.

Illumination is the deliberate application of light to produce an aesthetic or practical effect in the workplace. It includes the use of both artificial and natural light sources, such as lamps and daylight. Indoor lighting provided by electric lights represents a major component of energy consumption,

RECOMMENDED INDOOR LIGHT LEVELS

The outdoor light level is approximately 929 footcandles (10,000 lux) on a clear day. Near the windows in a building, the light level may be approximately 93 footcandles (1,000 lux). In the center of a building, away from windows, lighting levels may be as low as 2.3 to 4.6 footcandles (25 to 50 lux). Lighting must often be added to increase indoor lighting levels to 46 to 93 footcandles (500 to 1000 lux), depending on the activity.

accounting for a significant part of energy consumption worldwide. Thus, the determination of proper lamping is critical in fully serving the needs of building occupants. Daylight can be introduced into the facility through windows, skylights and clerestories, and can be used as a major source of light, diminishing energy consumption. Proper lighting can enhance task performance and the look and feel of a facility. Improper lighting leads to energy waste, increased cost, adverse occupant health and adverse environmental impacts.

Using more efficient lighting solutions reduces the amount of electricity that must be generated by electrical utilities. By reducing electricity consumption, the generation of sulfur dioxide and nitrogen oxides is reduced, both of which contribute to smog and acid rain. By leveraging environmentally conscious lighting solutions, occupant satisfaction and facility aesthetics will be maintained or improved, while the environmental footprint of the facility is decreased.

3 DETAILED FINDINGS

3.1 Lighting Options

Improved lighting enhances visual comfort, reduces eye fatigue and improves performance of visual tasks. Well-designed lighting can increase productivity and reduce absenteeism. Most lighting upgrades are cost effective based on energy savings alone. However, as the costs associated with a building's occupants greatly outweighs building operational costs, any lighting change that improves the indoor environmental quality is worth implementing. Upgrading lighting systems with efficient light sources, fixtures and controls can provide several benefits:

- Enhanced aesthetics
- Reduced lighting energy use
- Improved visual environment
- Reduced cooling load, potentially allowing smaller HVAC and electrical systems to be installed

There are several strategies available to minimize lighting energy requirements in any building. A study must be done to determine the illumination requirements for each use area within the building. This requires an analysis of lighting quality to ensure that glare and/or an incorrect color spectrum are not adversely affecting the occupants of the area. Space planning, interior architecture and paint palettes must be integrated with lighting design to ensure that competing factors are not evident and that the area and lighting solutions complement each other. Time of day scheduling should also be utilized to minimize energy usage. This can be accomplished automatically by using a real-time sensor as part of the building automation system (BAS), or can be performed manually.

Natural light should be used as a substitute for artificial light whenever possible. The positive effects of natural daylight are part of a total lighting solution. Access to views and windows through office configurations and the use of low partitions and/or glass walls, and full utilization of existing and/or new skylights and clerestories improve the quality of the workspace.

Fixtures and lamp types should be chosen to reflect the best available technology for energy conservation. Evaluation of current materials and their efficiency may provide cost-effective changes that can rectify poor performance in the lighting system. A preventive and proactive maintenance program for lighting systems should be implemented to minimize energy waste. This could be comprised of a scheduled group re-lamping process.

Finally, it is extremely important that building occupants are trained to utilize lighting equipment in the most efficient manner. If occupancy sensors or scheduled shutoffs are not in place, then it is imperative that personnel understand the need to turn off lights when they are not in use.

The specification of illumination requirements is a basic concept of deciding how much illumination is required for a given task (see Table 2). As shown in Table 2, different lighting levels are required to illuminate different spaces. For example, a hallway requires a different lighting level than an office or a workstation. Historically, a lighting engineer simply applied the same level of illumination design to all parts of the building without considering usage. This resulted in over-lighting or under-lighting portions of the facility. Generally speaking, the energy expended is proportional to the design illumination level. For example, a lighting level of 75 footcandles (807 lux) might be chosen for a work environment with meeting and conference rooms, whereas 35 footcandles (377 lux) could be selected for hallways.

Table 2: Lighting levels by activity

Activity	Footcandles	Lux
Warehouses, homes, theaters, archives	15	150
Easy office work, classes	25	250
Normal office work, PC work, study library, groceries, show rooms, laboratories	50	500
Supermarkets, mechanical workshops, office landscapes	75	750
Normal drawing work, detailed mechanical workshops, operating theatres	100	1000
Detailed drawing work, very detailed mechanical works	150-200	1,500-2,000

If the different lighting levels for space uses were not accommodated, the hallway lighting level would be the same as the conference rooms. As a result, over twice the amount of energy needed would be consumed for hallway lighting. There are areas in many facilities that do not fall under the same criteria as offices. These would include warehouses and spaces such as labs, conference rooms and videoconference rooms. Each needs to be treated based on lighting needs for the work performed.

Most of the lighting standards in recent history have been specified by industrial groups who manufacture and sell lighting, so that a historical commercial bias exists in designing most building lighting, especially in office and industrial settings. Beyond the energy factors being considered, it is important not to overdesign illumination. Energy could be wasted by over illumination. Additionally, over illumination can lead to adverse health and psychological effects such as headache frequency, stress and increased blood pressure. Also, glare can decrease worker efficiency.

The average commercial facility is full of opportunities to analyze, redesign or replace outmoded lighting systems with more efficient lighting technologies, such as T8 fluorescent lamps, electronic ballasts, compact fluorescent lamps, LEDs, lighting controls and occupancy sensors. The substitution in warehouses of T5 fluorescent bulbs or induction lighting for metal halide lamps are also possibilities that should be investigated. Entry and exit lighting must be addressed, as well as proper illumination and energy savings options for parking lots, parking structures and pedestrian paths.

3.2 Lighting and Global Standards

3.2.1 United States

The United States Department of Energy (DOE) requires that all states adopt a building standard as stringent as ASHRAE 90.1. ASHRAE 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings is a baseline standard that includes criteria for efficient lighting systems. ASHRAE 90.1 is typically used as a standard within local building codes and is also referenced in LEED® certification guidelines. Given the wide acceptance of ASHRAE 90.1, sustainable lighting systems are gauged by how their performance compares to ASHRAE 90.1. In 2004, ASHRAE 90.1-2004 was updated to permit a maximum of 1.0 watt per square foot (0.09 W/m^2) for commercial office buildings. The prior version of the standard allowed 1.3 W/sf (0.11 W/m^2). ASHRAE 90.1 is a standard developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). The standard is continually updated (Muszynski 2008).

While daylight dimming is not currently part of the standard, these systems have a relatively short ROI. Therefore, the 2010 version of the standard may require lighting within 15 feet (4.6 meters) from perimeter glazing to be controlled separately from interior spaces.

One of the greatest opportunities in the United States for reducing energy use is by retrofitting existing buildings with more energy-efficient systems. This is reflected by the passage of the Energy Independence and Security Act of 2007, also known as the Clean Energy Act of 2007. This Act sets energy policy for the United States. It outlines revised standards for appliances and lighting, requiring approximately 200 percent greater efficiency of light bulbs by the year 2020.

3.2.2 Europe

Europe has also implemented regulations and legislation dealing with this lighting efficiency. The European Parliament and Council Directive 2000/55/EC of September 18, 2000, includes energy efficiency requirements for ballasts for fluorescent lighting (Official Journal L 279 of 01.11.2000), improving energy efficiency to meet three goals of energy policy: security of supply, competitiveness, by consolidating competitive positions, and protection of the environment, by reducing carbon dioxide emissions. The Directive will allow harmonization at Community levels to prevent potential barriers to trade (Europe's Energy Portal 2009).

Under the SAVE Programme, the European Commission has investigated potential lighting energy efficiency improvements. A study carried out for the European Commission concluded that production of performance standards for fluorescent lamp ballasts would be one of the most effective actions the Community could take to reduce lighting energy consumption in commercial buildings. Since fluorescent lighting accounts for a significant share of electricity consumption, and various fluorescent ballast models available in the market have different consumption levels, the Directive proposes standardization of ballasts, improving energy efficiency and reducing carbon dioxide emissions. Implementing the recommendations of this study is expected to have a limited impact on the industry, as a long transition period is planned (Europe's Energy Portal 2009).

The Directive applies to electric mains-operated ballasts for fluorescent lighting. The Member States must take all necessary measures to ensure that ballasts covered by the Directive are placed on the market and put into service only if their power consumption is less than or equal to the maximum allowable power consumption for the category, calculated in accordance with stated procedures. Manufacturers of ballasts covered by the Directive are responsible for ensuring that every ballast placed on the market complies with the Directive power consumption requirements. Additionally, when ballasts are placed on the market they must bear the CE or ec marking. A CE or ec marking is a confirmative mark to symbolize that the product meets the "essential requirements" set by the Directive for the European Economic Area (Summaries of EU Legislation 2005; Europe's Energy Portal 2009).

At the December 8, 2008, meeting of the Ecodesign Regulatory Committee, European Union (EU) Member States' experts endorsed the European Commission's draft regulation to progressively phase out incandescent bulbs. The regulation would start in 2009 and end at the end of 2012. This regulation would reduce energy consumption by almost 40 TWh, roughly the electricity consumption of Romania, 11 million European households or the equivalent of the yearly output of 10 power stations of 500 megawatts. This energy reduction would lead to a reduction of about 15 million tons (13.6 metric) of carbon dioxide emission per year (Europe's Energy Portal 2009).

