Lighting Evaluations and Upgrades

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Lighting Evaluations and Upgrades

Direct Benefits of a Lighting Evaluation and Upgrade

According to the Worldwatch Institute, as much as 34% of power generated in the US is used for lighting. For certain industries, the percentage is higher than that. There are many benefits to evaluating and updating the lighting of your facilities that make investment your resources worth it. According to a recent McKinsey study, a lighting upgrade has one of the best returns on investment (ROI) of any type of energy efficiency upgrade. Benefits include:

- Greater worker productivity. A worker is more productive if he/she can see what one's doing adequately. According to Verifone, an improvement in lighting in their Costa Mesa, CA office was a major factor in boosting productivity by 5-7%.

- Increased safety. A better-lit area means fewer accidents. According to the World Health Organization, the rate of automobile fatalities at properly lit streets is 77% lower compared to unlit streets.

- Reduced energy/electricity usage and costs. As will be shown below, the selection of the type of light fixture used and its use can have a very significant effect on electricity usage. Given the rising cost of electricity these days and additional means of utilities to charge customers, any opportunity to reduce electricity usage will result in much money saved. Lighting is a major component of electricity usage.

- Reduced greenhouse gas (GHG) emissions. Worldwide GHG emission registries list electricity usage as a Scope 2 GHG emitting source. While the facility does not directly emit GHGs in this case, demand for electricity means that a power plant is potentially combusting more fuel and emitting GHGs to meet that demand. Therefore, in virtually all registries, reduction in electricity use may be used to demonstrate a reduction in GHG emissions.

- Increased sales. Proper lighting can influence business performance. For example, good lighting can attract shoppers to a store and put its products in a good position to influence sales. Two GNC stores installed innovative, energy efficient display lighting to highlight certain products and compared shopping behavior. Shoppers passing by and entering the stores increased from 2.6% to 4.6% when the special display lights were on. Furthermore, of the larger number that entered, 33.3% made purchases, compared to 14% of the smaller number who entered the store with the display lights off; a 133% increase in purchases when the special display lighting was on. (*Survey by Merchant Mechanics*).

- Lower cooling costs. Certain light fixtures emanate heat or other radiation which can form heat. It can be significant enough to cause an extra load to cool, raising the cost and energy usage to cool a building or store.

- Lower maintenance. Certain light bulbs last much longer than others. These require fewer replacements and, therefore, fewer trips and time by maintenance crews up the ladders to replace them.

Therefore, a good lighting evaluation can lead to many short- and long-term core business benefits. This course introduces the student to some basic lighting terminology and methods to approach a lighting evaluation and upgrade design.

Lighting Basics

The following are basic lighting terms:

- Lumens – quantity of light emitted from the bulb
- Footcandle – density of light reaching the receptor, expressed as lumens per square foot. Usually, footcandles are measured with a lightmeter. Sometimes this is expressed as “lux”. One footcandle equals 10 lux.

The following are recommended lighting requirements which are combined data from the US Army and the Illuminating Engineering Society:

Task Area	Footcandles
Offices	50-100
Conference rooms	20-50
Work stations/offices	30-50
Food prep/moder. manuf.	50-100
Detailed manuf.	100-200
Corridors/stairways/hallways	10-20
Loading docks/shipping prep.	20-30
Classrooms	50-75
Computer rooms	75
Machine work, circuit assembly, very fine inspection	200-500

Therefore, a good lighting evaluation performed to reduce energy use not only includes more efficient light bulbs and fixtures, but also adjusts the number and location of fixtures so that all areas are lit appropriately. An underlit area could certainly result in errors by workers and even safety issues, such as tripping over items not well seen and incorrect use of equipment. An overlit area not only is a waste of energy, but also may cause excessive shadows and glare and results in a non-optimum work environment to get things done and eye strain for the worker. This may mean removal of or adjustment of the lumens given off by fixtures.

Factors Involved in Effective Lighting

Before one designs or modifies the lighting system of a building or area, it is important to understand the needs. What type of tasks will be performed (manufacturing, office work, hallways, etc.) and where? How many workers will be involved? Even issues like the age of workers can influence their lighting needs. Together, this is called a "task lighting" analysis.

