Performance Assessments of Lighting Systems

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Abstract

Energy conservation is important; no one doubts that. But in context to lighting, the energy conservation decisions are normally based after productivity, safety and quality. The dollar savings derived from energy savings alone may be small compared to the overall value derived from more effective lighting.

This is not to say that one is exclusive of the other. Often, more effective lighting also results in lower energy consumption. The benefits of energy conservation are hidden. A large percentage of the energy input into the lighting system shows up as heat in the conditioned space, which impact the air-conditioning costs. High-efficiency lighting along with reduced air-conditioning reduces the peak electricity demand and usually raises power factor, both of which yield spare capacity on transformers. High efficiency lighting also contributes to reductions in emissions of pollutants associated with global warming, acid rain and smog.

Therefore, the objective must be to achieve the maximum lighting effectiveness with least energy consumption. This course provides a general overview of good lighting practices and discusses the performance assessment methodology.

Performance Assessment of Lighting Systems

Lighting plays a vital role in enabling people to carry out their tasks safely, efficiently and without discomfort, however electric lighting can account for around 30-40% of your electricity bill. An energy efficient lighting system combines low running and maintenance costs with good effective lighting and can reduce the facility's lighting costs by up to a third.

Evaluating Lighting Systems

Most interior lighting requirements are for meeting average luminance on a horizontal plane, either throughout the interior, or in specific areas within the interior combined with general lighting of lower value. The objective is to get the highest lighting at the lowest power consumption. Two terms may be used here: 1) efficient lighting and 2) effective lighting.

Although both the terms are often used interchangeably, there is a difference.

Efficient lighting

Efficient lighting systems can be described in engineering terms of performance. The term lighting efficiency measures the lamp's ability to convert input electric power into luminous power. Since electric power is measured in watts and luminous power in lumens, the unit of efficiency or efficacy is lumen per watt. If there are auxiliary devices necessary for a particular lamp operation, its energy consumption is charged towards the light source. This is the case with fluorescent, mercury, metal halide, and sodium lamps. All these lamps require ballast. Sometimes the efficiency is also defined in terms of watts per square foot.

Effective lighting

Effective lighting on the other hand, is described in terms of "how appropriate the lighting is for the function it is performing". In this case, effective means doing the right thing.

This is not to say that one is exclusive of the other. Often, more effective lighting also results in lower energy consumption or the efficient lighting systems also provide better lighting quality.

Energy conservation issues in context to lighting shall be considered only after determining which lighting system effectively supports the particular tasks, workers, and spaces at a site. If a strategy designed to reduce energy consumption also reduces productivity, every energy dollar saved could mean $10, $20 or more wasted because of lost productivity. The value derived from energy savings alone may be small compared to the overall value derived from more effective lighting.

Understanding Facility Lighting Systems

Lighting Systems

A lighting fixture or luminary consists of: 1) the light source (the lamp) & ballast, 2) lamp holders, 3) an optic system, 4) a means for connecting to a power supply and 5) housing.

Luminaries and controls together form a lighting system. The light source or lamp drives the system and is the starting point for lighting analysis and design.

Light Sources

Lighting professionals use the term lamp to describe light sources commonly called light bulbs and tubes. Incandescent, fluorescent, and high-intensity discharge (HID) lamps are the most common lamps used for building lighting systems.

Light sources vary considerably in terms of efficiency, color, life, and the other attributes that create better lighting. Energy-efficiency and lamp life affect economics. Lamp operation issues are also important. These include starting, flicker, thermal and vibration sensitivity, dimability, and end-of-life behavior.

The characteristics of different lamp types are described later in this course.

Ballasts

Ballasts are required to start and operate fluorescent and HID lamps. Fluorescent lamp ballasts provide the voltage to start the arc discharge and they regulate the lamp current to stabilize light output. Rapid-start ballasts also provide the heating current to the electrodes so that lower voltages are necessary to ignite the arc compared to instant-start systems.

The ballast must be compatible with the specific lamp it is operating, as well as the electrical supply voltage. Ballasts affect the system's light output, power consumption, and in some cases, lamp life. Thus, they contribute to achieving the targeted level of illumination and, more importantly, to system economics.

Ballasts use energy during operation, which decreases the overall efficiency of a lighting system (ballast loss). When fluorescent lamps are operated by electronic ballast at high frequency, they convert the input power to light output more efficiently. The lumens power watt (LPW) of the lamp-electronic ballast combination increases, which means the system either produces more light for the same power or produces the same light with less power. The U.S. Department of Energy has laid a mandatory requirement that all fluorescent lamp ballasts manufactured for commercial and industrial use for both new and renovation markets must be electronic by the year 2005.

Luminaires

Fixtures include the optics that direct light where it is desired and control glare. A well-designed fixture provides the desired distribution of light, good glare control, and high efficiency. The optical system includes the lamp cavity and diffusing media plus one or more of the following components: reflectors, refractors, lenses, baffles, or louvers.

1) Reflectors redirect light by using the principle of reflection. Retrofit reflectors upgrade the performance of fluorescent luminaires by increasing the interior reflectance.
2) A refractor is a component that redirects light by refraction.
3) Lenses enclose a fixture and help to alter the directional characteristics of light passing through it. Polystyrene lenses are the least expensive but emit yellow color due to the UV radiation from lamps. Lenses made from acrylic light are light-stabilized. Polycarbonate lenses are more durable than acrylic but will discolor faster; however, both plastic materials will attract dirt via static electricity. Borosilicate glass lenses are often used where the most durable, clean, and long-lasting optics are desired. They are heavier and more costly than plastic lenses.
4) Translucent sheets of milky-white plastic called diffusers scatter light uniformly in all directions below the ceiling plane, thereby reducing source brightness and shielding the lamps.
5) Parabolic luminaires use large-cell louvers formed in a parabolic shape. The resultant light distribution reduces glare, controls light output, and has high aesthetic appeal.

Controls

Controls can reduce the electrical energy used by lighting systems in two ways:

Electrical energy can be reduced either by reducing the lighting power (kW) or by reducing the time of use (hours). Since electric use is measured and billed by kilowatt- hours (kWh), reducing either will reduce electric costs. Operating hours can be reduced by switching, occupancy sensors, scheduling controls, or photocells.

The more tightly you control the lighting system, the less energy it will consume. The characteristics of different type of controls are described later in this course.

Performance Terms and Definitions

Lumen: Lumen or luminous flux is a unit of light output. The different types of lamps available in the market are labeled with an output rating in lumens.

Lux: The quantity of light that falls on a work surface, called illuminance, is measured in lux or foot-candles. The lux (lx) equals 1 lumen per sq-m and the foot-candle (FC) equals one lumen per sq. ft. A light meter can be used to measure the illuminance.

Average rated life: The rated life of a lamp is the value, in hours, at which half of a large group of that lamp fails under standard test conditions. Any particular lamp or group of lamps may vary from the published rated life. For fluorescent and HID lamps, the average rated life is affected by the burn cycle (the average time that a lamp is on before it is turned off).

Lamp lumen depreciation (LLD): Light sources lose their ability to produce light over time due to age. Lamp lumen depreciation (LLD) represents the percent of initial lumens remaining at 40 percent of rate life.

LLD can be calculated by dividing the design (mean) lumens by the initial lumen rating. For example, for a 32 watt T8 lamp that has an initial rate of 2,900 lumens and a design lumen rating of 2,610, LLD equals 0.90 (2,610/2,900 = 0.90). This means that the T8 lamp will retain 90 percent of its initial light output after 40 percent of its average rated life. Lumen depreciation is affected by the ballast used, line-voltage tolerances, and burn cycle.

Circuit Watts: Circuit watt is the total power drawn by lamps and ballasts in a lighting circuit under assessment.

Installed Load Efficacy is the average maintained illuminance provided on a horizontal working plane per circuit watt with general lighting of an interior. Unit: lux per watt per square meter ($lux/W/m^2$)

Installed Load Efficacy Ratio (ILER): The installed load efficacy ratio is the ratio of the average maintained illuminance provided on a horizontal working plane per circuit watt to the target illuminance on a horizontal working plane.

$$\text{Installed Load Efficacy Ratio (ILER)} = \frac{\text{Actual Lux}/W/m^2}{\text{Target Lux}/W/m^2} \quad \text{or} \quad \frac{\text{Target } W/m^2/100\text{Lux}}{\text{Actual } W/m^2/100\text{Lux}}$$

Average maintained illuminance is the average of lux levels measured at various points in a defined area. The ILER is an important indicator of lighting efficacy, (more details later in this course).

