LIGHTING

1. INTRODUCTION

This section gives a brief background about lighting and the various basic terminology and definitions used in industry with regards to lighting

1.1 Background

From the dawn of civilization until recent times, human beings created light solely from fire, though it is more a source of heat than light. We are still using the same principle in the 21st century to produce light and heat through incandescent lamps. Only in the past few decades have lighting products become much more sophisticated and varied. Estimates indicate that energy consumption by lighting is about 20 - 45% of a commercial building's total energy consumption and about 3 - 10% in an industrial plant's total energy consumption. Most industrial and commercial energy users are aware of energy savings in lighting systems. Often significant energy savings can be realized with a minimal investment of capital and common sense. Replacing mercury vapor or incandescent sources with metal halide or high pressure sodium will generally result in reduced energy costs and increased visibility. Installing and maintaining photo-controls, time clocks, and energy management systems can also achieve extraordinary savings. However, in some cases it may be necessary to consider modifications of the lighting design in order to achieve the desired energy savings. It is important to understand that efficient lamps alone would not ensure efficient lighting systems.

1.2 Basic Theory of Light

Light is just one portion of the various electromagnetic waves flying through space. These waves have both a frequency and a length, the values of which distinguish light from other forms of energy on the electromagnetic spectrum.

Light is emitted from the body due to any of the following phenomena:

- **Incandescence** Solids and liquids emit visible radiation when they are heated to temperatures about 1000K. The intensity increases and the appearance becomes whiter as the temperature increases.
- **Electric Discharge**: When an electric current is passed through a gas the atoms and molecules emit radiation whose spectrum is characteristic of the elements present.
- **Electro luminescence**: Light is generated when electric current is passed through certain solids such as semiconductor or phosphor materials.
- **Photoluminescence:** Radiation at one wavelength is absorbed, usually by a solid, and re-emitted at a different wavelength. When the re-emitted radiation is visible the phenomenon may be termed either *fluorescence* or *phosphorescence*.

Visible light, as can be seen on the electromagnetic spectrum, given in Fig 1, represents a narrow band between ultraviolet light (UV) and infrared energy (heat). These light waves are capable of exciting the eye's retina, which results in a visual sensation called sight. Therefore, seeing requires a functioning eye and visible light.

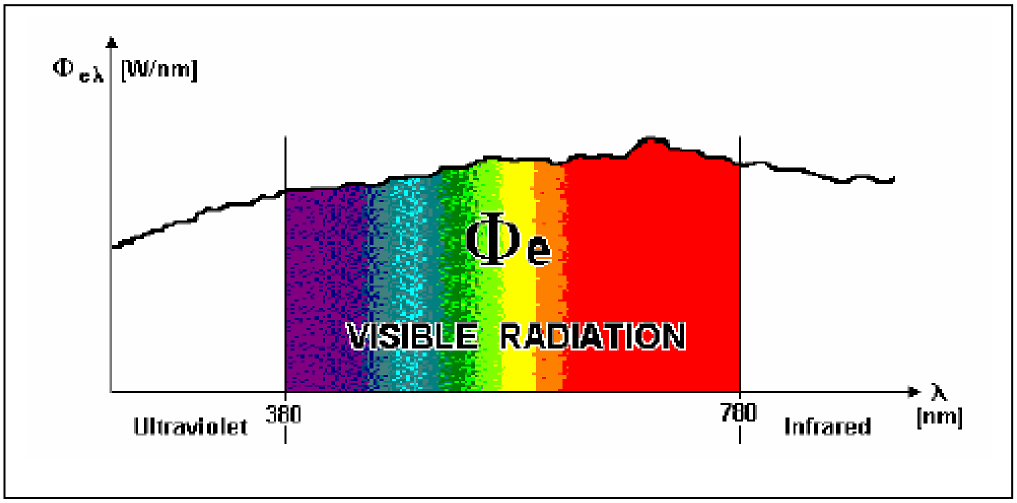


Figure 1. Visible Radiation
(Bureau of Energy Efficiency, 2005)

1.3 Definitions and Commonly Used Terms

Luminaire: A luminaire is a complete lighting unit, consisting of a lamp or lamps together with the parts designed to distribute the light, position and protect the lamps, and connect the lamps to the power supply.

Lumen: Unit of luminous flux; the flux emitted within a unit solid angle by a point source with a uniform luminous intensity of one candela. One lux is one lumen per square meter. The lumen (lm) is the photometric equivalent of the watt, weighted to match the eye response of the "standard observer". 1 watt = 683 lumens at 555 nm wavelength.