An issue that must be addressed is the need for direct lighting onto a subject or indirect lighting. Direct lighting falls directly on a task, and is the most efficient type of lighting, but it tends to produce shadows and glare. Glare can be reduced by moving the task object (usually a personal computer) away from the direct light source, such as at a 90° angle from a window. Indirect lighting is light reflected off adjacent ceilings and walls. Indirect lighting produces less eye strain and is more comfortable to work under than direct lighting. However, since indirect lighting is reflected, it is less efficient and more costly than direct lighting.

In designing offices, one does not know where a desk or other task locations will be, so traditionally ceiling lights are centrally located. Research appears to show that in many instances the most effective lighting to complete office tasks and to do so in an energy efficient manner is to turn off the ceiling lights and operate two small desk lamps at opposite ends of the work station or table.

How to Compare Effectiveness of Different Light Bulb Types

Two different ways to compare light bulb types to determine effectiveness is its <u>light efficiency</u> (in lumens per watt) and <u>how long they last</u> before they must be replaced (usually in total hours of use). Light efficiency is the major determinant in selection of light bulb for those interested in energy savings. Producing less lumens per watt means that that bulb must use more electricity to produce the same amount of lumens needed for a task than another alternative.

How long a type of light fixture lasts is based on many factors (such as frequency of turning it on and off, etc.) so it is inherently difficult to compare. However, many manufacturers do issue such ranges of hours for comparison purposes. Light bulb types that last long before having to replace them can be a significant O&M savings in terms of cost of replacement bulbs (space to store large numbers of bulbs now not required; labor to replace bulbs is reduced), and in terms of safety as fewer trips up and down a ladder to ceilings or other hard-to-reach locations means lower risk of accidents. These result in significant, quantifiable savings.

Performance of bulbs in Light Color terms:

Color rendering index (CRI) – appearance of lit object compared to appearance in sunlight. CRI = 100 if object looks the same as in sunlight.

Correlated color temperature (CCT) – appearance of overall room or area expressed in degrees Kelvin. However, although counterintuitive, please note that the greater the number of degrees, the "cooler" the area appears. Commonly ranges from 2700K ("hotter" or "warmer") to 5000K ("cooler"). Warmer colors tend to highlight better personal and intimate uses, such as in homes and restaurants, where detail is less important. Light bulbs with mid-range K ratings (generally, 3000 to 3500K) are generally assigned to spaces devoted to reading. High K ratings (generally, above 4000K) results in an increasingly bluish light that enhances detail. Such light bulbs are, therefore, used in applications where brightness, details, and the graphic nature of items are more important to be noticed by the viewer, such as art galleries, jewelry stores, and medical examination areas. Higher K-rated lights are often referred to as "daylight".

Lamp Lumen Depreciation (LLD) - the reduction in lumen production given constant electrical input over time. Some depreciate markedly over the lamp life; some little.

A ballast is the equipment needed to hold the light bulb, turns it on and off, and regulate its light intensity. It may be either electromagnetic or electronic; the latter is more commonplace these days and more efficient. Electromagnetic are the ones that "hum". Some bulbs require a ballast; others require specifically sized and shaped ballasts.

Light Bulb Types

Type	Lumens per Watt	Average Light (Hours)
Incandescent	5-20	1,000 – 8,000
Mercury	25-55	12,000 – 24,000
Fluorescent	30-80	7,000 – 20,000
Light Emitting Diode (LED)	60-80	

Incandescents – Electricity heats a filament (usually tungsten) which releases light.

Advantages:

- Low cost
- Small, compact size
- Easily dimmable
- Instant starting
- Can achieve warm color
- Excellent color rendering (CRI of 90-95)
- Requires no ballast

Disadvantages:

- Very energy-inefficient source of light (lumens/watt)
- Relatively short life span
- Generates much heat, a problem during AC season
- Its availability is beginning to be phased out in Europe and may be in the US, too.