Luminous efficacy (LPW): is the amount of light (lumens) emitted by a lamp for each watt of *power consumed by the lamp circuit, i.e. including control gear losses.* Unit: lumens per circuit watt (lm/W). The higher the LPW, the more efficient is the light source.

Installed Power Density: The installed power density per 100 lux is the power needed per square meter of floor area to achieve 100 lux of average maintained illuminance on a horizontal working plane with general lighting of an interior. Unit: watts per square meter per 100 lux ($W/m^2/100$ lux)

$$\text{Installed Power density } (W/m^2/100 \text{ lux}) = \frac{100}{\text{Installed load efficacy } (lux/W/m^2)}$$

Visual Comfort Probability (VCP): is a rating of lighting systems that is expressed as a percentage of people who, when viewing from a specified location and in a specified direction, will find the lighting system acceptable in terms of discomfort glare. The IESNA minimum recommendation of electronic offices is 80.

Color Rendering Index (CRI): Color rendering describes the effect a light source has on the appearance of colored objects. The higher the CRI, the less distortion of the object's color by the lamp's light. Color rendering is measured on a scale of 0 to 100. The maximum CRI is 100 (natural sunlight). A CRI of 100 indicates no color shift in the object when compared to a reference source. The lower the CRI, the more pronounced the color shift will be. CRI values are only taken into consideration once a color temperature range has been determined; however, the temperature effect cannot be discounted when assessing CRI.

A low CRI indicates that some colors may appear unnatural when illuminated by the lamp. CRI values should only be compared between lamps of similar color temperature.

Correlated Color temperature (CCT): The color temperature is described in terms of its lit appearance to the eye – whether it appears "warm" or "cool." CCT is measured on a Kelvin scale, ranging from 1,500 K (which appears red-orange) to 9,000 K, which appears blue. The greater the number, the cooler the lamp color; the smaller the number, the warmer the lamp color. Most light sources fall in the middle range, leaning either toward cool or warm. Generally, a lamp source should be selected to suit the color scheme of the space: warm range lights for warm color schemes and cool range lights for cool color schemes. Predominantly neutral or gray color schemes can be lit with either to accentuate or draw the scheme one way or another, or may employ a more neutral, midrange light.

A standard incandescent lamp has a color temperature of 2,700 K and appears yellow-white. When the incandescent lamp is dimmed, the color of the light shifts to the red end of the spectrum, making reds appear more saturated while greens and blues become grayed. A tungsten-halogen lamp may have a color temperature in the range of 3,000 to 3,200K and appear brilliant white. These lamps render all colors very close to their actual hue.

Note a difference: Correlated Color Temperature (CCT) describes the color of the light given off by the lamp, while the Color Rendering Index (CRI) describes the effect that the light source has on the apparent color of an object.

Purpose of the Performance Test

The main purpose of performance test is to calculate efficacy in terms of lux/watt/m² for lighting installation. The efficacy of an existing (or design) lighting installation can be assessed by carrying out a lighting survey or audit. The procedure involves 3 steps:

Step one: It starts with gathering information concerning the characteristics and the current condition of lighting systems and the lighted environment. This information is used as baseline data.

Step two: The calculated value can then be compared with the norms/standards for specific types of interior installations for assessing improvement options.

Step three: Identifying opportunities for improvements and investigating installing new types of lamps in existing fixtures, retrofitting or replacing fixtures, installing new controls, and more. Recommendations should discuss factors relevant to the management goals, including the quality of lighting, energy savings, cost reductions, and payback.

The next stage is implementing and monitoring the plan.

Facilities managers trying to understand and evaluate lighting systems must be familiar with fundamental concepts about lighting, including:

- Quantity
- Quality
- Lamp technologies
- Ballast technologies
- Luminaries
- Controls
- Maintenance
- Quantity of Light

It's important to remember that best intentions alone don't generate energy savings.

Quantitative Criteria

From the energy efficiency point of view, the main criteria of lamps evaluation is the amount of light emitted (lumens) and the energy they consume (watts). Combining these values gives what is termed “the lamp efficacy” (lumens/watt), which is the amount of light emitted for the amount of energy put in. Therefore, the higher the efficacy, the lower shall be the running costs.

Light Level or Illuminance (FC)

A host of issues must be given careful consideration before a hasty conclusion is reached regarding appropriate light levels. These include, but are not limited to:

- The type of space;
- How it is used;
- Flexibility of use;
- Desired lighting effects;
- Visual tasks; and
- Owner's liability

There are several weighting factors: occupants' age; importance of speed and/or accuracy in performing a task; and reflectances. These judgments are best made by an experienced lighting professional.

The standard recommendations on the illumination levels based on the space use are also set in by the Illuminating Engineering Society of North America (IESNA) or CIBSE, UK. These consensus recommendations have been agreed upon by lighting professionals and the norms can be best referred to in the IESNA/CIBSE handbook.

Power Density (W/ft^2)

The first basis for identifying opportunities for improvement is power density (PD). Power density is the power allowance for a building, measured in watts per square foot. The efficiency of installed lighting systems can be determined by using power density as a figure of merit. New, efficient office lighting systems (without daylight contribution) should measure 1.0 w/sq-ft. Office lighting systems that calculate above this value are usually considered inefficient and are good candidates for upgrade or relighting.

The power density of lighting systems can be used by the auditor as a screening measure. If a particular lighting upgrade is calculated to be cost-effective for spaces of a certain PD, then all similar spaces measuring higher than that PD can also be upgraded cost effectively.

Preparation (before Measurements)

Before starting the measurements, the following care should be taken:

1) All lamps should be operating and no luminaries should be dirty or stained.
2) There should be no significant obstructions to the flow of light throughout the interior, especially at the measuring points.
3) Accuracies of readings should be ensured by
   - Using accurate illuminance meters for measurements
   - Sufficient number and arrangement of measurement points within the interior
   - Proper positioning of illuminance meter
   - Ensuring that no obstructions /reflections from surfaces affect measurement.

The procedure recommended for such site measurement is described in next section.

Procedure for Lighting Systems Assessment

The lighting layouts can be modeled or reviewed either using lighting power density method or the lighting level (lumen) method. Both of these techniques require photometric information for the luminary (lamp and ballast), the luminary layout, the three-dimensional shape of the space, and the reflectances of the surfaces. The assessment methodology is as follows:

Step 1: Measure the floor area of the interior

Step 2: Calculate the Room Index and determine the number of measurement points

Step 3: Determine the total circuit watts of the installation by a power meter, if a separate feeder for lighting is available. If the actual value is not known, a reasonable approximation can be obtained by totaling up the lamp wattages including the ballasts

Step 4: Divide 3 by 1 to calculate watts per square meter

Step 5: Ascertain the average maintained illuminance, E-avg. maintained (average lux levels)

Step 6: Divide 5 by 4 to calculate lux per watt per square meter

Step 7: Obtain target Lux/W/m² lux for the type of interior/application and RI

Step 8: Divide 6 by 7 to calculate 'Installed Load Efficacy Ratio' (ILER)

(Follow an example later at this section)

Room Index

To determine the minimum number and positions of measurement points; calculate the *Room Index:*

$$\text{Room Index (RI)} = \frac{L \times W}{H_m (L + W)}$$

Where

- L = length of interior
- W = width of interior
- H_m = the mounting height, which is the height of the lighting fittings above the horizontal working plane.

The working plane is usually assumed to be 0.75 m above the floor in offices and at 0.85 m above floor level in manufacturing areas.

It does not matter whether these dimensions are in meters, yards or feet as long as the same unit is used throughout. Ascertain the minimum number of measurement points from table below.

Determination of Measuring Points

Room Index	Minimum Number of Measuring Points
Below 1	9
1 and below 2	16
2 and below 3	25
3 and above	36

The interior is divided into a number of equal areas, which should be as square as possible. The illuminance at the centre of each area is measured and the mean value is calculated. This gives an estimate of the average illuminance on the horizontal working plane.

To obtain an approximately "square array", i.e. the spacing between the points on each axis to be approximately the same, it may be necessary to increase the number of points. (Refer to the example later in this section)

Target (lux/W/m²) Values for Various Facilities

How much light is required to illuminate workspaces or to perform tasks?