3.2.3 Australia and New Zealand

Australia and New Zealand are also enacting legislation to reduce electrical consumption through lighting. Lighting generates almost 25 million tons (2.3x107 tonnes) of greenhouse emissions each year in Australia. It is responsible for about a third of the greenhouse emissions from the commercial sector, and is a significant contributor to both residential and industrial sector emissions. Lighting also costs over $2 billion Australian dollars annually. These statistics clearly illustrate why improving the efficiency with which Australians use energy is a priority of the Ministerial Council on Energy (MCE).

Greenlight Australia is a 10-year strategy to reduce lighting energy consumption. It is part of a package of measures being implemented under the National Framework for Energy Efficiency and is the outcome of consultations with stakeholders in both Australia and New Zealand. These extensive consultations determined which lighting technologies and market sectors should be included in the framework, voluntary and mandatory measures, and priority areas and products targeted for action in the first three years.

The Greenlight Australia program has the support of both industry and government. The long-term strategy to improve the energy efficiency of lighting sets immediate and future priorities for consideration of specific lighting products. The Lighting Council of Australia supports the strategy, and has suggested a target of 20 percent reduction in energy usage over business as usual over the course of the strategy.

Greenlight Australia will improve the efficiency of all lighting equipment, including lamps, ballasts, transformers and luminaires, in the residential, commercial, industrial and public lighting sectors. The framework also broadly considers lighting controls, including dimmers and timers, and lighting design. It will include a maximum illumination power density for interior spaces in commercial buildings; make concessions for intelligent lighting controls; set the criteria for mandatory time switches or occupancy sensors for large spaces; and establish minimum efficacy and sensing requirements for exterior lighting (Greenlight Australia 2004).

3.3 Effective Lighting Measures

Lamps, commonly called light bulbs, are the removable and replaceable portion of a luminaire that converts electrical energy to both visible and non-visible electromagnetic energy. Common characteristics used to evaluate lamp quality include efficiency measured in lumens per watt, typical lamp life measured in hours and color rendering index (CRI) on a scale of 0 to 100. Cost of replacement lamps is also an important factor in design. There are a number of measures that can be implemented in a facility that will upgrade lighting quality and improve energy efficiency and costs related to the overall lighting system.

LUMEN

A lumen is a unit of measure of the actual amount of light produced by a light source, also known as a bulb or lamp.

WATTAGE

The energy input into a lamp. A 75 watt incandescent lamp can produce 1,000 lumens while a 70 watt high-pressure sodium lamp produces 6,000 lumens. Lumen output is listed by the manufacturer on the package.

3.4 Wash and Re-Lamp Procedures

Wash and re-lamp procedures are an effective cost-savings strategy. Light output from fluorescent lights will decrease in brightness and whiteness over time, prior to the lamp burning out. The wash and re-lamp procedure includes preventive maintenance to clean the interior surface of each fixture and eliminate the labor of replacing lamps one by one. Part of a preventive maintenance program includes cleaning lighting fixtures and reflectors to remove built-up dust or debris that can absorb light and heat. Clean fixtures run cooler, last longer and provide higher lighting levels. When cleaning, consider replacing lamps in batches rather than intermittently as they fail. This process is called group re-lamping. Scheduling the replacement of lamps in conjunction with washing the fixtures saves maintenance time, allowing two activities to be completed at one time. A carefully planned re-lamping schedule allows for the repair or replacement of defective parts in a fixture, such as sockets and ballasts, and can assist budgeting future costs more accurately. Finally, group re-lamping can be performed during office downtime, minimizing inconvenience and interruptions and mitigating occupant complaints.

When it is time to re-lamp, it is crucial to remember to maintain the same or equal performance as the original installation. If a high-lumen/high-performance T8 lamp was used, 8 to 10 percent lumen depreciation will occur at the end of lamp life. If re-lamping is done with less expensive 700 series T8 lamps, the lighting level will be lower prior to re-lamping. A standard 700 series T8 starts out with 15 percent less lumens compared to an 800 series T8. This means a 5 percent decrease in lighting level may occur and desired energy savings may not be achieved. Conversely, if a facility currently uses 700 series lamps, upgrading to a higher standard makes sense because the lumen depreciation will be less and efficiency will be increased.

Installing longer life bulbs during group re-lamping means less maintenance. Utilizing lower watt bulbs can generate the same light level while consuming less energy. Using fewer lamps per fixture, retrofitting with reflectors or minimizing number of bulbs per fixture when possible will also reduce maintenance and energy costs. By installing longer lasting bulbs, the number of lamps made, transported and recycled is reduced, reducing environmental impacts.

3.5 Fluorescent Lamp Development

Developments in lighting technologies over the last 10 years have created the possibilities of reducing lighting costs by as much as 30 to 50 percent and total facility energy consumption and costs by up to 20 to 25 percent. New T8 fluorescent bulbs, when used with high-efficiency electronic ballasts, can reduce total system wattage by 45 percent, compared to T12 bulbs with magnetic ballasts, and by as much as 20 to 30 percent, relative to the use of older T8 lamps and electronic ballasts. In fact, major lighting manufacturers are now on their seventh generation of high-efficiency T8 lamps. If a building was built, or a lighting upgrade performed, more than five years ago, significant cost savings are likely. It has frequently been found that the less expensive and less effective T8 lamps are being used primarily because the purchasing department has a prearranged buying agreement or a lighting contractor installed the least expensive lamp. An upgrade of old lighting systems to state-of-the-art energy-efficient solutions can cut operating costs, save energy and contribute to an organization's perception as an environmentally responsible good corporate citizen.

Figure 2: Fluorescent tube

T8 bulbs have continued to improve. Originally the standard replacement for the T12 was the 32 watt T8. Over time, a 30 watt long life lamp that provided comparable light output, with a 20 percent extended life, was introduced. Later, a 28 watt bulb that offered an additional 6 percent energy savings was introduced. The 28 watt bulb offered a higher output and longer lamp life, and provided an option to minimize the number of lamps per fixture. The newest improvement is the 25 watt lamp. Although the 25 watt lamp does not produce as much light as a standard T8, it has an extended life.

The older 700 series T8 lamps are as common today as T12 lamps were in the past. Price is very low and they can be found in most hardware and home improvement stores. One reason contractors sometimes provide these types of lamps for a facility is due to their accessibility and low initial cost. The perception that these 'new' lamps will save more energy may be misleading. High-performance 800 series T8 lamps are typically only stocked by lighting and electrical distributors. Well-stocked distributors may carry complete lines of all lamp types mentioned above, so needs must be determined and specified for optimal solutions.

The benefits of lighting retrofits include energy efficiency and cost savings which, when utilized with available utility rebates, will minimize the time for payback on the project. Above and beyond that, it will continue paying through energy savings, longer lamp and ballast life, and improved illumination. Finally, the decrease in wattage from lighting decreases the HVAC cooling load to a space. Every watt of lighting reduced equals 0.33 watt less cooling needed, decreasing cooling costs.

There are still over 1 billion T12 lamps in use in the United States utilizing magnetic ballasts. Ballast replacement should also be considered as part of any lighting retrofit. Replacing magnetic ballasts with basic electronic ballasts can save an additional 10 percent of energy consumption, with an even greater savings when premium electronic ballasts are used. The change to T8 bulbs with electronic ballasts can achieve an almost 50 percent reduction in energy usage. Changing out a 32 watt T8 to a 25 watt lamp will also generate savings. Ballasts can also be upgraded. Upgrades can include instant start ballasts for dimming and sensor use or power shed ballasts to coincide with demand-response programs.

Retrofitting older 1.5 inch diameter (38 mm) T12 fluorescent fixtures with energy-efficient T8 fixtures and installing electronic ballasts is of primary importance. T8s are high-efficiency lamps that are thinner in diameter, have a higher efficacy (lumens per watt) rating and better color rendering than T12 lamps. Depending on the ballast used, the T8 lamp often delivers the same lumen output while consuming 20 to 40 percent fewer watts. T8s last longer and require less maintenance over the useful life of the lamp. As the light quality is also better, fewer fixtures per unit area are needed, making de-lamping possible. De-lamping is the removal of one or more fluorescent tubes from an existing ballast where lighting levels are too high, reducing the total wattage. De-lamping and the use of reflectors in overhead fixtures can reduce energy costs by 33 to 50 percent.

T12 bulbs with magnetic ballasts are being replaced with T8 lamps with electronic ballasts as the industry standard because they can save a significant amount of electricity, reducing costs from about 40 to 50 percent. Technological advances in the last 10 years have allowed for the 32 watt T8 to replace the T12, previously the most popular bulb used. The T8 has several advantages over the T12:

- Color rendering index (CRI) from 75 to 90
- High system efficacy of about 90 lumens per watt when used with an electronic ballast
- Smaller bulb diameter than the T12
- T8 has a 1 inch (25 mm) diameter bulb
- T12 has a 1.5 inch (38 mm) diameter bulb
- Lower amount of phosphors within the bulb

TYPICAL COST OF LIGHT

(all costs in US dollars)

Building Information

- **6,000 square foot space (557 square meters)**
- **Average lighting plan with 120 fixtures, 12 rows, 10 fixtures per row**
- **Two T8 lamps per fixture, total = 240 lamps**

Cost (all in US dollars)

- **Cost of electricity = $2,680/year**
- **Lamp replacement cost = $72/year**
- **Ballast replacement cost = $120/year**
- **Labor to replace lamps cost = $300/year**
- **Labor to replace ballasts cost = $96/year**
- **Disposal of lamps = $24/year**

TOTAL = $3,292

3.5.1 T5 Lamps

T5 lamps are being installed in many facilities as they offer various opportunities for lighting designers and manufacturers. T5 lamps measure 5/8 inch in diameter (16 mm). The smaller diameter lamp allows for smaller luminaires, including surface mounted, cove lighting and cabinetry applications.