Fluorescents – Electrical current inside tube excites mercury atoms, causing it to emit photons. Phosphor coating inside the tube releases light when it is hit by photons. The two most common types of fluorescent bulbs are T-12 (12 x 1/8" diam. = 1.5": diam.) and T-8 (8 x 1/8" diam. = 1" diam.). Pins are identically spread, so a T-12 bulb can fit into a T-8 ballast. There is growing popularity is T-5 fluorescent bulbs, and they are more energy efficient than T-12 or T-8. However, a T-5 bulb does not fit into a T-12 or T-8 ballast, requiring a new ballast, raising the cost of replacing with T-5 and potentially lengthening the ROI. The smaller the diameter, the more energy efficient the fluorescent bulb is.

Advantages:

- 3-4 times more energy efficient than incandescents
- Long life (10-20 longer than incandescent), resulting in less maintenance time (fewer labor hours and trips up the ladder to change bulbs) and storage needs
- Low lamp cost
- Available in a variety of sizes and colors
- Can achieve cool color
- Less heat generated than incandescents

Disadvantages:

- Large in size
- Are dimmable, but require relative expensive controls to do so
- Outdoor bulbs may be difficult to start in winter in northern climates (need initial warmth to excite electrons)
- Mercury in lamp must be disposed of carefully

Compact Fluorescent Lights (CFLs) – Fluorescent lights that have been miniaturized and can be screwed in and fit in an incandescent light socket. Therefore, they have all of the advantages of fluorescents above, but need no ballast and can use existing sockets. When replacing incandescents with CFLs, one should select CFLs with similar light output; then one reaps benefits of lower electricity usage (wattage).

Rule of thumb comparison with incandescents:

Incandescent Wattage	**CFL Wattage**	**Light Output (lumens)**
40	8 - 11	400 – 500
60	13 - 16	800 – 1,000
75	17 - 20	1,100 – 1,300
100	23 - 27	1,600 – 1,800

Replace incandescents with compact fluorescent lights (CFLs) wherever possible because of the huge energy savings (see example below). Convert existing T-12 fluorescents to T-8 systems in electronic ballasts. Consider replacing with T-5s, but will need to replace ballasts, and this could be expensive. Use silver reflectors in ballast.

Example to illustrate energy cost savings: a facility proposes to replace 1,000 80-watt incandescent light bulbs with 20-watt CFLs. Given a cost of $4 per CFL, 6,000 hours of operation/year, $0.14/kWh rate for electricity usage, $10/kw-month demand charge, what is the simple payback for the lamp replacement? Use a one year basis.

Wattage savings is 80 – 20 = 60 watts x 1,000 lights = 60 kW savings.

$10/kW-month x 60 kW savings x 12 months/year = $7,200/year savings demand

$0.14/kWh x 60 kW savings x 6,000 hours/year = $50,400/year savings usage

Total savings: $57,600/year. Cost of CFLs: $4,000

$4,000/$57,600/year = 0.07 years or just under 1 month.

This is why switching from incandescents to CFLs is a “no brainer”.

Switching from T-12 to T-8 fluorescents typically result in a 2-4 year simple payback.

Other Specialty Lamps

Mercury vapor lamps – These create light by an electronic discharge through mercury. They are commonly used for outdoor security lighting.

Advantages:

- More efficient than incandescents, but less so than fluorescents
- Wide variety of shapes, sizes and lumen ratings
- Long life: up to 24,000 hours; very important as they are located often up at high, inconvenient locations

Disadvantages:

- Poor Lamp Lumen Depreciation
- Requires 5 or more minutes of warmup time (generally, acceptable as dark arrives in outdoor areas gradually)
- Distinctive bluish light
- Requires a ballast

Metal halide lamps – Mercury plus iodidic discharge of light.

Advantages:

- Can successfully replace mercury vapor lamps in many applications.
- Long lamp life
- More energy efficient than mercury vapor and many fluorescents
- Good color rendition; high CRI. This makes it attractive to people; good for stores, malls, etc.