The most effective lighting in terms of performance and cost begins with a thorough understanding of the specific application. The nature of the industry - its visual requirements and its workforce - determines the basic lighting needs and the quality and quantity of illumination. The specifics of the space and equipment, and the need for flexibility, determine what equipment will best provide the desired lighting and where it will be placed.

The table below, which is based on CIBSE recommendations, provides the target lux/W/m² (W/m²/100lux) values for maintained illuminance on horizontal plane (for all room indices) for different applications:

TARGET lux/W/m² or (W/m²/100lux) VALUES

Room Index	Commercial Lighting (office, retail stores etc.) & very clean industrial applications, Standard or good color rendering, Ra: 40 - 85	Industrial Lighting (manufacturing areas, workshops, warehouse etc.) Standard or good color rendering, Ra: 40 - 85	Industrial Lighting installations where standard or good color rendering is not essential, but some color discrimination is required, Ra: 20 – 40
5	53 (1.89)	49 (2.04)	67 (1.49)
4	52 (1.92)	48 (2.08)	66 (1.52)
3	50 (2.00)	46 (2.17)	65 (1.54)

2.5	48 (2.08)	44 (2.27)	64 (1.56)
2	46 (2.17)	42 (2.38)	61 (1.64)
1.5	43 (2.33)	39 (2.56)	58 (1.72)
1.25	40 (2.50)	36 (2.78)	55 (1.82)
1	36 (2.78)	33 (3.03)	52 (1.92)

Ra: Color Rendering Index

The principal difference between the targets for Commercial and Industrial Ra: 40-85 (Columns 2 & 3) is the provision for a slightly lower maintenance factor for the latter. The targets for very clean industrial applications, with Ra of 40 - 85, are indicated in Column 2.

The Illuminating Engineering Society of North American (IESNA) provides light level (illuminance) recommendations. The new IESNA Lighting Handbook, 9th edition, contains the latest illuminance recommendations, which are intended to prevent under-lighting and over-lighting. Over-lighting wastes energy and reduces lighting quality.

Indicators of Performance (ILER Assessment)

Compare the calculated ILER with the information in the table below:

Indicators of Performance

ILER	Assessment
0.75 or over	Satisfactory to Good
0.51 to 0.74	Review Suggested
0.5 or less	Urgent action required

ILER Ratios of 0.75 or more may be considered to be satisfactory. Existing installations with ratios of 0.51 - 0.74 certainly merit investigation to see if improvements are possible. Of course there can be good reasons for a low ratio, such as having to use lower efficacy lamps or less efficient luminaries in order to achieve the required lighting result, but it is essential to check whether there is a scope for a more efficient alternative. Existing installations with an ILER of 0.5 or less certainly justify close inspection to identify options for converting the installation to use more efficient lighting equipment.

Having derived the ILER for an existing lighting installation, the difference between the actual ILER and the best possible (1.0) can be used to estimate the energy wastage. For a given installation:

Annual energy wastage (in kWh) = (1.0 - ILER) x Total load (kW) x annual operating hours (h)

This process of comparing the installed load efficacy (ILE) with the target value for the Room Index and type of application can also be used to assess the efficiency of designs for new or replacement general lighting installations. If, when doing so, the calculated ILE (lux/W/m²) is less than the target value then it is advisable to ascertain the reasons. It may be that the requirements dictate a type of luminaire that is not as efficient as the best, or the surface reflectance's are less than the normal maxima, or the environment is dirty, etc. Whatever the reasons are they should be checked to see if a more efficient solution is possible.

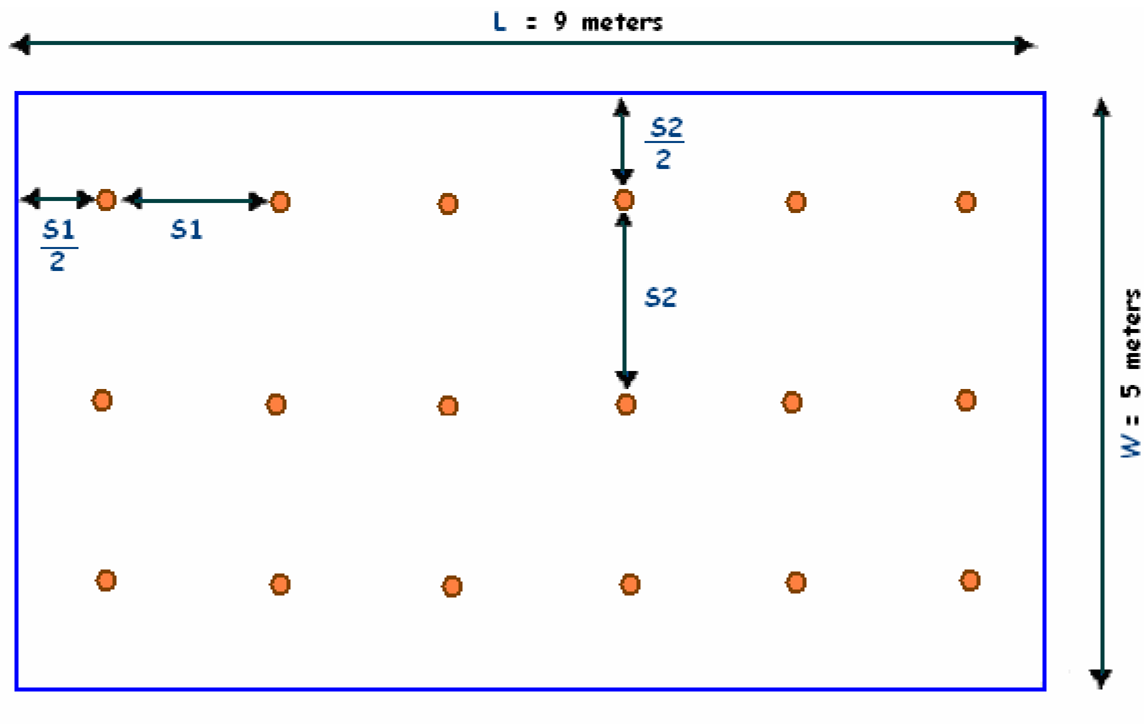
Example

For example, the dimensions of an interior are: Length = 9m, Width = 5m, Height of luminaries above working plane (Hm) = 2m, then calculate room index as follows:

$$\text{Room Index (RI)} = \frac{9 \times 5}{2 \times (9 + 5)} = 1.93$$

Corresponding to RI of 1.93, the minimum number of measurement points are 16 (refer to the table above).

Sketch a layout of the room on a piece of paper to arrange the 16 measuring points. As it is not possible to approximate a "square array" of 16 points within such a rectangle, it is necessary to increase the number of points to say 18; i.e. 6 x 3. These should be spaced as shown below:



MEASUREMENT POINTS

Therefore in this example, the spacing between points along the length of the interior, S1 = 9 ÷ 6 = 1.5m, and the distance of the 'end' points from the wall $S1_{/2}$ = 1.5 ÷ 2 = 0.75m.

Similarly the distance between points across the width of the interior, S2 = 5 ÷ 3 = 1.67m, with half this value, $S2_{/2}$ = 0.83m, being the distance between the 'end' points and the walls.

It is important to note here, that if the grid of the measurement points coincides with that of the lighting fittings, large errors are possible and the number of measurement points should be increased to avoid such an occurrence.

STEP 1 :	Measure the floor area of the interior:	Area = 45 m²
STEP 2 :	Calculate the Room Index	RI = 1.93
STEP 3 :	Determine the total circuit watts of the installation by a power meter if a separate feeder for lighting is available. If the actual value is not known, a reasonable approximation can be obtained by totaling up the lamp wattages including the ballasts:	Total circuit watts = 990 W
STEP 4 :	Calculate Watts per square meter, 3 ÷1 :	W/m² = 22

STEP 5 :	Ascertain the average maintained illuminance, E avg. Maintained (average lux levels measured at 18 points)	E avg. maintained = 700
STEP 6 :	Divide 5 by 4 to calculate lux per watt per square meter	Lux/W/m² = 31.8
STEP 7 :	Obtain target Lux/W/m² lux for type of the type of interior/application and RI (2):	Target Lux/W/m² = 46
STEP 8 :	Calculate Installed Load Efficacy Ratio (6 ÷ 7):	ILER = 0.7

ILER of 0.7 means that there is scope for review of the lighting system and the annual energy wastage can be computed as:

Annual energy wastage = (1 – ILER) x watts x no. of operating hours

= (1 – 0.7) x 990 x 8 hrs/day x 300 days

= 712 kWh/annum

Areas for Improvement

Assess scope for more energy efficient lamps and luminaries. You can upgrade the lighting in an existing facility using three basic strategies:

- Changing lamps only
- Changing lamps and ballasts
- Changing entire luminaries (lamp and fixture)

Examples:

In a warehouse space, replace 1,000 watt Mercury Vapor high bay and retrofit existing fixture to 400 watt Metal Halide

In a retail space, replace 75 watts recessed downlight incandescent with 15 watt compact fluorescent lamp

In a manufacturing facility, replace magnetic ballast of fluorescent lights with polished reflectors and electronic ballasts.