Some care must be taken in the application of T5 lamps. T5s are designed mainly for new construction and not intended for retrofit applications. Optimum use of T5 lamps are in high bay ceilings, such as outdoor overheads and warehouses. When T5 lamps are installed, fewer fixtures are needed, resulting in cost savings because fewer parts are needed, resulting in lower installation and energy costs.

T5 bulbs are available in lengths of 2 to 5 feet (0.6 to 1.5 meters). However, they are actually 2 inches (51 mm) shorter than a T12 or T8 lamp. Therefore, in order to complete a retrofit using T5 bulbs, the ballasts would need to be replaced. A T5 lamp will outperform a T8 when mounted at high ceiling heights. For example, T8 lamps provide better lighting quality and less glare when mounted at ceiling heights of 18 feet (5.5 meters) or less. To date there are only two types of T5 high output (HO) lamps available: 28 watt T5 and the 54 watt T5 HO. Both lamp types are 4 feet (1.2 meters).

The 54 watt T5 high output lamp will supply 5,000 lumens and provides superior performance at elevated temperatures. They have a 30,000 to 36,000 hour life, depending on starting frequency, and are suggested replacements for metal halide fixtures, as they offer a 60 percent energy savings over metal halide with 75 percent longer lamp life.

The number of lamps required to achieve the desired lighting level is an important factor when upgrading a lighting system. As a general rule, a four-lamp T5 HO fixture will replace a standard 400 watt HID fixture on a one for one basis. This update will also improve light levels and reduce energy consumption by 40 to 50 percent.

If T8 lamps were used, instead of the 400 watt HID fixtures, six T8 800 high-lumen or high-performance series lamps with high ballast factor ballasts would be needed to achieve the same result.

3.6 Ballasts

All lamps, except incandescent lamps, require a ballast (Gordon 2003). A ballast limits the current flowing through the lamp at a constant value (Hughes 1988). Electronic ballasts take advantage of the higher efficacy of lamps operated with higher current. An electronic ballast uses solid state components to transform voltage. A ballast also changes the frequency of the power from 60 Hz to 20,000 Hz, or higher, depending on the ballast characteristics. An electronic ballast does not use coils and electromagnetic fields. Therefore, it can function more efficiently and cooler than a magnetic ballast. The frequency change also greatly reduces flicker in the lamp due to burn in or improper power.

Electronic ballasts run cooler than magnetic ballasts. The operating temperature of magnetic ballasts is roughly 140 to 160°F (60 to 71°C), compared to electronic ballasts that operate about 10 degrees higher than ambient temperature.

Figure 3: Electronic ballast

To get high output performance out of a T8 fixture, the lamps need to be combined with T8s with high ballast factor. This combination will safely overdrive the lamp output by an additional 12 to 15 percent and provide the highest lumen per watt ratio currently available on the market today.

Every ballast has a ballast factor, either low, normal or high. The ballast factor is the ratio of lamp lumens generated on commercial ballasts to those generated on test-quality ballasts (Hughes 1998). Common ballast factors are 0.77, 0.87, 1.0 and 1.15.

RULE OF THUMB

(Rated lamp lumens) x (Ballast factor) = Light output

Building Description

- 10,000 square foot (929 square meters) area with a 12 foot (3.7 meters) ceiling

Standard Design

- 56 standard 32 watt ceiling mounted lamps
- Illumination = 30 footcandles (323 lux)
- Ballast factor = 0.87

Efficient Design

- 36 high lumen 32 watt lamps
- Illumination = 30 footcandles (323 lux)
- Ballast factor = 1.15

The efficient design will generate the same level of light using fewer fixtures. Eliminating 20 fixtures from the design saves construction, maintenance, lamp replacement and energy costs.

3.6.1 Ballast Types

Rapid Start Ballasts: Rapid start ballasts are predominantly used for T12 lamps. They start the lamps quickly, usually within 0.5 to 1.0 seconds, without flicker or a strobe effect. The lamp is started by heating the lamp electrodes and simultaneously applying a starting voltage of about 500V. The electrodes are continually heated during lamp operation, consuming 2 watts per lamp. Lamps within rapid start ballasts are wired in series. Therefore, one failure will affect all lamps in the series. Lamps operated on rapid start ballasts typically fail after 15,000 to 20,000 on/off switching cycles.

Instant Start Ballasts: Instant start ballasts are typically used with T8 lamps. They start the lamps without cathode heating with minimum delay, less than 0.1 seconds, or flicker. The starting voltage of 600V is sufficient to start the lamp without the need to heat the lamp electrodes, which maximizes energy savings. Instant start ballasts do not require the electrode to be continually heated during lamp operation. Therefore, compared to rapid start ballasts, instant start ballasts save 2 watts per lamp. Instant start ballasts are wired in parallel, so if one lamp fails, it does not affect any others. Lamps operated on instant start ballasts will fail after 10,000 to 15,000 on/off switching cycles.

Programmed Start Ballasts: Programmed start ballasts can be used with both T8 and T5 lamps to provide a controlled lamp starting sequence. They start quickly, within 1.0 to 1.5 seconds, without flicker. The starting voltage is 320V and ramps up to 700V until the lamp strikes. The electrodes are precisely heated to 1292°F (700º C) by tightly controlling the preheat duration before applying the starting voltage. This process minimizes the stress on the electrode and reduces emitter depletion. The ballasts are wired in series, so one failure affects other lamps in the fixture. Parallel wiring for programmed start ballasts is in development. Programmed start ballasts provide maximum lamp life of up to 50,000 on/off switching cycles for frequent starting applications. Programmed start ballasts are recommended for installations using occupancy sensors and electronic dimming ballasts.

The more starts to which a lamp is subjected, the shorter the lamp life will be. The choice of the proper ballast will make a significant difference in lamp longevity.

3.6.2 Fluorescent Ballast Developments

Old generation ballasts were a maximum of 85 percent efficient and used 120V or 277V power. Newer generation ballasts are over 90 percent efficient and operate in a power range of 108V to 305V. Additionally, newer generation ballasts are:

- Anti-striation, providing cleaner light
- Offer low temperature starting, while rated for use at high temperatures
- Anti-arcing
- Supplied with various ballast factors
- Can be used with controllable or dimmable light
- Can be used for programmed starts to accommodate lighting sensors

3.7 Occupancy Sensors

Occupancy or motion sensors are devices that turn lights and other equipment on or off in response to the presence or absence of people in a defined area. Some sensors can also control lighting based on the amount of daylight within an area.

In an average facility, lights are left on in unoccupied spaces for a large percentage of the day, (see Table 3). From Table 3, if occupancy sensors are not used, a large amount of energy can be wasted daily. According to the United States Environmental Protection Agency (EPA), energy savings can range from 40 to 60 percent in classrooms, 20 to 50 percent in private offices, 30 to 90 percent in restrooms, 22 to 65 percent in conference rooms, 30 to 80 percent in corridors and 45 to 80 percent in storage areas.

Table 3: Typical time spaces are unoccupied

Space	Time unoccupied
Private office	68%
Restrooms	68%
Classrooms	63%
Conference room	57%
Break room	39%

Having lights turned off when space is unoccupied can save energy and money. Occupancy sensors eliminate wasted electricity, minimize lighting pollution and enhance security in the workplace. Due to their relative simplicity and high energy savings, combined with the requirement in energy codes for automatic lighting shutoff, occupancy sensors should be considered a standard feature when determining lighting solutions.

State energy codes in the United States must be at least as stringent as ASHRAE 90.1-1999. This standard requires automatic shutoff of lighting in commercial buildings greater than 5,000 square feet (460 square meters). Automatic shutoff can be provided by occupancy sensors or programmable time-scheduling devices. When occupancy in a space is intermittent or not predictable, occupancy sensors are the most economical solution. Occupancy sensors use different technologies to detect the presence of people in a space. The three most prevalent applications are passive infrared (PIR), ultrasonic and dual technology.

Figure 4: Occupancy sensor

3.7.1 Passive Infrared (PIR) Sensors

PIR sensors monitor the difference in heat emitted by people in motion from that of the background space. They require a line of sight and have an effective range of 15 feet (4.6 meters) for minor movement. PIR sensors are best used in smaller, enclosed areas.

3.7.2 Ultrasonic Sensors

Ultrasonic sensors detect occupancy by emitting an ultrasonic high-frequency signal. By sensing changes in the frequency of the reflected signal, they interpret these changes as motion. These sensors do not require a direct line of sight but fabric panels minimize effectiveness. They are more effective for low motion activity with a range of about 25 feet (7.6 meters). Ultrasonic sensors are suitable for open spaces, spaces with obstacles and spaces with hard surfaces. Dual technology sensors utilize both PIR and ultrasonic sensors, activating lights only when both technologies detect occupants in the space.

3.8 Energy Management

There are energy management activities that can be taken in conjunction with local utilities or at the facility level per directives by the facility manager. Two of the most prevalent are peak load management and demand response programs. In demand response programs, customers agree to reduce their electricity load on the hottest days or when there is a large demand for power. This can be accomplished by either using less electricity or using alternative sources of power generation. Participants are paid for enrollment and/or for responding during a peak event. Some utility companies offer lower rates to participants of the demand response program. Other utilities might create a tariff-based incentive by passing along short-term increases in the price of electricity. Alternately, during a heat wave, a mandatory decrease for selected high-volume users could be imposed, with compensation for participation. Other users may receive a rebate or other incentive based on firm commitments to reduce power during periods of high demand.

During times of peak demand, smart-grid-enabled lighting systems receive a digital message from the grid requesting to curtail power usage by a predetermined amount based on site evaluations.