Disadvantages:

- Requires 2-5 minutes of warmup time
- Long cool down period
- Some lamps are position sensitive and some are prone to breakage, requiring closed fixture
- Requires a ballast

High bay fluorescents – An open fixture surrounding several (typically, 4) fluorescent bulbs. Inside can be coated with silver to reflect additional light. Besides the advantages and disadvantages of fluorescents, the high bay fixtures are good for large, high areas, such as warehouses. One may turn off one or two bulbs (manually or automated) to save energy or the way to dim an area.

High pressure sodium – Light caused by electric discharge through sodium. It is also great for outdoor use. However, it has a clear yellow hue in the light.

Advantages:

- Can successfully replace mercury vapor lamps in many applications.
- Long lamp life
- Fairly strong energy efficiency
- Relatively short warmup.
- Good lumen maintenance and low lumen depreciation
- Wide range of sizes, types and wattages available

Disadvantages:

- Yellowish light
- Light tends to “blink” in period before burnout; a sign to replace it
- Requires a ballast

Low pressure sodium – While good light to use outdoor, it does not allow strong differentiation of objects (all cars in the parking lot “look” the same; grayish tint of receptor). It has a clear orange hue in the light. Is rarely used in the U.S. and, if found, should probably be replaced with High pressure sodium bulbs.

Light Emitting Diodes (LEDs) – These units emit lights in bands. The units appear as dots, mainly red dots. LEDs emit light when an electrical current is driven through the junction of two semi-conducting materials. LED light was originally red only, and later green and blue lights developed. Therefore, they were first used for “Exit” or street crossing signs.

The main advantage of LEDs is the very high energy efficiency. Currently, LEDs are producing as much as 150 lumens per watt, exceeding typical CFL efficiency of 90 lumens per watt and incandescent of 15 lumens per watt. A 40 watt incandescent can be replaced by a 2-4 watt LED. Another major advantage is how long lasting LEDs currently are; on average an estimated 50,000 hours of operation before replacement is necessary. This is about 6 times longer than CFLs and double that of conventional fluorescents. Unlike CFLs, LEDs contain no mercury or other toxic substance, so should not require special disposal handling. One potential negative is the heat produced by and emitted from the electronics (not the light itself). Be careful where in a room one places the LED electronics.

Another advantage is their compact size, allowing them to be used in small-sized applications, such as backlighting of cell phones, hand-held games, etc.

Currently, for most applications and in the short term, LED lighting is more expensive than equivalent CFLs. The cost of LEDs will likely drop as its manufacturing procedures mature. Given its long life and lack of need for special waste disposal, its long-term costs are competitive with CFLs. The manufacturing of LEDs is an energy intensive process. According to some life cycle analyses, this comes close to negating the gains in GHG emissions caused by using it compared to other sources. In time, it is likely that LEDs can be manufactured in a less energy-intensive manner.

In the last couple of years LED has quickly become a popular choice as more and more companies use “green” factors in making decisions because of its energy savings. Currently, the vast majority of the LED market is devoted to low intensity light uses, such as “Exit” and traffic signs and mobile phone and PDA backlighting. Research is resulting in improved brightness and therefore, the high and ultra-high brightness LED markets (i.e., backlighting for TV screens, automotive, and general lighting) are growing. In addition, LED use is being spurred by the development of white LED lighting. Wider use of LED lighting has been spurred by the development of “white” LEDs developed by the mixture of red, blue, and green LED lightwaves or conversion from ultraviolet. This will allow LEDs to be commercially feasible for more general lighting applications.

Induction lighting – A high frequency generator can induce a current in a bulb. Because there are no electrodes in the bulb under stress, using an electric current from the outside induction lighting has a very long life, generally from 60,000 to 100,000 hours. Other advantages include good CRI (about 80) and good efficiency (70-80 lumens per watt). However, induction lighting is relatively new and does not have a strong track record.