Standard Recommendations

While each facility demands its own lighting solution, here are some guidelines for optimizing the result. The recommended luminance does, however, provide a foundation for lighting design.

Use of daylight

The majority of people like natural light and it can make a positive contribution to the operation of a facility. The benefit of natural light must not be ignored, and advantage should be taken of it where possible.

Challenges

1) Adequate day lighting can only be provided for a limited distance from windows or roof lights and will only be available for part of the working day. For this reason, correctly controlled artificial lighting must always be provided.

2) Large areas of un-curtained glass present problems. At night they will act as shiny black walls and cause discomfort and during the day they may well prove uneconomical because of high solar gain or heat loss. The use of special glass or outside shades will reduce this problem and also reduce visual discomfort.

3) The level of natural light does vary (e.g. weather, time of day) and supplementary artificial light is normally required to maintain adequate lighting levels. These should be controlled to maintain a reasonably constant level of illumination at the work place.

4) Direct sunlight creates powerful shadows so it is typically baffled, redirected, or diffused before reaching the workspace. Properly controlled sources of top lighting can admit effectively and diffuse illumination of excellent color quality.

5) The variable intensity of daylight requires careful balancing of nearby electric lighting. Where (and when) the admitted daylight is minimal, electric lighting must provide adequate illumination. Where daylight is maximized, it may overwhelm adjacent areas with much lower levels of electric lighting, creating shadows and extreme contrast.

Human Factors & Safety

In any lighting application, the essential first step is analyzing the visual tasks themselves in terms of the **quality and quantity** of illumination required. Select light sources with appropriate color quality for the activities they will illuminate.

Good lighting is seen to be a valuable contribution to safety. While the health and safety executives state that lighting should be suitable and adequate, such may require proper interpretation.

Quality and Quantity

The quality of an illuminated environment is established through the manipulation of light to communicate specific information. In order to understand how visual quality and quantity of light affect the experience of users of a space, one must understand the concepts of brightness and reflectance.

Brightness: refers to how much light energy is reflected by a surface. The degree of brightness of an object depends upon the color value and texture of its surface. Brightness can be relative or measured. When a gray object is viewed first on a black background and then on a white background, the brightness level appears different. However, the measured brightness or luminance of the object would be equal.

Reflectance or Brightness Ratio: is defined as the ratio of light incident upon a surface to that reflected. Reflectance of major surfaces in a space is critical to achieving intended brightness ratios.

Brightness is of significant benefit to the viewer, as the ability to distinguish fine detail increases with object brightness. Of equal importance is relative brightness between objects being viewed and their surroundings. Some degree of contrast in brightness is required. For example, it is very difficult to see any object against a similarly colored background. This need is easily understood on the printed page where dark letters can best be read when printed on light paper. A maximum brightness ratio of 3:1 between the task surface and background is recommended by the IESNA. Between the task area and darkest part of the surrounding space, the brightness ratio should not exceed 5:1. Brightness ratios higher than these values can lead to glare, visual fatigue, and loss of performance.

Appearance

A room in which all the light is concentrated on a horizontal working plane, and little or no light is allowed to fall on walls or ceilings, is likely to have a depressing atmosphere. In rooms of up to 25 m^2, the feeling of claustrophobia can be mitigated by using light colored walls, but in very large areas of 100 m^2 or more, where the field of view is extensive, it is more effective to let some light reach the ceiling. The reflectors of most luminaries are slotted in order to allow a small proportion of upward light to relieve this tunnel effect.

Generally, increasing emphasis is being placed on the need to achieve not only effective lighting condition for visual performance but also attractive visual environments.

Task/Ambient vs. General Lighting Schemes

Task lighting is a focused light utilized for a specific task. This approach to lighting is based upon illuminating a task in an appropriate manner while balancing the illumination of surrounding areas (ambient light). **Ambient lighting** involves a uniform light with no apparent single source. It provides a low level of overall diffused lighting adequate for circulation needs and for preventing areas of darkness.

Facilities with a wide range of visual activities intermixed throughout the space, such as a fabricating machine shop with a variety of tools and processes, can benefit from using separate ambient and task lighting systems. With this approach, it is easy to tune the task lighting to the distinctive requirements of the different operations within the facility. Facilities with a more homogenous distribution of activities, such as a warehouse or assembly operation, can often apply a more general lighting scheme with a single primary system. Specialized lighting can then be applied to those limited areas with more critical illumination requirements, such as intricate assembly, finishing, or inspection.

The major advantages of task lighting include:

- Highly controllable and user-friendly sources,
- Energy savings possible through lower overall ambient light level,
- Wide range of sources and models,
- Highly portable and adjustable, and can be used to create high local light levels where necessary.

The major disadvantages of task lighting include:

- Expense in terms of capital investment,
- Requirement for multiple power outlets,

- Wide assortment of models can lead to problems with aesthetics, coherence, and maintenance,
- Desk versions can be space consuming,
- Poor adjustment can lead to glare for colleagues, and
- Under-shelf models may produce glare for user.

Direct & Indirect Glare

Glare is the sensation produced by brightness (luminance within the visual field) sufficiently greater than the brightness to which the eye is adapted to cause a loss of visual performance. Discomfort glare in building interiors is annoying and diminishes lighting quality by interfering with employee productivity more than with visual performance.

Direct Glare from light sources and reflected glare from other surfaces in the field of view can often make seeing uncomfortable (discomfort glare) or it can reduce visibility (sometimes to a dangerous degree). It can, of course, produce both effects together. Glare is not confined to electric (artificial) lighting conditions. Severe glare can be caused by badly positioned windows, and most people experience both direct and reflected glare out of doors, e.g. when driving towards the sun or looking across water.

Fortunately, direct glare can be avoided and controlled by controlling the light level and by blocking the direct view of bare lamps. Louvers such as those in deep-cell parabolic luminaires or low-glare acrylic lenses that reduce surface brightness at high viewing angles may be used. The use of indirect lighting by allowing more light to fall on walls and ceilings is the one of the best way to reduce glare in office interiors.

Reflected glare is more difficult to overcome and it is a common fault in offices and situations where glossy, light colored objects are in the field of view. Typical examples of reflected glare are:

a. Drawing offices where pencil lines become invisible because reflected light raises their brightness to that of the surrounding paper, and
b. Reflected images of luminaries in the screens of visual display units

In these and other similar situations, the reflected glare problem can be overcome or minimized to an acceptable level by suitable positioning of the luminaries relative to the task and in some instances, the use of luminaries having a more suitable light distribution.

Reflected glare significantly reduces the ability to see the visual task, thereby reducing productivity. Such problems are not always easy to solve, and it is usually best to seek professional advice.

Fixture Location

Task lighting equipment should be located as close to the task as practical. This limits the potential for shadowing and reduces the amount of light and energy cost required. Fixtures for ambient lighting need to be mounted high enough to clear permanent and moving equipment and to distribute light effectively onto elevated vertical surfaces. Observe the spacing-to-mounting height ratio for ambient fixtures. The mounting height is calculated to the relevant task plane. Excessive spacing will create dark areas. Note that the higher the fixtures, the more broadly the light will spread and the less illumination will fall on horizontal surfaces near the facility floor. High-mounted fixtures also incur more maintenance costs, especially where lifts or other equipment may disrupt facility operation.

Initial cost depends significantly on the number of fixtures installed and the number of separate electrical connections. Concentrating too much light in too few fixtures typically results in problematic illumination with both shadows and glare. Designs that locate lighting where it is needed, on the other hand, economize on energy while enhancing human factors. Arranging the fixtures so they can be through-wired or easily connected together, and limiting the variety of fixtures and lamps are both practical and cost-saving measures.