3.8.1 Energy Management System (EMS)/ Building Automation System (BAS)

The terms energy management system (EMS) and building automation system (BAS) are often used interchangeably within the buildings industry. An EMS/BAS is a computer system, sensors, meters and sub-meters that control and monitor the heating, ventilating, air conditioning and lighting systems within a building or group of buildings. The core functionality of a BAS is to keep the building at the specified conditions; control lighting and mechanical equipment; monitor system performance and device failures; and provide email and/or text notifications to building engineering staff about device failures or maintenance needs. Most BAS can also be connected to electricity, gas and water meters. Utility meter data, as well as data from sensors and meters directly connected to the BAS, can be used to perform trend analysis and forecast annual energy consumption.

Lighting can be turned on and off with a BAS based on time of day using occupancy schedules, or occupancy sensors and timers. A typical example of an occupancy application is to turn the lights off in a space where it has been a half hour since the last motion was sensed. A second example is using a photocell outside of a building to sense darkness, modulating lights to turn on in a parking lot.

3.9 New Lighting Trends

3.9.1 Compact Fluorescent Lamps (CFL)

A compact fluorescent lamp (CFL) is a type of fluorescent lamp. Many CFLs are designed to replace incandescent lamps and can fit into most existing fixtures that use incandescent lamps. CFLs are more energy efficient than incandescent lamps, typically using 75 percent less energy and generating less heat, and can last 10 times as long.

Compared to general service incandescent lamps producing the same amount of visible light, CFLs generally use less power and have a longer rated life, but a higher purchase price. In the United States, a CFL can save over $30 (US dollars) in electricity over the lamp life compared to an incandescent lamp and can reduce greenhouse gas emissions by 2,000 times the weight of the lamp. Like all fluorescent lamps, CFLs contain mercury, complicating their disposal.

CFLs radiate a different light spectrum than incandescent lamps. Improved phosphor formulations have improved the subjective color of the light emitted by CFLs such that some sources rate the best soft white CFLs as subjectively similar in color to standard incandescent lamps.

Figure 5: Compact fluorescent lamp

3.9.2 CFL Energy Savings

CFLs use between one-fifth and one-third of the power of an equivalent incandescent lamp. Since lighting accounted for approximately 9 percent of household electricity usage in 2001 in the United States, widespread use of CFLs could save as much as 7 percent of total US household electricity usage. The Energy Independence and Security Act of 2007 contains language to phase out current incandescent lamps between 2012 and 2014.

CFLs can be used in refrigerators and freezers. Using CFLs in walk-in refrigerators is a good energy-saving strategy because the CFLs give off less heat compared to incandescent light, so the refrigerator does not have to work as hard.

Lighting accounted for approximately 9% of household electricity usage in the US in 2001. Widespread use of CFLs could save as much as 7% of total US household energy usage.

Although CFLs require more energy to manufacture than incandescent lamps, this energy consumption is offset because the operational life is longer and CFLs use less energy during their lifespan.

3.9.3 Cost of CFLs

While the purchase price of a CFL is typically 3 to 10 times greater than an equivalent incandescent lamp, the extended lifetime and lower energy use will more than compensate for the higher initial cost. An article titled "The End of the Light Bulb as We Know It" (US News & World Report 2007) states:

> *"A household that invested $90 in changing 30 fixtures to CFLs would save $440 to $1,500 over the five-year life of the bulbs, depending on your cost of electricity. Look at a utility bill and imagine a 12 percent discount to estimate the savings."*

CFLs are extremely cost effective in commercial buildings when used to replace incandescent lamps. Using average US commercial electricity and gas rates for 2006, a 2008 article printed by the United States Department of Energy (DOE) (EERE 2009) found that replacing each 75W incandescent lamp with a CFL resulted in yearly energy savings of $22 (US dollars), reduced HVAC cost and reduced labor to change lamps. The incremental capital investment of $2 (US dollars) per fixture is typically paid back in about one month. Savings are greater and payback periods shorter in regions with higher electricity rates and, to a lesser extent, in regions with higher than average cooling requirements.

In the United States and Canada, the ENERGY STAR program labels compact fluorescent lamps that meet a set of standards for starting time, life expectancy, color and consistency of performance. The intent of the program is to reduce consumer concerns from product variability. CFLs with a recent ENERGY STAR qualified products label start in less than one second and do not flicker.

3.9.4 Use of CFLs Worldwide

In the United Kingdom a program similar to ENERGY STAR is run by the Energy Saving Trust to identify lighting products that meet energy conservation and performance guidelines.

In Australia the demand for CFLs is growing rapidly and the range of available products is expanding. In this context, consumers should be able to easily identify and purchase quality CFLs that meet their requirements. The Australian National Appliance and Equipment Energy Efficiency Committee (NAEEEC) plans to introduce Minimum Energy Performance Standards (MEPS) for CFLs, together with an endorsement label for complying high-performance products. MEPS and endorsement labels for CFLs exist in many other countries and there is considerable interest in the harmonization of CFL standards between China, the United States, Europe, Brazil and other countries. Australian CFL test standards AS 60969 and AS 60901 already exist, and are technically equivalent to the standards used in Europe and China (IEC 60969 and IEC 60901). It is intended that Australian MEPS and high-efficiency levels will match the equivalent existing Chinese standards for self-ballasted CFLs. Subject to the agreement of Standards Australia, an additional section will be added to each Australian Standard, detailing a mandatory minimum energy performance level and a more stringent voluntary high-efficiency level, suitable for an endorsement label and Energy Allstars registration.

3.10 Solid State Lighting (SSL)

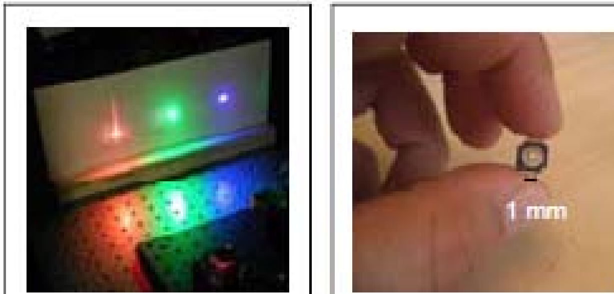
Solid state lighting (SSL) is a type of lighting that uses light-emitting diodes (LEDs), organic light-emitting diodes (OLED) or polymer light-emitting diodes (PLED) as illumination sources, as opposed to electrical filaments, gas or plasma (used in arc lamps such as fluorescent lamps). Solid state refers to the fact that light in an LED is emitted from a solid object, a block of semiconductor, rather than from a vacuum or gas tube, as is the case in traditional incandescent and fluorescent lamps. Compared to incandescent lighting, SSL creates visible light with reduced heat generation or parasitic energy dissipation, similar to that of fluorescent lighting. In addition, the solid-state nature provides greater resistance to shock, vibration and wear. This increases the lifespan of the lamps significantly. Solid state lighting is often used in traffic lights and is also used frequently in vehicle lights, train marker lights and remote controls.

On June 30, 2009, US President Barack Obama passed legislation that called for stricter energy-efficient lighting standards. Solid state lighting was a part of this initiative. Products made in the United States or imported for use in the United States are required to meet new energy parameters starting in 2012. According to the United States Department of Energy (DOE), the changes in lamps and lighting equipment would prevent the emission of about 594 million tons of carbon dioxide between 2012 and 2042. This is roughly equivalent to removing 166 million cars from the road for a year. It would save consumers $1 billion to $4 billion (US dollars) annually from 2012 through 2042 and save enough electricity in those three decades to power every home in the United States for up to 10 months. Finally, it will eliminate the need for up to 7.3 gigawatts of new generating capacity by 2042, which the DOE says is equivalent to as many as fourteen 500MW coal-fired power plants.

A press release from IFMA in July 2009 on solid state lighting noted that the US DOE solid state lighting research activities represent an essential component of the Department's strategy for achieving zero energy buildings, buildings that produce as much energy as they use. The development of highly efficient, cost-effective solid state lighting technologies, along with advanced windows and space heating and cooling technologies, can help reduce total building energy use by 60 to 70 percent. This improvement in component and system energy efficiency, coupled with on-site renewable energy supply systems, can result in marketable net zero energy buildings. Some solid state lighting products last 10 times longer than fluorescent lamps, are not breakable and do not contain mercury. It is estimated that the use of SSL in the industrial/commercial market will save billions of dollars in maintenance and energy costs, reduce carbon emissions by 31 to 44 million tons (28 to 40 million metric tons) annually and potentially reduce spending on electricity by $125 billion (US dollars) over the next 20 years.

Not only will SSL lead to energy and environmental savings, but it will change the way we think about lighting. SSL devices:

- Are vibration and shock resistant
- Have exceptionally long operational lives
- Allow for a wide variety of lighting, including artificial lighting similar to natural daylight
- Control color and intensity of the light with appropriate circuitry
- Can be coupled with light pipes, allowing for efficient distribution of light
- Can be manufactured as flat packages of any shape, allowing them to be placed on floors, walls, ceilings or even furniture
- Can be made with either inorganic or organic semiconductors. Light-A emitting diode (LED) is an inorganic semiconductor.



Lasers
Ultra high brightness
Point sources

LEDs
Medium brightness
Point sources

Figure 6: Solid state lighting *(Philips Lighting Academy 2009)*

3.10.1 Light Emitting Diodes (LED)

The emergence of efficient LED devices signals a shift in lighting technology. Major government-sponsored industry consortia currently exist and are being formed in Europe, Japan, Korea and Taiwan. The goal of these efforts is to save energy and gain market share in the emerging SSL industry. It is believed that there is a need for a national initiative to develop SSL. Such an initiative would reduce the need for new power plants, hastening the day in which the US consumer will benefit from reduced energy and environmental costs of solid state lighting. The LED is an environmentally friendly option for many lighting needs. A single kWh of electricity will generate 1.34 lbs (0.6 kg) of CO_2 emissions. Assuming the average light bulb is on for 10 hours a day, a single 40 watt incandescent bulb will generate 196 lbs (89 kg) of CO_2 every year. The electricity needed to operate a 13 watt LED equivalent will result in the emission of 63 lbs (29 kg) of CO_2 over the same time span. A building's carbon footprint from lighting can be reduced by 68 percent by exchanging all incandescent bulbs for new LEDs.