Lux: This is the metric unit of measure for illuminance of a surface. Average maintained illuminance is the average of lux levels measured at various points in a defined area. One lux is equal to one lumen per square meter. The difference between the lux and the lumen is that the lux takes into account the area over which the luminous flux is spread. 1000 lumens, concentrated into an area of one square meter, lights up that square meter with an illuminance of 1000 lux. The same 1000 lumens, spread out over ten square meters, produce a dimmer illuminance of only 100 lux.

Luminous Intensity and Flux:
The unit of luminous intensity I is the candela (cd) also known as the international candle. One lumen is equal to the luminous flux, which falls on each square meter (m2) of a sphere one meter (1m) in radius when a 1-candela isotropic light source (one that radiates equally in all directions) is at the center of the sphere. Since the area of a sphere of radius r is $4\pi r^2$, a sphere whose radius is 1m has $4\pi m^2$ of area, and the total luminous flux emitted by a 1- cd source is therefore 4π1m. Thus the luminous flux emitted by an isotropic light source of intensity I is given by:

Luminous flux (lm) = $4\pi \times$ luminous intensity (cd)

Installed Load Efficacy: This is the average maintained illuminance provided on a horizontal working plane per circuit watt with general lighting of an interior expressed in lux/W/m².

Installed Load efficacy ratio: This is the ratio of *target load efficacy* and *installed load.*

Rated luminous efficacy: The ratio of rated lumen output of the lamp and the rated power consumption expressed in lumens per watt.

Room Index: This is a ratio, which relates the plan dimensions of the whole room to the height between the working plane and the plane of the fittings.

Target Load Efficacy: The value of Installed load efficacy considered being achievable under best efficiency, expressed in lux/W/m².

Utilization factor (UF): This is the proportion of the luminous flux emitted by the lamps, reaching the working plane. It is a measure of the effectiveness of the lighting scheme.

The Inverse Square Law
The inverse square law defines the relationship between the luminance from a point source and distance. It states that the intensity of light per unit area is inversely proportional to the square of the distance from the source (essentially the radius).

$$\mathbf{E = I / d^2}$$

Where E = illuminance, I = luminous intensity and d = distance
An alternate form of this equation which is sometimes more convenient is:

$$E1\ d1^2 = E2\ d2^2$$

Distance is measured from the test point to the first luminating surface - the filament of a clear bulb, or the glass envelope of a frosted bulb.

<u>Example:</u> If one measures 10.0 lm/m² from a light bulb at 1.0 meter, what will the flux density be at half the distance?

<u>Solution:</u> $E1m = (d2 / d1)^2 * E2$
$= (1.0 / 0.5)^2 * 10.0$
$= 40$ lm/m²

Color Temperature
Color temperature, expressed on the Kelvin scale (K), is the color appearance of the lamp itself and the light it produces. Imagine a block of steel that is steadily heated until it glows first orange, then yellow and so on until it becomes “white hot.” At any time during the heating, we could measure the temperature of the metal in Kelvin (Celsius + 273) and assign that value to the color being produced. This is the theoretical foundation behind color temperature. For incandescent lamps, the color temperature is a "true" value; for fluorescent and high intensity discharge (HID) lamps, the value is approximate and is therefore called correlated color temperature. In the industry, “color temperature” and “correlated color temperature” are often used interchangeably. The color temperature of lamps makes them visually "warm," "neutral" or "cool" light sources. Generally speaking, the lower the temperature is, the warmer the source, and vice versa.

Color Rendering Index
The ability of a light source to render colors of surfaces accurately can be conveniently quantified by the color-rendering index. This index is based on the accuracy with which a set of test colors is reproduced by the lamp of interest relative to a test lamp, perfect agreement being given a score of 100. The CIE index has some limitations, but is the most widely accepted measure of the color rendering properties of light sources.

Table 1. Applications of color rendering groups (Bureau of Energy Efficiency, 2005)

Color rendering groups	CIE general color rendering Index(R_a)	Typical application
1A	Ra > 90	Wherever accurate color rendering is required e.g. color printing inspection
1B	80 < Ra < 90	Wherever accurate color judgments are necessary or good color rendering is required for reasons of appearance e.g. display lighting
2	60 < Ra < 80	Wherever moderate color rendering is required
3	40 < Ra < 60	Wherever color rendering is of little significance but marked distortion of color is unacceptable
4	20 < Ra < 40	Wherever color rendering is of no importance at all and marked distortion of color is acceptable

A common misconception is that color temperature and color rendering, both describe the same properties of the lamp. Again, color temperature describes the color appearance of the light source and the light emitted from it. Color rendering describes how well the light renders colors in objects.