Rule of Thumb Guidelines

The lighting load is typically determined from the nameplate wattage from the lighting layout drawings. An estimate can be made using the rule of thumb guidelines below. Note that the lighting values for most energy conscious construction will have lower values and could be very high if fancy lighting is used.

Location	Rule of thumb (Watts/sq-ft)
General Office Areas	1.5 to 3.0
Private	2.0 -5.0
Conference Rooms	2.0 – 6.0
Public Places (Banks, Post offices, Courts etc)	2.0 – 5.0
Precision Manufacturing	3.0 – 10.0
Computer Rooms/Data Processing Facilities	2.0 – 5.0
Restaurants	1.5 – 3.0
Kitchens	1.5 – 2.5
Pubs, Bars, Clubhouses, Taverns etc	1.5 – 2.0
Hospital Patient Rooms	1.0 – 2.0
Hospital General Areas	1.5 – 2.5
Medical /Dental Centres, Clinics	1.5 – 2.5
Residences	1.0 – 4.0
Hotel & Motels (public places and guest rooms)	1.0 – 3.0
School Classrooms	2.0 – 6.0
Dining halls, Lunch Rooms, Cafeterias	1.5 – 2.5
Library, Museums	1.0 – 3.0

Location Rule of thumb (Watts/sq-ft)	
Retail, Department & Pharmacist Stores	2.0 – 6.0
Jewellery Showrooms, Shoes, Boutiques etc	2.0 – 4.0
Shopping Malls	2.0 – 4.0
Auditoriums, Theatres	1.0 – 3.0
Religious Places (Churches)	1.0 – 3.0
Bowling Alleys	1.0 – 2.5

The above table provides rule of thumb data, and in cases where use is not mentioned specifically, the determination shall be based upon the most comparable use.
The electrical load of lighting systems in office space ranges from 1 W/sq-ft, or less for efficient lighting, to 2 to 3 W/sq-ft for older systems.

IES - Recommendations

The Illuminating Engineering Society (IES) has published illuminance recommendations for various activities. These tables cover both generic tasks (reading, writing etc), and hundreds of very specific tasks and activities. All tasks fall into 1 of 9 illuminance categories covering from 20 to 20,000 lux, (2 to 2000 foot candles). The categories are known as A - I and each provide a range of 3 illuminance values (low, mid and high). See Table below.

IES Illuminance Categories and Values - For Generic Indoor Activities

ACTIVITY	CATEGORY	LUX	FOOTCANDLES
Public spaces with dark surroundings	A	20-30-50	2-3-5
Simple orientation for short temporary visits	B	50-75-100	5-7.5-10
Working spaces	C	100-150-200	10-15-20

where visual tasks are only occasionally performed			
Performance of visual tasks of high contrast or large size	D	200-300-500	20-30-50
Performance of visual tasks of medium contrast or small size	E	500-750-1000	50-75-100
Performance of visual tasks of low contrast or very small size	F	1000-1500-2000	100-150-200
Performance of visual tasks of low contrast or very small size over a prolonged period	G	2000-3000-5000	200-300-500
Performance of very prolonged and exacting visual tasks	H	5000-7500-10000	500-750-1000
Performance of very special visual tasks of extremely low contrast	I	10000-15000-20000	1000-1500-2000

The category A through C is for general illumination throughout the area or luminance over a large area (i.e. lobby space)

The category D though F is for localized tasks or for illumination on the task

The category G through I is for extremely difficult visual tasks and would require a combination of general lighting and task lighting.

Once the category is determined, use the weighting factors to decide which of the values in the illuminance range to use. For instance for public facilities like libraries there may be many individuals over 55 years of age, so select the high factor. Similarly decide whether the demand for speed and accuracy is critical or not so important; e.g. say a drafting work may be critical but sorting the library cards may be not very critical. Assign low, mid and high illuminance values accordingly. In general aim for a 5:3:1 ratio for work, peripheral work area, and immediate surroundings, respectively.

Choice of Lamps

Besides energy efficiency (lumens/watt), the other things to consider when choosing a lamp type include:

Color appearance – Combination of color rendering and how “warm” or “cool” would you want the light to appear

Switch on times – High pressure lamps, like sodium or metal halide may take a while to reach full output levels and will not usually switch on when they are warm. These are unsuitable for switching on and off too often during a day

Flicker – Some lamps flicker on and off at high speeds e.g. fluorescents. The eye cannot see this, but it may cause rotating machinery to appear to be running faster or slower or even in a different direction. Ballasts are used to start and operate such lamps correctly, and high frequency ballasts are available which overcome the problem of flicker and use less energy

Lamp life – Where maintenance is problematic, for example where lights are mounted high up or over delicate areas such as food preparation, long-life lamps should be used

Light fittings – should be selected to screen the lamp and help to direct the light to where it is required. These are often called ‘Luminaries’ in the trade

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Lamp Types

Through continued research and technological advancements, thousands of lamp types are available to serve a great spectrum of users. General application lamps are currently classified into three basic categories: incandescent, fluorescent and high intensity discharge. Each category has its own unique operating characteristics, special considerations, and applications.

Incandescent Lamps

Incandescent lamp – is a tungsten filament lamp that dissipates lot of heat to accompany the light emitted from its glowing filament. They are inexpensive and available in hundreds of sizes, shapes, and wattages and are easily dimmed. However, they are the least energy efficient light source – as low as 8 LPW (lumens per watt) and only 10% of its energy is emitted in the form of light and the balance goes as heat further adding to the air conditioning load. Incandescent lighting, therefore, is most often used for residential lighting or the aesthetic display of merchandise.

Incandescent sources come in a variety of forms and shapes. Their versatility is enhanced by their availability in a wide range of wattages. Incandescent light emanates from a relatively small source; because some lamps themselves are quite small, their light distribution can be controlled easily. Incandescent lamps are easy to install, are not adversely affected by frequent switching, and can be easily dimmed.

Incandescent lamps are voltage sensitive. Lamp life, lumen output, and wattage depend on the applied voltage. *When 130-volt lamps are used on 120-volt circuits, lumen output will be lower and life will be longer.*

Incandescent have the highest color rendition index (CRI) of around 95. Their small size and the fact that a point source can be easily controlled and manipulated by a luminary provide some benefits when it comes to task lighting. Examples include low brightness task fixtures for use in control rooms and luminaries that produce light in a narrow controlled beam to illuminate the interiors of small machinery or intricate parts.

Tungsten-halogen lamps are more efficient than standard incandescent lamps. A halogen fill gas combines with the tungsten molecules that boil off the filament. The resulting halogen cycle increases the LPW, produces whiter light and longer life, and lowers LLD (lamp lumen depreciation).

Fluorescent Lamps (FTL Lamps)

Fluorescent lamps are low-pressure discharge light sources. The typical fluorescent lamp is comprised of a cylindrical glass tube, sealed at both ends, which contains a mixture of an inert gas and low-pressure mercury vapor. Cathodes at the tube's ends emit a stream of electrons, activating the phosphor coating on the inside of the tube, thus producing light. Fluorescent lamps have a long life, typically lasting 10 to 15 times longer than incandescent lamps, while producing about four times as much light per watt (60 to 80 lumens per watt).

Characteristics of fluorescent lamps are long life (12,000 to 22,000 hours), high efficacy (75 to 90 lumens per watt), and excellent color rendering. Fluorescent lamps are, however, temperature sensitive and their rated lamp life is dependent upon the hours per start. On average, 40 watts of energy in a fluorescent tube produces as much light as a 150-watt incandescent bulb. New T-8 fluorescent lamps (CRI = 85) are much more efficient than older T-12 lamps (CR = 62).

While fluorescent lamps have a longer life, produce more light and save more energy than incandescent lamps do, some disadvantages to their use exist. They can produce a flat, diffuse light which may appear monotonous and tiring. Also, large tube sizes limit optical control. These lamps also need some form of starting device (starters) and a means of controlling the lamp current once started (ballast). A capacitor is also normally connected to provide power factor correction and to reduce the current drawn from the mains for a given wattage.

Compact Fluorescent Lamps (CFL)

CFL is the generic name for a family of single-ended fluorescent lamps of folded or bridged tube design that can be plugged into an existing incandescent lamp socket. These have been developed to fit into the space of the conventional 25 to 100 watt incandescent lamp. These fluorescents provide longer life and high energy savings, as much as 82 percent over incandescent lamps, while approaching the preferred color of incandescent light. A 13-watt compact fluorescent lamp (CRI = 82) replaces a 60-watt incandescent for the same light output.