Figure 7: Light emitting diodes (LED)

LEDs can emit light of an intended color without the use of color filters that traditional lighting methods require. They also light up very quickly and are ideal for use in applications that are subject to frequent on-off cycling. Comparing LEDs to other lighting options, fluorescent lamps tend to burn out more quickly when cycled frequently and HID lamps require a long time before restarting. LEDs can very easily be dimmed either by pulse-width modulation or by lowering the forward current. In contrast to most light sources, LEDs radiate very little heat in the form of infrared (IR) that can cause damage to sensitive objects or fabrics. Wasted energy is dispersed as heat through the base of the LED. LEDs mostly fail by dimming over time, rather than the abrupt burnout of incandescent bulbs, and they have a relatively long useful life. Estimates from 20,000 to 50,000 hours of useful life have been reported (Wotton 2009), although time to complete failure of the lamp may be longer. CFL lamps are typically rated at about 6,000 to 10,000 hours, depending partly on the conditions of use, and incandescent light bulbs are rated at 750 to 2,500 hours.

LEDs, being solid state components, are difficult to damage with external shock, unlike fluorescent and incandescent bulbs, which are fragile. LEDs are also nontoxic, unlike compact fluorescent lamps that contain traces of mercury. LED lamps have been advocated as the newest and best environmental lighting method (Wotton 2009). According to the Energy Saving Trust, LED lamps use 10 percent of the power used by a standard incandescent bulb, 20 percent of the power used by a compact fluorescent and 70 percent of the energy used by a halogen lamp.

A downside is still the initial cost, which is higher than that of compact fluorescent lamps. However, when the life expectancy and other factors are incorporated, LEDs are more cost effective than CFLs. Additionally, by 2015, organic LEDs will be expected to be available at a cost comparable to incandescent lamps.

Light is produced from an LED by electroluminescence when a low voltage is directly applied to a special type of semiconductor. The current passing through the semiconductor is controlled by a driver (Wotton 2009). LEDs are generally small, less than 0.002 in^2 (1 mm^2) and use optical components to shape the radiation pattern and assist with reflection.

The application of LEDs is diverse. They are used as low-energy indicators, video displays, within sensors and within automotive lighting applications, and are useful for communications technologies because they have high switching rates.

LEDs present many advantages over traditional light sources:

- Lower energy consumption
- Longer life
- Improved robustness
- Smaller size
- Faster switching

Although there are multiple advantages to LEDs, facility managers who decide to procure LEDs must be careful due to the disparate types of manufacturers in the market. Be sure to check the life and light output of the lamps being considered. The best way to ensure a quality LED product is to check if the lamp has been tested to meet IESNA Standards LM-79-08 and LM-80-08 for life and lumen ratings. An additional resource to consult is the United States Department of Energy (DOE) LED standards for consumer reference study completed by the Illuminating Engineering Society of North America (IESNA).

An additional disadvantage of LEDs is that they are relatively expensive and require more precise current and heat management than traditional light sources.

3.10.2 Cost of LEDs

LEDs are currently more expensive in terms of initial capital cost than most conventional lighting technologies. The additional expense partially stems from the relatively low lumen output and the drive circuitry and power supplies needed. When considering the total cost of ownership (including maintenance costs and energy consumption), LEDs far surpass incandescent or halogen sources and are becoming a threat to compact fluorescent lamps.

Light emitting diodes are rapidly evolving to provide light sources for general illumination. This technology holds promise for lower energy consumption and reduced maintenance, as the cost per lumen has been steadily falling as performance has been consistently increasing. By the year 2000, the cost per lumen for red LEDs dropped to $0.06/lm (US dollars). At this price, the LEDs in a typical 25 lumen application contribute only $1.50 (US dollars) to the cost of the complete unit. White LEDs now cost about $0.20/lm (US dollars). If white LEDs follow the same development pattern as red LEDs, and the cost per lumen of white LED lamps falls by a factor of 10 each decade, then white light produced by LEDs cost $0.05/lm (US dollars) by about 2005 and $0.01/lm (US dollars) by about 2012. With these predicted costs, a 50 lm/W LED lamp paid for itself through energy savings in 3,000 to 10,000 hours in 2005 and has a projected payback of 500 to 1,500 hours in 2012.

3.10.3 Organic Light Emitting Diodes (OLED)/ Light Emitting Polymer (PLED)

An organic light emitting diode (OLED), also known as a light emitting polymer (PLED) or organic electro luminescence (OEL), is any light emitting diode (LED) with an emissive electroluminescent layer composed of a film of organic compounds. The layer usually contains a polymer substance where suitable organic compounds are deposited by a simple printing process. The resulting matrix of deposits emits light of different colors. OLEDs/PLEDs are used in television screens, computer displays, for signs used for advertising and the display of information, indicator lights and small, portable system screens, such as cell phones and PDAs, and general space illumination.

OLEDs typically emit less light per area than inorganic solid-state based LEDs, as solid-state LEDs are usually designed for use as point-light sources. A significant benefit of OLED displays over traditional liquid crystal displays (LCDs) is that OLEDs do not require a backlight to function. As a result, OLEDs:

- Draw less power
- Operate longer from the same charge when powered from a battery
- Have a thinner display, compared to an LCD panel

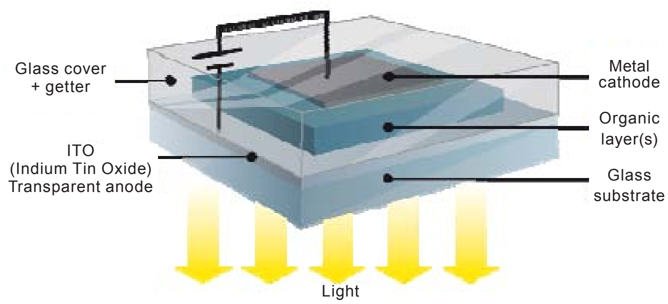


Figure 8: Organic light emitting diodes (OLED)/light emitting polymer (PLED) (Philips Lighting Academy 2009)

3.11 Induction Lighting

Induction lights are similar to fluorescent lights, as they use excited gases that react with phosphor to produce a pure white light. Unlike fluorescent lamps, induction lamps are rated at 100,000 hours. Fluorescent lamps have a shorter rated life because electrodes that must be used to excite the gases within the tube degrade over time. Induction lamps utilize the principle of induction, instead of electrodes, to transit energy by a magnetic field. The life of induction lamps translates to over 20 years of lamp life at 11 hours a day. Induction lighting can provide high lumen per watt outputs. Metal halide lamps, in some cases, can be replaced by lamps ranging from 400W to 1,000W.

Figure 9: Induction lamp components

Induction lamps are most appropriate for areas in which lighting is hard to access, such as high bay warehouse lighting, parking lots and structures, and tunnel and street lighting. Given the long life of induction lights, replacement intervals are minimized. Induction lamps also use a lower wattage compared to metal halide, high-pressure sodium or mercury vapor lamps that typically serve these areas.

Induction lamps have a lamp life of up to 100,000 hours. Most lamps have a lamp life of 10,000 to 20,000 hours.

Comparing the lamp life of induction lamps to several other lamp types, four to five re-lamping rounds would be needed (see Table 4). The cost of the reduced re-lamping rounds when using induction lamps can be minimized by 400 to 600 percent.

KELVIN

A numerical measurement expressed on the Kelvin (K) scale to describe the color appearance of light produced and of the lamp itself.

Lamps are categorized as warm, neutral or cool, based on how the light source appears visually. Warm, soft-light sources will have a lower color temperature of 3500K or less. Warm lamps will appear in the red-yellow color range. Warm light sources are traditionally used for applications where warm colors or earth tones dominate the environment, and provide a feeling of comfort, coziness and relaxation.

Neutral sources, between 3500K and 4100K, will appear to be more yellow. As the color temperature increases, the lamp becomes more blue, sometimes called "hard' light. Lamps with a color temperature of 5000K are considered cool light sources and are described as pure white light or full spectrum. Cool light sources have high color rendering capabilities. Cool light sources are traditionally used when there is a need to enhance all colors equally, to help increase productivity and reduce errors within the office environment, and to create a more natural, day-lit feel in an indoor environment.

Table 4: Lamp life by lamp type and re-lamping rounds when compared to induction lamps

Lamp type	Lamp life (hours)	Number of re-lamping rounds, compared to induction
Induction	100,000	N/A
Metal halide	20,000 to 24,000	4 to 5
High pressure sodium	24,000	4 to 5
Mercury vapor	24,000	4 to 5

Some additional characteristics of induction lamps include:

- High color rendering: Up to color rendering index (CRI) of 85. A CRI of 85 means that the color of the item under the lamp will appear as it actually is.
- Multiple lamp colors are available, with a range of color temperatures from 2700K to 6500K.
- Minimal color shifting over the lamp life.
- Energy efficient: 85 lumens/watt.
- Less than 5 percent of energy consumed is lost as heat.
- Instant on/re-strike capability. No warm-up period.
- Can be used with both photo and motion sensors.
- Starting temperature as low as 40°F (4.4°C).
- Does not flicker, have strobe effects or make noise, like some HID lamps.
- Superior lumen maintenance.
- At 90,000 hours, 70 percent of light output is maintained.