Lighting Controls

While it is a positive action to replace light bulbs with more energy efficient ones, greater savings can be achieved by minimizing total hours of operation of all or many lights, particularly by installing controls over hours of operation. Turning a light off for the many hours when it is not needed reduces even an 80-watt incandescent or 20-watt CFL down to zero electricity usage and is therefore very effective to reduce electricity consumption and cost. Control devices include:

- Occupancy sensors. These represent a “no brainer” for energy savings; turning off lights when unneeded (as no one is in the room). These are normal sensors that use infrared technology which turns on a light when the IR beam is disturbed (motion). A timer turns off the light after a period of time when there is no motion in the room. Many occupancy sensors are also programmable per time of day (shut light off on a weekday at, say, 6 pm, when the office’s occupants have likely left for the night, and turn light on again at 8 am the next morning) or even amount of sunlight entering the room (i.e., turn lights off at sunset). Most occupancy sensors are very inexpensive themselves and have a quick ROI. Care should be taken in buying sensors that are compatible with the existing type of light fixture in the building. For example, not every sensor works with every model of CFL.

- Motion sensors. Besides the in-office use described above, these are most popular for outdoor use. They ensure that lights are off until there is movement in the area, indicating a need to light the area so the person can see his/her way through. It is critical for the sensor to ensure that extraneous movements do not trigger an inappropriate turning on of the light, such as the swaying of trees by the wind. In addition, it is important to ensure that the motion detector is properly pointed at the appropriate area (i.e., the front of a doorway or a parking lot), rather than at an inappropriate area which would not be used anyway.

- Dimmers. Allows the user to reduce the electricity fed to the fixture(s), resulting in less intense lighting when called for. Not all dimmers are compatible with CFLs or other fluorescent bulbs.

- Photocells and time clocks. Allows user to program information to the ballast controlling the electrical feed to it or its distribution to multiple lights within it. For example, a time clock can program lights to turn off at a certain time at night and back on at a certain time in the morning. These units are relatively inexpensive, but should be installed by a professional electrician.

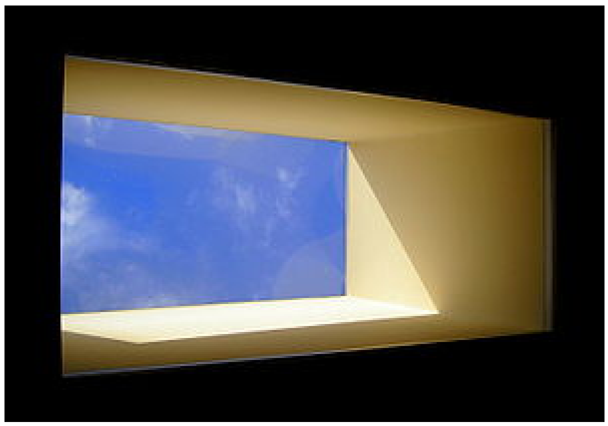
Note that many of these sensors involve data programming (i.e., what time a certain activity should happen, etc.). Ensure that a professional is involved in this. Also ensure that under certain circumstances, information can be overwritten by the user. In modern systems, sensors, photocells, and time clocks can be programmed and overridden by signals from mobile phones, BlackBerries, and other similar devices.

Daylighting

While this may go under the heading of a lighting control, a good way to minimize the use of lighting fixtures in a building and therefore saving electricity and costs is to maximize the use of natural light, that is, the sun shining into buildings. Here are some options used in designing buildings:

- Windows. From a heating and cooling retention point of view, it is preferable to minimize the number of windows in a building because these are a prime locations for leaks of warm air in the winter and cooled air in the summer. However, windows are a reality in most applications, and also an opportunity to allow sunlight in. The number of windows should be maximized in the parts of the building facing the sun on a normal day, mainly southern exposure. Clearly, windows allow daylighting in peripheral sections of a building. Shades or curtains can be used to minimize air losses.

- Skylights. Installation of skylights in the proper location(s) in the ceiling can allow sunlight into a building and minimize air losses. If the skylight is large enough, it can illuminate and reduce the use of lighting fixtures in a large area of the center of a building where windows would be ineffective.