A disadvantage with compact fluorescent appears in the mounting positions; some compact lamps require specific mounting positions (e.g. vertical-base up).

Halogen Lamps

A halogen lamp is an incandescent bulb with an added halogen gas. Halogen lamps run at a higher temperature, providing a whiter light and greater efficiency.
Halogen lamps are more energy efficient than standard incandescent lamps. For the same amount of electricity, they generate up to 30 percent more lumens per light, up to 22 lumens per watt. Also, because halogen bulbs blacken much less than standard incandescent, they stay almost continuously bright as they age. Their bright light and small size makes them ideal for activity and accent lighting.

The typical life ranges from 2,000 to 4,000 hours with wattage ranges of 5 to 300 watts. Other benefits include bright, intensely focused light and ease of use with dimmers for energy savings.

The popular types of halogen lamps are described below.

Low-pressure sodium

This light source converts nearly 35% of the energy consumed into light. Low-pressure sodium bulbs should last at least 10,000 hours and deliver as much light at the end of their life as in the beginning. However, they are the most expensive lighting source. They are also the largest, and hence, most difficult to control in terms of light distribution. In addition, because of their singular yellow color, they have very low color rendition index (CRI). Objects under low-pressure sodium illumination appear yellow, gray, or black. Sodium lamps are also used for lighting public parks and for some indoor industrial interiors etc.

High Intensity Discharge (HID)

Whereas fluorescent lamps rely on the interaction between an energized gas and the reactant coating on the inside of the lamp, HID lamps produce light through the direct excitement of a pressurized gas. HID sources tend to be extremely efficient and long-lived, but typically have long start-up times and operate with poor color rendition and consistency.

Mercury vapor lamps were the first HID source developed but are used less frequently than other HID sources. They produce light by passing an electron stream through a gas vapor. Advantages of mercury vapor lamps include excellent maintained light output, high light output in relation to energy use, low cost, and exceptionally long life. Warm-up time (usually 1 to 7 minutes) before full brightness, time to cool down before restarting if power is interrupted and high heat output are a few disadvantages. The National Electric Code (NEC) requires a backup lighting system for HID lighting for public safety.

Exterior landscape lighting makes the best use of mercury vapor lamps as the color rendition emphasizes the greens of landscape. Due to limited color rendering and mercury content, mercury vapor lamps are seldom used any longer.

Common HID lamp types are mercury vapor, metal halide, and high-pressure sodium lamps:

High-pressure mercury vapor lamps (HPMV) - Mercury lamps cover a wide range of light from low pressure discharge devices of a few watts (providing a source of ultra violet light) to very high pressure lamps of 1000 watts. When fully run up, the mercury vapor lamps operate at pressures from 2atm to 10atm. The disadvantages of mercury vapor lamps include very low color rendition, high lumen depreciation, and high mercury content. They are generally used for factory and flood lighting at stadiums, airports, and street lighting.

Metal halide lamps (MH) – Metal halide lamps work in much the same way as mercury vapor lamps. The primary difference is the addition of metal halides to the mercury or argon in the metal halide arc tube.

Metal halides have superior efficacies (70 to 94 LPW), high light, better color rendering, and precise beam control (due to their small size). Metal halide lamps have the best CRI of the high-intensity discharge lamps. Applications include commercial lighting interiors and lighting building facades.

Disadvantages to these lamps include shorter life, lower lumen maintenance (light output decreases faster), and certain restrictions on the positions in which the lamps may be burned. If operated improperly metal halide lamps may explode; thus, they require fixtures with protective lenses. No metal halide lamps should be operated continuously. They should be turned off once a week for at least 15 minutes. This permits older lamps to fail passively when restarted. Additionally, metal halide lamps should not be operated beyond their rated average lives.

Metal halide lamps work well in offices, retail spaces and public interiors.

High-pressure sodium lamps (HPS) – High Pressure Sodium (HPS) lamps are the newest addition to the HID field. The lamps have efficacies of 60 to 140 lumens per watt and rated lives of 10,000 to 24,000 hours. Unlike metal halide lamps, they are not as sensitive to burning position. While normally the light source has a yellow-orange glow, recent improvements have resulted in a white color-rendering property.

Due to its thin, linear shape, the HPS provides excellent optical control. The two distinct disadvantages are shorter life compared to other HID sources and severely distorted salmon appearing color output among non-color-corrected lamps. HPS have low CRI of about 25. Their poor color quality limits their effectiveness in occupied spaces as that tends to blacken red and blue objects. Unfortunately, improvement of color rendering results in lower lamp life and efficacy. Recent advances in HPS lamps include higher CRI models and models that do not cycle at end of life. A double arc-tube HPS lamp is available for safety and security applications.

These are however used in storage areas and warehouses. Their small size and excellent efficiency make them the most popular choice for roadway lighting, street lighting and flood lighting.

Characteristics of Different Types of Lamps

Type of Lamp	Lamp Wattage (Watts)	Lumens	Lamp Efficiency (Lumens/Watt)	Choke Rating (Watts)	Life of Lamp (Hours)	Capacitor Rating Required (Micro farads)	Color Rendering Index
HPSV	70	5600	80	13	15000 - 20000	0.2 - 0.39	12
HPSV	150	14000	93	20	15000 - 20000	0.2 - 0.39	20
HPSV	250	25000	100	20	15000 - 20000	0.2 - 0.39	32
HPSV	400	47000	118	40	15000 - 20000	0.2 - 0.39	45
HPSV Super	70	---	---	---	---	---	---
HPSV Super	100	9500	95	18	15000 - 20000	0.2 - 0.39	---
HPSV Super	150	15500	103	20	15000 - 20000	0.2 - 0.39	---
HPSV Super	250	30000	120	25	15000 - 20000	0.2 - 0.39	---

Type of Lamp	Lamp Wattage (Watts)	Lumens	Lamp Efficiency (Lumens/Watt)	Choke Rating (Watts)	Life of Lamp (Hours)	Capacitor Rating Required (Micro farads)	Color Rendering Index
HPSV Super	400	54000	129	40	15000 - 20000	0.2 - 0.39	---
HPSV Super	600	---	---	---	---	---	---
HPMV	80	3400	43	9	4000 - 5000	0.6 - 0.69	8
HPMV	125	6300	50	12	4000 - 5000	0.6 - 0.69	10
HPMV	250	13000	52	16	4000 - 5000	0.6 - 0.69	18
HPMV	400	22000	55	25	4000 - 5000	0.6 - 0.69	18
Metal Halide	70	4200	84	26	10000	0.9 - 0.93	---
Metal Halide	150	10500	70	20	10000	0.9 - 0.93	---
Metal Halide	250	19000	76	25	10000	0.9 - 0.93	---
Metal Halide	400	31000	76	60	10000	0.9 - 0.93	---
Metal Halide	1000	80000	80	65	10000	0.9 - 0.93	---
FTL	40	2400	60	15	4400	0.8 - 0.89	3.2 - 3.8
FTL Super	36	3250	90	5	14000	0.8 - 0.89	3.2 - 3.8

In summary, the performance characteristics and efficiencies of common light sources is indicated below:

Comparable Luminous Efficacies (Lumens/watt)

LAMP	Lumens/watt
Tungsten Incandescent	8-33
High Intensity Mercury	24-63
Fluorescent	19-100
Metal Halide	69-125
High Pressure Sodium	73-140

Improvements in lighting efficiency (technically called efficacy) decrease building cooling loads. However, this will also increase the heating load during the heating season. Most large commercial buildings in the south require some cooling year round. A building in the northeast will usually require more heating. Therefore, the geographic location is yet another factor to consider while deciding on the type of lighting.

Some Good Practices in Lighting

Installation of energy efficient fluorescent lamps (T8) in place of conventional fluorescent lamps (T12)

Energy efficient lamps are based on the highly sophisticated tri-phosphor fluorescent powder technology. They offer excellent color rendering properties in addition to the very high luminous efficacy.

Installation of Compact Fluorescent Lamps (CFL's) in place of incandescent lamps

Compact fluorescent lamps are generally considered best for replacement of lower wattage incandescent lamps. These lamps have efficacy ranging from 55 to 65 lumens/watt. The average rated lamp life is 10,000 hours, which is 10 times longer than that of normal incandescent lamps. CFL's are highly suitable for places such as living rooms, hotel lounges, bars, restaurants, pathways, building entrances, corridors, etc.