Table 5: Comparison of lamp type to reduced light output

Lamp Type	Reduction in light output	Time period reduction occurs
Induction	30%	Over lifetime
Metal halide	50%	After 6 months

3.12 Daylighting

Greater reliance on natural light reduces energy consumption, favorably impacts human health and improves workplace and academic performance. For example, it is clear that student test scores are higher when children learn in environments with greater amounts of natural light. Based on research at Carnegie Mellon University and others, daylighting appears to improve productivity and reduce absenteeism by at least 20 percent. A 20 percent increase in productivity by an employee making $50,000 (US dollars) annually yields $10,000 (US dollars) to the company.

Daylight also benefits employees in the workplace. Sunlight generally makes people happier and more energetic, as it provides a vital boost of vitamin D and serotonin, both of which affect mood and the enjoyment of life.

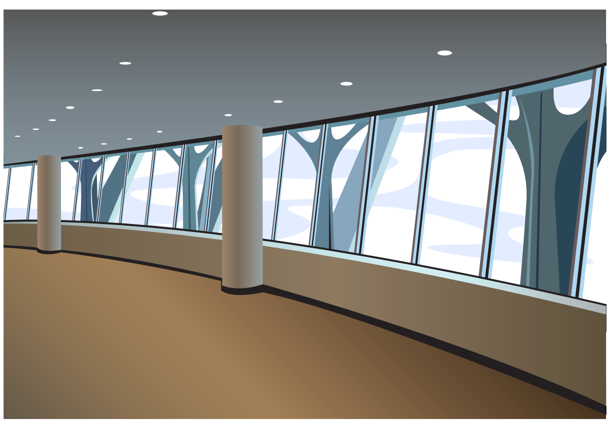


Figure 10: Daylighting

3.12.1 Skylights

Skylights are horizontal windows or domes placed at the roof of buildings, often used for daylighting. Skylights admit more light per unit area than windows, and distribute the light more evenly over the space. The optimum material to use for skylights is a white translucent acrylic. This material is a Lambertian diffuser, meaning that the light transmitted through the skylight is perfectly diffused and distributed evenly over the area the light hits.

The optimum number of skylights, usually quantified as effective aperture, varies based on climate, latitude and characteristics of the skylight. However, 4 to 8 percent of the floor area is a good rule of thumb to determine the optimum number of skylights for a space. When selecting skylights, it is important to select models with at least two panes of glass and a heat reflecting coating. The heat reflecting coating will help to reduce the heat gain transmitted through the skylight to the space. Single pane skylights may weep or leak when condensation builds up around the skylight.

Figure 11: Skylight

Some of the major advantages of skylights are:

- Interior blinds, shades and exterior heat-block awnings can be installed at the skylight to control heat loss and heat gain.
- Properly designed skylights are very energy efficient (Murdoch 2003).
- Skylights are not dependant on building orientation (Murdoch 2003).
- Fixed and vented modules are available with a large selection of glass.

—Electro chromatic glazing can allow the occupant to darken or lighten the glass using a remote control, without losing a view of the sky.

- Some dual pane, argon gas-injected, low-e glass models are ENERGY STAR qualified.

—These models also block UV rays from the sun that can fade furniture.

3.12.2 Clerestories and Light Tubes

A clerestory is a row of windows above eye level to allow light into a space. In modern architecture, clerestories provide light without distractions of a view or compromising privacy. Often, clerestory windows provide light into interior wall surfaces painted white or another light color. The walls are placed to reflect indirect light to interior areas where it is needed. By redirecting the light, the light can be softer and more diffuse, reducing shadows.

Another type of device used to redirect light is the light tube, also called a solar tube or the tubular skylight. Light tubes can be placed into a roof and admit light to a focused area within the interior of a building. Light tubes passively collect light using a rooftop dome and transmit the light into a space through a highly reflective rigid or flexible tube to a ceiling diffuser that looks very much like a recessed light fixture (Gordon 2003). An advantage of light tubes, compared to skylights, is that they allow less heat to be transferred to the space, as light tubes have less exposed surface area.

3.13 Daylight Harvesting

Daylight harvesting, also known as constant daylight, is the process of using light level detectors to augment natural light with artificial light to maintain a constant lighting level within a space, while reducing energy consumption. This technique is similar to a heating control with a thermostat.

Daylight harvesting assumes an area in a building, such as an office, will have a natural source of light available during the daylight hours. A processing device monitors the natural light level and continuously adjusts the artificial light level using dimming to maintain the required light level.

Daylight harvesting can reduce the energy consumption from artificial lighting 35 to 60 percent. Daylight harvesting can also provide significant opportunities to reduce peak demand charges, as peak demand typically occurs when the most natural light is available.

3.13.1 Simplified Daylight Harvesting

Simplified daylight harvesting (SDH) is an approach designed to operate as a bi-level lighting system and be applicable to existing bi-level systems. These systems have been required in California by Title 24 since 1983. A SDH system works without any calibration or commissioning. A SDH system automatically operates the bi-level lighting system through high, low and off states based on available daylight levels using a simplified control algorithm. The simplified control algorithm avoids cycling and supports an occupant on/off adjustment through a wall switch or fixture-mounted switch. SDH can also be controlled via a wireless infrared or radio frequency sensor. Initial studies have found that SDH systems can significantly reduce energy and peak demand, offering 100 percent savings for most daylight hours in work spaces adjacent to windows (CLTC 2009).

The key elements of SDH are automatic calibration and occupant controls. SDH automatically calibrates during installation, without any site- or building-specific calibration. SDH automatically updates the switching part of the algorithm each time the sensor switches the lighting system from high to low. This continuous, automatic calibration process accounts for lumen depreciation and changes in reflectance within the space that may occur from furniture being moved, spaces being repainted or other changes that occur over the building life. The SDH system offers a simplified, robust, user-friendly and low-cost approach to interior lighting (CLTC 2009).

3.14 Exterior Lighting

The first step to select exterior lighting for a facility is to identify where the lighting is needed and what hours of operation are necessary. Lighting should only light the area that must be illuminated for safety and property identification during business hours to minimize light trespass. Drawings and/or documents that are used to define the location of the lighting should include the function of the space and the anticipated hours of operation of the lighting. Exterior lighting is commonly used in parking lots, at doorways, along walkways, for signage and for decorative lighting.

It is important to control the direction and spread of light by choosing the correct type of fixture. The correct lamp type must also be selected based on need and application. Induction lights, because of their long lamp life, are a viable option for parking lots and exterior walls. Metal halide lamps should not be considered for exterior lighting applications because they are expensive, are energy intensive and make a greater contribution to light trespass.

Shutoff controls such as sensors, timers and motion detectors should be utilized. Automatic controls can be used to turn on exterior lights when they are needed for safe passage of pedestrians. Using shutoff controls and/or automatic controls allows lights to be turned off after a business is closed to the public. When using shutoff and/or automatic controls, it is good practice to turn off lights a half hour after the business is closed to the public. If dusk-to-dawn fixtures are used, consider using fixtures that have a night step-down or shutoff control for late night hours.

Often businesses will keep lights on all night as a method to protect the property. However, it should be acknowledged that lights alone will not protect a property and are poor security devices. If protection of property at night is important, other means of property protection and methods to discourage criminal activity should be used.

Figure 12: Exterior pole mounted lighting

Light trespass is a major issue in the United States. To minimize the amount of light that escapes from a property, the height of fixtures should be limited and lamps should be shielded. Fixtures should be located no closer to the property line than four times the fixture mounting height and should not exceed the height of adjacent structures. Exceptions may be made for larger parking areas, commercial zones adjacent to highways or fixtures with greater cut-off shielding behind the pole mount in commercial zones (Dark Sky Society 2009).

Light should not be allowed to cross property lines. Light levels at the property line should not exceed 0.1 footcandles (1 lux) adjacent to business properties, and 0.05 footcandles (0.5 lux) at residential property boundaries. Light levels and uniformity ratios should not exceed recommended values, per IESNA RP-33 Lighting for Exterior Environments or RP 20 Lighting for Parking Facilities. Lumen caps for areas to be illuminated are recommended as shown in Table 6 (Dark Sky Society 2009)

Table 6: Lumen cap per area

Area	Lumen cap
Commercial properties in nonurban commercial zones	25,000 lumens/acre (61,800 lumens/ha)
Residential and LBO zones	10,000 lumens/acre (24,700 lumens/ha)

For the illumination of signage, top-mounted sign lighting is recommended, with RLM (dish) type shields, provided that the light falls entirely on the sign and is positioned so that the lamp is not visible from any point off the property or into the roadway (Dark Sky Society 2009).

For large projects over 15,000 lumens, greater energy conservation and control of light pollution, light trespass and glare may be achieved with the help of a professional lighting designer with dark sky lighting experience. Once a lighting project or lamps are replaced in an outdoor setting, a post-installation inspection should be conducted to check for compliance. Substitutions by electricians and contractors are common and should not be accepted without review and approvals (Dark Sky Society 2009).

The Illuminating Engineering Society of North America (IES or IESNA) is an organization that establishes updated standards and illumination guidelines for the lighting industry. They have published Recommended Practices (RP-33-99): Lighting for Exterior Environments and (RP-20): Parking Lots that will guide the selection and installation of exterior lighting. For instance, the following list can serve as a guide to exterior lighting levels for lampposts (Dark Sky Society 2009).

Table 7: Recommended lumen levels by mounting height for exterior fixtures (Dark Sky Society 2009)

Mounting height in feet (meters)	Recommended lumen maximum
6 feet (1.8)	500 - 1,000 lumens
8 feet (2.4 meters)	600 - 1,600 lumens
10 feet (3.5 meters)	1,000 - 2,000 lumens
12 feet (3.7 meters)	1,600 - 2,400 lumens
16 feet (4.9 meters)	2,400 - 6,000 lumens

3.14.1 Impact of Interior Lighting on Exterior Lighting

Interior lighting should be designed so that it does not illuminate the outdoors. To prevent this, determine interior lighting photometrics at the perimeter of the building, ensuring that the interior lighting falls substantially within the building and does not exit the building through the windows. When the building is unoccupied, interior lighting should be turned off. Automatic shutoff, occupancy sensors or automated lighting schedules can be used to help ensure that interior lights are turned off when the building is not occupied.