- Painting. Walls near windows (particularly of offices) can be painted a light color to minimize light absorption and maximize its reflection throughout the office to use the light, and reduce the need for general lighting in the area.

- Light-colored furniture or shelves. These, too, would minimize light absorption, reflect to ceilings, and reduce the need for general room lighting.

Performing a Lighting Evaluation or Audit

Building lighting evaluations or audits are generally performed as part of an overall energy audit. However, audits focused only on lighting have been performed and have their benefits.

Such an evaluation should begin with the engineer collecting relevant data from the facility, such as:

- Electricity bills. Determination of the total number of kilowatt-hours used on a monthly basis for at least the last 12 months, and preferably the last two years. If the building has sub-metering, then electricity usage data of each subdivision should be collected.

- Understanding building usage. The building manager should be able to explain clearly the different uses of the building(s) in question, such as quantity of office space, lobbies, warehousing, manufacturing (and type), retail space (and type), and other functions. Ideally square footage for each type of usage should be provided. How much parking space is there? Are there other needs for outdoor lights?

- Inventory of lighting fixtures. The facility should provide a rough inventory of lighting fixtures throughout subject building(s). An exact quantity of fixtures, operating bulbs, etc. is not necessary. But, such information should be separated into the separate functions of the building (the office part, the warehouse part, etc.) if available. One does not need to climb up on ladders to see exactly what type of bulbs are in certain fixtures. Checking the building's or section's equipment storage area can provide a proper estimate of the type of bulbs used, as every building must keep a backup of bulbs for replacement.

- Management of change. What future changes may occur in the building(s), such as a building addition or planned expansions or contractions of certain work areas (i.e., manufacturing, offices, etc.)?

Now that this information is collected, the auditor can look for areas of energy savings with the basis of recommending strategies with the shortest return on investment (ROI). As mentioned earlier, here are some "no brainers" which any auditor should focus on and recommend first:

1. Replace incandescents with compact fluorescent lights (CFLs) wherever possible because of the huge energy savings relative to their cost. In addition, CFLs reduce long term labor, as Maintenance spends less time climbing ladders to replace light bulbs. This reduces total workplace safety risk, as well.

2. Convert existing T-12 fluorescents to T-8 systems in electronic ballasts. Consider replacing with T-5s, which save more electricity. However, installing T-5s requires the replacement of existing ballasts, and this could be expensive, raising the ROI.

3. Use silver reflectors in ballast to shine more light onto the work area.

4. Look for opportunities to delamp. For example, recommend table lamps for office workers or workplaces (such as, for CADD drawing areas) and take out or disconnect overhead, ceiling lighting, if workers are comfortable with this. In many cases, two low wattage CFL table lamps, one on each side of the worker is superior (less electricity, sufficient lighting, less glare) than an overhead fluorescent. Another example is to

disconnect or program the turning off of 2 bulbs of a 4-bulb fluorescent ballast because the light from all 4 bulbs is not needed for the task at hand.

5. Use sensors to turn off lights when not in use. These are mainly occupancy sensors that by lack of movement sense that no one is in a work area and shuts lights off. Other sensors can be programmed to turn on and off lights at given times or in given sunlight.

A key to making recommendations to upgrade lighting is the return on investment or ROI. While complex calculations can be performed based on the value of current and future money, most ROI calculations are based on simple paybacks: the cost of the lights and fixtures compared to the time it will take to earn back that cost in electricity savings. An example of a ROI calculation was given earlier in this course. All of the listed recommendations above, except perhaps Items 1 and 2, have a typical ROI of less than one year. Item 1 ROI is typically a month or less!). Item 2 ROI may be one to two years. The ROI and ultimate long-term cost savings are the selling points to the lighting audit. A good auditor should evaluate and present options for other opportunities to upgrade lighting at a facility to ensure that the right number of lumens is involved for the task at hand ("task lighting" described earlier), even if the ROI is longer or non-existent.

A good lighting evaluation or audit should have a final report with an Executive Summary (as most clients only read this) and sections for Background, for Summary of Data, and for Options (with ROI calculations for all). Raw building or summarized data should be placed in an Appendix.