Installation of metal halide lamps in place of mercury / sodium vapor lamps

Metal halide lamps provide high color rendering index when compared with mercury & sodium vapor lamps. These lamps offer efficient white light. Hence, metal halide is the choice for color critical applications where, higher illumination levels are required. These lamps are highly suitable for applications such as assembly line, inspection areas, painting shops, etc. It is recommended to install metal halide lamps where color rendering is more critical.

Installation of High Pressure Sodium Vapor (HPSV) lamps for applications where color rendering is not critical

High pressure sodium vapor (HPSV) lamps offer more efficacies. But the color rendering property of HPSV is very low. Hence, it is recommended to install HPSV lamps for applications such street lighting, yard lighting, etc.

Installation of high frequency (HF) electronic ballasts in place of conventional ballasts

New high frequency (28-32 kHz) electronic ballasts have the following advantages over the traditional magnetic ballasts:

1) Energy savings up to 35%
2) Less heat dissipation
3) Lights instantly
4) Improved power factor
5) Operates in low voltage load
6) Less in weight
7) Increases the life of lamp

Light Distribution

Energy efficiency cannot be obtained by mere selection of more efficient lamps alone. Efficient luminaires along with the lamp of high efficacy achieve the optimum efficiency. High-performance materials, such as mirror-optic luminaires with a high output ratio and bat-wing light distribution, specular aluminum, improve both fixture output and control. Fixtures and fixture lamps collect dust and dirt which significantly degrades their efficiency. Periodic cleaning is needed to maintain system performance. Air flow through an open fixture reduces dirt accumulation.

For achieving better efficiency, luminaires that are having light distribution characteristics appropriate for the task interior should be selected. The luminaires fitted with a lamp should ensure that discomfort glare and veiling reflections are minimized. Installation of suitable luminaires depends upon the bay height (Low, Medium & High Bay. Luminaires for high intensity discharge lamp are classified as follows:

1. Low bay, for heights less than 15'
2. Medium bay, for heights between 15' -25'
3. High bay, for heights greater than 25'

The installation of luminary is very important.

- When mounting fixtures close to the task or target surface, use those with a wide light distribution that will cover the area
- When mounting fixtures 25' or more away, use those with a narrower light distribution to punch light downwards. These fixtures require special reflectors and are often called "high bays".

System layout and fixing of the luminaires play a major role in achieving energy efficiency. Therefore, fixing the luminaires at optimum height and usage of mirror optic luminaries lead to energy efficiency.

Two terms on luminaries are important:

The coefficient of utilization (CU) is the percentage of lamp lumens that are received on the work plane. The CU is a function of luminary efficiency, room geometry, and room surface reflectances. CU values, found in luminary manufacturer catalog data, are used to evaluate how effectively a luminary delivers light to the work plane in a given space. It is not appropriate to compare luminaires only by CU except for use in the same space.

Spacing criteria (SC) provides information regarding how far apart luminaires may be spaced to maintain uniform lighting. To use the spacing criteria, multiply the net mounting height by the spacing criteria value. The resulting number represents the maximum (center-to-center) distance that the luminaires may be spaced.

Lighting Energy Consumption and Controls

Lighting energy consumption depends on the electrical load and the hours of use. It is therefore affected by the design of a lighting installation to meet the lighting requirements of the space, together with its associated controls, and also its management in operation. The installed load required to satisfy the lighting requirements depends on the efficiency of the equipment: lamps, ballasts, luminaries and the properties of the space (room size and surface reflectances).

The length of time the lighting is in use is determined primarily by the occupancy pattern of the space, and the ability of the occupants to control the lighting. For example switching on lighting only in those areas where it is needed, can have a major influence on energy consumption. The availability of daylight within the space can also affect the use of the lighting. The inclusion of a suitable lighting control system is therefore a major factor in ensuring energy efficiency.

Lighting controls can be used to adjust lighting levels, providing only what is needed when it is needed, and thus save money. The logic is simple: Keep the lights off when nobody is in the room. For example, the typical private office is empty 53 percent of the day, storerooms 56 percent, meeting rooms 66 percent, and restrooms are empty 70 percent of the time. Installing the occupancy sensors can reduce office lighting energy use by 25 to 50%.

Described below are the different types of lighting controls commonly applied.

Local switches: Local switches are those most common in the work place and home, typically located by the entrance of a room. A local switch can be either a simple on/off switch, dimmer or a remote control device which transmits signals to switch or dim the lights.

On-off switching can be provided by single or three- or four-way switches, multi-circuit switching. Multi-circuit switching is accomplished by subdividing the lighting circuits into small areas and providing each area with a switch. The smaller the area covered by a switch the better. One switch should not control too many lights. It is recommended to control lights in groups parallel to windows to maximize day lighting wherever possible.

Time Controls: Time control scheduling is the control strategy employed to adjust lighting according to a predetermined schedule and is best suited for facilities where certain things happen at certain times.

Time clocks are the easiest way to switch lights ‘on and off’ at set times. There are several types, including preset, electromechanical, electronic, and astronomical.

Outside lights could have a combination of light sensor and time switch. This would allow lights to be switched on at dusk but off at midnight. They could then come on again at 6 PM for example and switch off at dawn.

Try setting timers to switch off lights at convenient times during the day when it is expected that either there will be sufficient daylight, or when rooms will be unoccupied such as at lunchtime or set break times. When timers are used to turn off lights in occupied areas, they should have a feature that warns occupants when lights are going to be turned off so occupants can extend the “on” time. Time-activated sweep systems are used to sweep off building lighting sequentially and usually use the components of low-voltage relay systems.

Occupancy Sensors: Occupancy sensors detect an occupant present in the sensor’s ‘line of sight’, which triggers the light to switch on or off, and often has a delayed switch off timer to prevent an area plunging into darkness when an occupant stops moving. Occupancy recognition is the strategy applied to intermittently occupied areas to turn lights on when people are present and automatically turn lights off after the room is unoccupied.

Occupancy sensors: The two principal technologies used for occupancy sensors are passive infrared (PIR) and ultrasonic.

1) ***Infrared or PIR* sensors** react only to body heat and sense occupancy by detecting the difference in heat from a body and the background. A lens creates conical detection zones so PIR sensors use line-of-sight sensing to "see" an area and control it. Infra-red sensors are most sensitive to lateral motion.

2) ***Ultrasonic sensors*** use volumetric detectors and transmit waves above the range of human hearing, then measure the time for the waves to return. Ultrasonic units can detect persons behind obstructions, but are sensitive to common air movements. Ultrasonic sensors are most sensitive to motion toward or away from the sensor.

A delay feature prevents rapid cycling due to air motions. Occupancy sensors are most effectively used in intermittently used rooms, such as warehouses, rest rooms, conference rooms, meeting rooms and corridors. Cost effectiveness of a control device is dependent upon the wattage controlled, and the hours.

Photo-Sensitive Sensors: This type of control responds to light levels at the work area and adjusts these levels accordingly to ensure optimum lighting throughout the day.

Photocells are light-activated switches used to turn off lights when daylight is adequate for safety and task performance. A time clock in conjunction with a photocell prevents outdoor lighting from coming on during the day because of inclement weather.

Lights in parallel to windows should be controlled to allow as many lights as possible to be switched off when sufficient daylight is available. A delay feature prevents rapid cycling during cloudy days.

Control Strategies to Reduce Lighting Power

Dimming, daylight harvesting, and lumen depreciation compensation are the three major control strategies used to reduce lighting energy use. Dimming involves adjusting the light output of luminaires to a specific level.

Dimming: Fluorescent dimming is now accomplished with adjustable light output electronic ballasts that can dim to 5 percent light output for energy-management applications. HID dimming is accomplished by voltage reduction. Two-level control is a common type of HID control that uses relay switching of capacitors in the ballast compartment, resulting in a fixed reduction.

Daylight harvesting: is the control strategy that is applied where daylight can be used effectively for lighting interior spaces. Daylight harvesting systems change the light level gradually according to the daylight level. The strategic application of photo-sensors is the key. Unlike photocells that switch lights based on light level, these silicon sensors gradually increase or decrease the light output of a fluorescent system using dimming ballasts.