3.15 Summary

Effective lighting solutions must be addressed in a holistic fashion. When it comes to proper illumination, one size does not fit all. Specific lighting needs must be addressed throughout the facility to minimize problems that arise with over-lighting or under-lighting an area. In an existing building there are certain confines one needs to work within, including the placement of fixtures, office layout and adjacencies. Although complete standardization may make some decisions easier, a smart selection of lighting alternatives, including lamps and ballasts, will provide the optimum benefits to the facility.

When upgrading a lighting system in an existing facility, the first step is to determine what lamps and ballasts are currently being used. Second, determine what upgrades are possible. Two simple upgrades are:

- If T12 lamps are currently in use, replace them with a more efficient alternative, such as a 32 watt or 700 series lamp.
- If incandescent lamps are used, replace them with compact fluorescent lamps.

When determining what upgrades are possible, also be sure to consider:

- If a wash and re-lamp program could be used to save money and manpower
- The use of T5 lamps within high bay areas and for accent lighting
- The use of LEDs for accent lighting
- The use of occupancy sensors and/or occupancy schedules to turn off lights when the building is not occupied
- When natural light can be used, instead of electric lights

There are resources that can assist in these efforts. Local utility companies are very interested in saving energy and can help evaluate a facility and provide information on lighting system upgrades rebates or incentives. Electricians, lighting contractors and lighting manufacturers can also be contacted to discuss the best alternatives for a facility. Most manufacturers will provide a representative to evaluate the current status and make recommendations for comprehensive lighting solutions.

4 MAKING THE BUSINESS CASE

Tens of thousands of companies nationwide have proven that lighting upgrades can reduce lighting costs by as much as 30 to 50 percent, reducing total facility costs by up to 25 percent. For example, a 200,000 square foot (18,600 square meter) building that has a 30 percent energy reduction could save about $54,000 (US dollars) annually. The United States Department of Energy (DOE) has confirmed that lighting products provide the quickest return on investment in terms of energy savings.

Lighting accounts for about 20 percent of all electricity used in the United States and up to 40 percent of electricity used in commercial buildings. In a commercial building of approximately 200,000 square feet (18,600 square meters), about $180,000 (US dollars) is spent on lighting each year, approximately $0.90 a square foot ($9.70 per square meter). According to the United States Environmental Protection Agency, lighting also affects other building systems through its electrical requirements and waste heat produced.

Increasing the energy efficiency of the lighting system has an impact on reducing the overall environmental impacts, such as greenhouse gas emissions, and reducing energy bills. The reduction of greenhouse gas emissions and an energy-efficiency focus will be critical to businesses if the United States Federal Climate Change Waxman-Markey Bill passes, as businesses will be taxed on greenhouse gas emissions.

4.1 Retrofit

A commercial building of 1 million square feet (92,900 square meters) that uses T12 fluorescent fixtures would require about 18,000 lamps, or about 4,500 fixtures. Based on a cost of $0.10/kWh (US dollars), the cost of electricity would be approximately $348,300 annually. Upgrading to T8 lamps with electronic ballasts could reduce these costs by 50 percent. Further analysis of retrofit alternatives is shown in Table 8.

Table 8: Retrofit scenarios

	Scenario description	Energy consumption per fixture per year	Cost per fixture per year	Savings compared to base case
Base Case	40W T12 lamps and magnetic ballasts	172W	$77.40	N/A
Alternate #1	34W T12 lamps with magnetic ballast	144W	$64.90	$12.50
Alternate #2	32W T8 with standard electronic ballast	85W	$38.25	$39.15
Alternate #3	30W T8 with high efficiency electronic ballasts	79W	$35.55	$41.85
Alternate #4	28W T8 with high efficiency electronic ballasts	74W	$33.30	$44.10
Alternate #5	25W T8 with high efficiency electronic ballasts	68W	$30.60	$46.80

Notes:

1. *All scenarios are four lamp fixtures*
2. *Hours of operation: 4,500 hrs/yr*
3. *Cost: $0.10/kWh (US dollars)*

4.2 Waxman-Markey Bill

If the Waxman-Markey Bill is passed, Title II of the bill will mandate new energy efficiency standards for lighting. The bill will require state governments to update building codes, requiring new buildings to be 30 percent more energy efficient by the year 2012 and 50 percent more efficient by 2016. The bill would also include new standards for lighting products. These new requirements would support the business case for lighting efficiency and new buildings.

4.3 Cost of Lighting

Lighting accounts for 35 to 50 percent of building energy consumption, averaging about 37 percent of the operational cost of a commercial building. Of the 37 percent, about 31 percent of the cost is for interior lighting and 6 percent is for exterior lighting.

Eighty-six to 88 percent of the cost of lighting is for electricity, 8 to 10 percent is for labor (install/replacement), 3 to 4 percent of the cost is for lamp replacement and 1 percent of the cost is for lamp recycling.

4.4 Energy Policy Act (EPAct) 2005

The Energy Policy Act (EPAct) 2005 contains a number of provisions that directly affect lighting. These include new lighting products subject to federal efficiency standards, a new tax deduction provision for energy-efficient lighting in commercial buildings, the establishment of a solid state lighting program at the DOE and promotion of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and International Energy Conservation Code (IECC) standards.

Tax incentives available under EPAct 2005 provide a tax deduction of up to $1.80 (US dollars) per square foot ($19.40 per square meter) for building investments that achieve specified energy cost reductions beyond ASHRAE 90.1-2001. Of the $1.80 per square foot, $0.60 per square foot can be used for lighting, $0.60 per square foot for HVAC and $0.60 per square foot for the building envelope. Building envelope investments can include roofs, walls, windows, doors, floors and foundations. To achieve the maximum deduction for lighting, $0.60 per square foot, a 40 percent reduction from ASHRAE 90.1-2001 is required. A $0.30 per square foot ($0.03 per square meter) savings can be achieved for lighting when the 25 percent reduction of ASHRAE 90.1-2001 is met.

To document how the lighting reductions will be made to meet EPAct requirements, a spreadsheet should be used, noting how the project meets the EPAct watts-per-square-foot requirements and meets seven other procedural requirements.

4.5 Local Utilities

Many utility companies now offer rebates for energy-efficient improvements, especially lighting. A helpful resource for finding information about energy-related financial incentives is DSIRE: Database of State Incentives for Renewables & Efficiency, www.dsireusa.org. DSIRE is a comprehensive source of information on state, local, utility and federal incentives and policies that promote renewable energy and energy efficiency. DSIRE is an ongoing project of the North Carolina Solar Center and the Interstate Renewable Energy Council funded by the United States Department of Energy.

The site can be searched by state and lists can be filtered by renewable type or energy-efficient strategy. Additionally, links to specific rules and necessary criteria to receive the funding are provided.

4.6 Summary

As stated earlier, a lighting retrofit has the best return on investment (ROI) of any energy-efficient technology with typical paybacks of 14 to 18 months. Depending upon the technology being replaced, potential energy savings, rebates and incentives, a lighting retrofit could be a low-cost or no-cost implementation.

5 CASE STUDIES

To further demonstrate the benefits of lighting retrofits, two case studies are provided. The first is a case study that replaces T12 lamps with T8 lamps as a retrofit, including the installation of occupancy sensors for an office and warehouse. The second is a case study comparing workstation luminaires to traditional overhead office lighting completed by the Lawrence Berkeley National Laboratory.

5.1 Pacific Building Care: T12 to T8 Retrofit and Addition of Occupancy Sensors

Pacific Building Care (PBC), located in Southern California, recently underwent a lighting retrofit for its headquarters space. PBC specializes in green cleaning and also offers sustainable workplace consulting services, including ENERGY STAR guidance, waste stream management and lighting retrofits. The decision to upgrade the lighting in the PBC offices was derived from a couple of drivers:

- Leading by example by practicing what the company preaches
- Economics

The office and warehouse are about 13,000 square feet (1,200 square meters). A total of 207 fixtures with T12 lamps and magnetic ballasts were replaced with 28 watt T8 lamps with high-efficiency electronic ballasts. Additionally 42 occupancy sensors were installed within offices and common areas.

After the retrofit was complete, the improvement in lighting quality was immediately evident: The yellowish light of the T12 lamps was replaced by a much whiter light produced by the T8 lamps. Lights that had stayed on during all the hours the premises were occupied were turned off by the occupancy sensors when spaces were unoccupied. The total cost of the investment was $19,301. After a rebate of $3,300 from Southern California Edison, the cost of the retrofit was about $16,000. The estimated electrical cost savings is $15,253 annually, or about $1,270 per month. Therefore, the payback of the project is about 12 months. After the payback period, PBC will realize about a $15,000 (US dollars) savings annually.

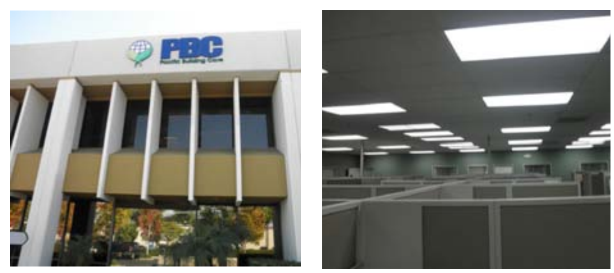


Figure 13: Pacific Building Care building: exterior and interior

5.2 Workstation Luminaires at the Phillip Burton Federal Building

In the summer of 2007, the Lawrence Berkeley National Laboratory (LBNL) conducted a pilot study of workstation lighting for the Phillip Burton Federal Building. Two different workstation luminaires were installed and tested in 15 cubicles. As defined by the study, a workstation luminaire is an indirect/direct pendant-hung luminaire (see Figure 14) that has separate control of ambient and task lighting. A dimmable lamp was used to meet ambient lighting needs and a dimmable lamp was used to provide task lighting. Ambient light was provided by uplighting and task lighting by downlighting. An occupancy sensor within each luminaire was used to control both the task and ambient lighting (Rubinstein 2009a, 2009b).

Figure 14: Phillip Burton Federal Building with workstation cubicle lighting (photo provided by F. Rubinstein)

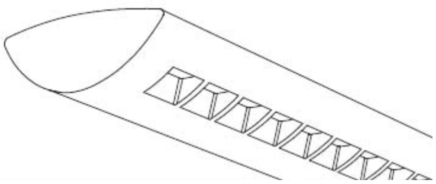


Figure 15: Workstation cubicle lighting (Rubinstein 2009a)

LBNL researchers compared the energy consumption and lighting levels for the two types of workstation luminaires to open-plan luminaires placed over the cubicles within the building. The researchers found that the use of workstation luminaires resulted in up to a 78 percent energy savings, when compared to US national office building energy use (Rubinstein 2009), see Table 9. Such a significant savings can result from the use of workstation luminaires because:

- Luminaires, both uplight and downlight components, are operated based on cubicle occupancy/vacancy, as determined by the occupancy sensor
- Occupants select the desired lighting level whenever the cubicle is occupied

Although energy savings can be significant, workstation luminaires have a high capital cost because two dimming ballasts and an integrated control sensor are required. However, in the case of the Phillip Burton Federal Building, with careful selection of components from several sources and the selection of Digital Addressable Lighting Interface (DALI) capable lighting controls, the workstation luminaires were installed for about $400 (US dollars) per luminaire. Given an installation density of about one luminaire per 100 square feet, the cost per luminaire translates to about $4 (US dollars) per square foot ($43 per square meter). If this lighting solution was considered during an investment-grade lighting retrofit, the workstation luminaires would cost about $2 per square foot ($22 per square meter) more than the Government Services Administration (GSA) base lighting system (Rubinstein 2009a, 2009b).

Table 9: Workstation luminaire energy consumption compared to GSA base case and US national average

	Daily lighting energy (watt-hours/ft²/day)	Daily lighting energy (watt-hours/m²/day)	Estimated annual EUI (kWh/ft²/yr)	Estimated annual EUI (kWh/m²/yr)	Energy savings from WS luminaires relative to GSA base	Energy savings from WS luminaires relative to US national average
Workstation-specific luminaires	5.34 (± 0.5)	57 (± 5)	1.39	15	59%	78%
GSA base case	13.2 (± 0.8)	142 (± 9)	3.42	4	0%	53%
CA Title 24			3.9	42		
US national average for offices	24.8 (± 1)	267 (± 11)	6.45	69	N/A	0%

(Rubinstein 2009a, 2009b)

The simple payback to compare the GSA base lighting system and the US national average to the workstation luminaires was also calculated. An electrical cost, typical for a large office building in San Francisco, California, of $0.15/kWh (US dollars), including demand, was used to calculate the simple payback. It was found that the workstation luminaires would save about $0.33 per square foot per year ($3.60 per square meter) in lighting energy compared to the GSA base lighting system, equal to about a six-year payback (Rubinstein 2009a, 2009b).

6 APPENDICES

6.1 Appendix A: References

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6.2 Appendix B: ADDITIONAL RESOURCES

American Society of Heating, Refrigerating and Air-Conditioning Engineers www.ashrae.org

Consortium for Energy Efficiency (CEE) www.cee1.org

DesignLights Consortium www.designlights.org

ENERGY STAR www.energystar.gov

Light Right Consortium www.lightright.org

National Lighting Bureau www.nlb.org

Illuminating Engineering Society www.ies.org

Solid-State Lighting www1.eere.energy.gov/buildings/ssl

United States Department of Energy www.energy.gov

United States Environmental Protection Agency www.epa.gov

Utility Rebates www.dsireusa.org

6.3 Appendix C: GLOSSARY

Ballast: An auxiliary piece of equipment required to start and to properly control the flow of current to gas discharge light sources such as fluorescent and high-intensity discharge (HID) lamps. Magnetic ballasts, also called electromagnetic ballasts, contain copper windings on an iron core. Electronic ballasts are smaller and more efficient than magnetic ballasts and contain electronic components.

Ballast Factor (BF): The percentage of a lamp's rated lumen output that can be expected when operated on a specific, commercially available ballast. Note that rated output is measured on a reference ballast, unlike those actually operated in the field. A ballast with a ballast factor of 0.93 will result in the lamp's emitting 93 percent of its rated lumen output. A ballast with a lower BF results in less light output, and also generally consumes less power.

Bulb: Another term for lamp. A bulb refers to the outer glass containing the light source.

Candela (cd): The measure of luminous intensity of a source in a given direction for both English and metric units. The term has been retained from the early days of lighting when a standard candle of a fixed size and composition was defined as producing one candela in every direction; once referred to as candlepower.

Compact Fluorescent Lamp (CFL): The general term applied to fluorescent lamps that are single-ended, have smaller diameter tubes compared to traditional fluorescent tubes, and are bent to form a compact shape. Some CFLs have integral ballasts and medium or candelabra screw bases for easy replacement of incandescent lamps.

Color Rendering Index (CRI): An international system, based on a 0 to 100 scale used to rate the ability of a lamp to render the true color of an object. The higher the CRI, the richer the color generally appears. CRI ratings of various lamps may be compared, but a numerical comparison is only valid if the lamps are close in color temperature. A CRI may be visually different when the CRI values differ by a value of at least three to five.

Cost of Light: Usually refers to the cost of operating and maintaining a lighting system on an ongoing basis. The 88-8-4 rule states that typically 88 percent is the cost of electricity, 8 percent is labor and 4 percent is the cost of the lamps.

Efficiency: The fraction of electrical energy converted to light for each watt of electrical power consumed, without concern for the wavelength the energy is radiated.

Energy Policy Act (EPAct): Comprehensive energy legislation passed by the US Congress in 1992 and 2005. The lighting portion includes lamp labeling and minimum energy efficacy (lumens/watt) requirements for many commonly used incandescent and fluorescent lamps. Canadian federal legislation sets similar minimum energy efficacy requirements for incandescent reflector lamps and common linear fluorescent lamps.

Fluorescent Lamp: A high-efficiency lamp utilizing electric discharge through inert gas and low pressure mercury vapor to produce ultraviolet (UV) energy. The UV excites phosphor materials to create visible light. The phosphor is applied as a thin layer on the inside of a glass tube (Kaufman, Christensen 1989).

Footcandle: A unit of measure used by the English system to measure illuminance or light falling onto a surface. A footcandle is the light level on a surface "one square foot (0.1 square meters) in area with a uniformly distributed flux of one lumen" (Kaufman, Christensen 1989). One footcandle is equal to one lumen per square foot. For metric equivalent, see definition of lux.

Incandescent lamp: A light source that heats a thin filament wire, usually made of tungsten, using an electric current to generate light.

Induction lighting: A light source where light is generated by gases excited by radio frequency or microwaves passing over a coil, inducing electromagnetic fields. Unlike conventional discharge lamps, induction lamps do not have electrodes inside the lamp.

Kelvin (K): A unit of temperature starting from absolute zero, parallel to the Celsius temperature scale. 0°C is equal to 273K.

Kilowatt (kW): The measure of electrical power equal to 1000 watts.

Kilowatt Hour (kWh): The standard measure of electrical energy and the typical billing unit used for electricity use. A 100 watt lamp operated for 10 hours consumes 1000 watt-hours (100 x 10) or one kilowatt-hour.

Lamp: "A generic term for a man-made light source" (Kaufman, Christensen 1989). A lamp includes the complete light source, including the base, filament, bulb and other internal parts.

Light: Radiant energy that can be sensed or seen by the human eye. Visible light is measured in lumens (Kaufman, Christensen 1989).

Lumens: A measure of the luminous flux or quantity of light emitted by a source. A dinner candle provides about 12 lumens. A 60 watt soft white incandescent lamp provides about 840 lumens. Lumens are used to measure luminous flux in both the English and metric systems.

Luminaire: A complete lighting unit consisting of a lamp(s), ballast(s) and the parts necessary to distribute light, position the lamp, protect the lamps and connect to the power supply (Kaufman, Christensen 1989). A luminaire is often referred to as a fixture.

Lux (lx): A metric (SI) unit of measure for illuminance or light falling onto a surface. One lux is equal to one lumen per square meter. Ten lux approximately equals one footcandle. For the English equivalent, see footcandle.

Programmed Rapid Start: A lamp starting method that preheats the lamp filament and uses open circuit voltage to start the lamp. A half- to one-second delay after turning on the lamp may occur while the preheating process takes place.

Rapid Start: A lamp starting method in which lamp filaments are heated while open circuit voltage is applied to start the lamp.

T12, T8, T5: A designation for the diameter of a tubular bulb in eighths of an inch. For example, a T12 is twelve-eighths of an inch (38 mm) in diameter, or 1.5 inches. A T8 is 1 inch (25 mm) in diameter.

Voltage: A measurement of the electromotive force in an electrical circuit or device expressed in volts. Voltage is analogous to the pressure in a waterline.

Watts: A unit of electrical power. Lamps are rated in watts to indicate the rate of energy consumption.

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