Lumen depreciation compensation: is the newest lighting control strategy that employs special photosensors that detect the actual light level and track the lumen depreciation of the lamps. When the lamps are new and surfaces are clean, the output of the dimming ballasts and input power is low, saving energy. Input power and light gradually increase as lamps age and surfaces accumulate dirt to compensate for these depreciation effects.

Microprocessor based controllers: Another method is usage of microprocessor based controllers along with building management systems (BMS). The lighting control can be obtained by using logic units located in the ceiling, which can take pre-program commands and activate specified lighting circuits. Advanced lighting control system uses movement detectors or lighting sensors to feed signals to the controllers.

Standards and Codes

Local building and energy codes govern lighting installations in the US. They are usually based on the National Electric Code. The national Energy Policy Act of 1994 (EPACT), imposes standards on local codes, using ASHRAE-IES 90.1 as a guide. ASHRAE-IES 90.1 is a consensus standard developed by the American Society of Heating, Refrigerating and Air Conditioning Engineers and the Illuminating Engineering Society of North America. It sets the maximum power density (watts/square foot) that can be permitted by state codes (which can be still more stringent) and also establishes minimum requirements for lighting controls.

ANSI-IES RP-1 is the recommended practice for the lighting of offices established by the IESNA and adopted as a national standard by ANSI. ANSI-IES RP-1 is not a mandated code; however, it recommends professional design practice (by the consensus process) and includes specific illuminance and luminance ranges.

Lighting facts

In summary, note certain lighting facts:

1. Compact fluorescent lamps last 10 to 13 times longer than the traditional incandescent light bulb, while consuming 75 percent less energy.
2. Fluorescent lamps produce approximately five times the lumens per watt of standard incandescent lamps.
3. T10 lamps produce 24% more light than a F40-T12 while consuming 3% more energy.
4. T8 lamps with a CRI of 85 produce 7% more light than a conventional F40-T12 while consuming 16% less energy.
5. T8 lamps generally contain 25% less mercury than conventional T12 lamps.
6. The high frequency operation of electronic ballasts increases the efficacy of the lamps by 10 to 12 percent, compared with conventional magnetic ballasts.

7. High pressure sodium lamps produce more than twice the light of similar wattage mercury vapor lamps. High Pressure Sodium systems produce up to 130 lumens per watt.
8. Low pressure sodium lamps are the most energy-efficient of all lamps, producing approximately three times the lumens per watt of mercury vapor lamps. Low Pressure Sodium lighting systems produce up to 183 lumens per watt.
9. At average national electric rates, replacing a 150-watt incandescent lamp with a 35-watt metal halide lamp (drawing a total of 45 watts) would save about $30 a year.
10. Halogen lamps can save 60 watts per lamp in retail situations, while providing better lighting quality than incandescent lamps.
11. Low Pressure Sodium lamps emit a monochromatic light which can be effective as security lighting, roadway lighting and to supplement white light.
12. Increasing light levels can be achieved by utilizing a higher output lamp, upgrading the lens or louver, cleaning the luminaries, or adding reflectors.
13. A facility lit with parabolic luminaires, T8 lamps, and electronic ballasts can be lit at half the watts per square foot normally used in conventional lighting designs.
14. Fixture efficiency can be significantly improved by replacing translucent diffusers or small-cell louvers with clear acrylic lenses or large-cell parabolic louvers.
15. Smooth surfaced, highly reflectant (89%) acoustical ceiling panels can increase the effectiveness of indirect lighting systems and provide lighting energy savings up to 20% compared to conventional ceiling panels.
16. Decreasing light levels can be achieved by delamping, using lower wattage lamps, power reducers, partial output electronic ballasts, and dimming systems.
17. When designing a new installation, the lamp type selected should have as high an efficacy as possible and with characteristics that suit the requirements of the installation (color properties, appearance and rendering, life or service period, etc.)
18. For an existing installation, a change to a more efficient lamp type will reduce energy consumption and therefore cost. Some of these changes involve little or no capital expenditure; others may require the addition of or change of control gear or a change of luminary type and/or position.
19. Lighting quality includes a number of lighting parameters that are highly subjective and not easily quantified, including veiling reflections, glare, color, and flicker. Controlling these parameters effectively is essential to creating lighting that meets

the needs and expectations of people working in a space, making them comfortable and more productive.

20. In general, the light should be brightest on your immediate work area, but should not over-illuminate or you will create too much contrast. Lighting levels should decrease as you move into the general environment of the room.
21. *Each kilowatt hour of lighting requires 3,412 BTUs of air cooling. One ton of air conditioning requires 12,000 BTUs. Every 100 kilowatts removed during a lighting retrofit cuts cooling load by about 28 tons; enough capacity to cool an 8,000 square foot commercial space.*
22. High-efficiency lighting reduces peak wattage demand and usually raises power factor, both of which yield spare capacity on transformers and other parts of a building's electric service.
23. High efficiency lighting contributes to reductions in emissions of pollutants associated with global warming, acid rain and smog.

Lighting "Rules of Thumb"

In the design of lighting for various spaces, some general guidelines should be considered.

1. To see the detail of an object, contrast between the object and its background is necessary.
2. Luminance of surfaces in the area surrounding an object can adversely affect a person’s ability to see surface detail of the object.
3. When a space is to be illuminated directly, the lighting should emphasize the prominent characteristics (module, shape and material) in a consistent and complimentary fashion.
4. To conform with expectations, use light sources of relatively low color temperature at low levels of illumination, and sources of higher color temperature at higher levels of illumination.
5. In general, illuminate continuous elements such as walls evenly or with even gradients so they appear continuous.
6. Because of adaptation and time orientation, the same amount of artificial lighting in interior spaces will appear much brighter at night than during the day.

7. Because of simultaneous contrast and adaptation, objects with identical levels of illumination appear brighter when seen against a darker background.
8. When illumination levels must be low, emphasize potentially dangerous edges in circulation paths by changes in material, the use of color, or definitive shadows.
9. Grazing lighting (lighting at a shallow angle of incidence) always highlights irregularities in the surface upon which it falls.

Summary

The energy consumed by electric lighting in buildings is substantial and represents a significant cost to the owners and occupiers of buildings. Efficient lighting systems aid in productivity, improve the working environment and keep operating costs down. In order to select the right light source for the job, you should consider important performance variables such as light output (lumens), efficiency (lumens/watt – technically referred to as "efficacy"), lamp life, and color rendering properties measured in terms of the color rendering index (CRI).

Start with a lighting audit to evaluate the current lighting systems and assess how well the systems perform compared to state-of-the-art systems. The benchmark is lighting power density (LPD), which is expressed as watts per square foot (watts/ft^2). When assessing the efficiency of a lighting installation, it is essential to consider both installed power and hours of use together. A higher installed load combined with a suitable control system to give low hours of use may result in lower energy consumption than an alternative installation with a lower installed power but poorer control.
Each application is different. Of the thousands of lamps available, fluorescent lamps are the principal light source used in industrial & commercial facilities, due to their versatility and low cost. Metal halide and high pressure sodium lamps are used in high-mounting applications, while incandescent lamps are used more in domestic applications due to very high CRI. Low pressure sodium vapor lamps provide highest efficiency (lumens/watt) but suffer from poor CRI.

In summary a reference lamp characteristic table is shown below:

Type of Lamp	Lumens / Watt		Color Rendering Index	Typical Applications	Typical Life (hours)
	Range	Avg.			
Incandescent	8 - 18	14	Excellent	Homes, restaurants, general lighting, emergency lighting	1000
Fluorescent Lamps	45 - 60	50	Good w.r.t coating	Offices, shops, hospitals, homes	5000
Compact fluorescent Lamps (CFL)	40 - 70	60	Very gooc	Hotels, shops, homes, offices	8000 -10000
High pressure mercury (HPMV)	45 - 57	50	Fair	General lighting, industries, garages, parking areas, flood lighting	5000
Halogen lamps	18 - 24	20	Excellent	Display, flood lighting, stadium exhibition grounds, construction areas	2000-4000
High pressure sodium (HPSV) SON	67 -121	90	Fair	General lighting in factories, warehouses, street lighting	6000-12000
Low pressure sodium (LPSV) SOX	101 - 175	150	Poor	Roadways, tunnels, canals, street lighting	6000 -12000

Readers are advised to consult with a lighting consultant or with manufactures for the most up to date information with respect to product performance and interchangeability of lamps and circuit components in view of the rapid rate of development in the lighting industry.