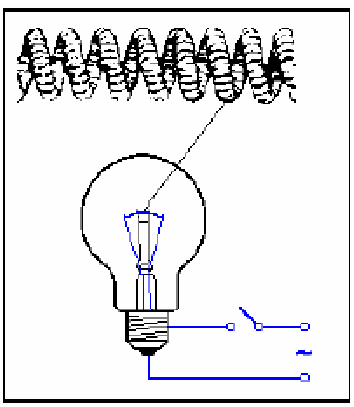
Mounting height: The height of the fixture or lamp above the working plane.

2. TYPES OF LIGHTING SYSTEMS

This section describes the various types and components of lighting systems.

2.1 Incandescent (GLS) Lamps

An incandescent lamp acts as a 'grey body', selectively emitting radiation, with most of it occurring in the visible region. The bulb contains a vacuum or gas filling. Although this stops oxidation of the tungsten filament, it will not stop evaporation. The darkening of bulbs is due to evaporated tungsten condensing on the relatively cool bulb surface. With an inert gas filling, the evaporation will be suppressed, and the heavier the molecular weight, the more successful it will be. For normal lamps an argon nitrogen mixture of ratio 9/1 is used because of its low cost. Krypton or Xenon is only used in specialized applications such as cycle lamps where the small bulb size helps to offset the increased cost, and where performance is critical.
Gas filling can conduct heat away from the filament, so low conductivity is important. Gas filled lamps normally incorporate fuses in the lead wires. A small break can cause an electrical discharge, which can draw very high currents. As filament fracture is the normal end of lamp life it would not be convenient for sub circuits fuses to fail.



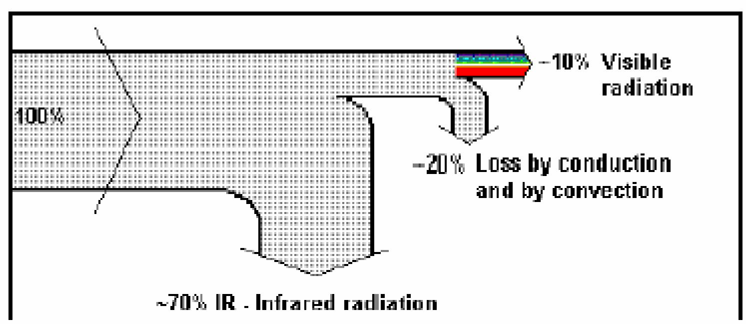


Figure 2. An Incandescent lamp and Energy Flow Diagram of Incandescent Lamp
(Bureau of Energy Efficiency, 2005)

Features
- Efficacy – 12 lumens/Watt
- Color Rendering Index – 1A
- Color Temperature - Warm (2,500K – 2,700K)
- Lamp Life – 1-2,000 hours

2.2 Tungsten--Halogen Lamps

A halogen lamp is a type of incandescent lamp. It has a tungsten filament just like a regular incandescent that you may use in your home, however the bulb is filled with halogen gas. Tungsten atoms evaporate from the hot filament and move toward the cooler wall of the bulb. Tungsten, oxygen and halogen atoms combine at the bulb-wall to form tungsten oxyhalide molecules. The bulb-wall temperature keeps the tungsten oxyhalide molecules in a vapor. The molecules move toward the hot filament where the higher temperature breaks them apart. Tungsten atoms are re-deposited on the cooler regions of the filament–not in the exact places from which they evaporated. Breaks usually occur near the connections between the tungsten filament and its molybdenum lead-in wires where the temperature drops sharply.

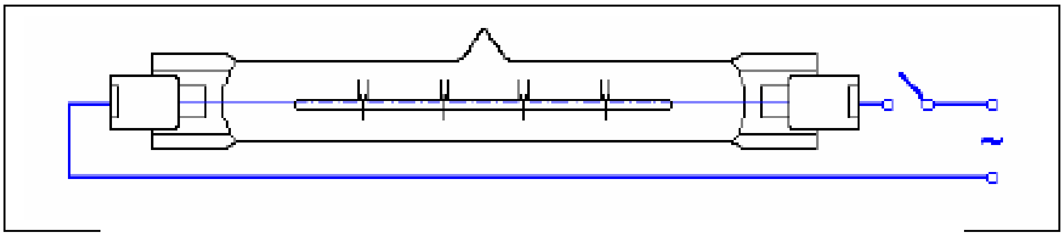


Figure 33 Tungsten halogen Lamps

Features
- Efficacy – 18 lumens/Watt
- Color Rendering Index – 1A
- Color Temperature – Warm (3,000K-3,200K)
- Lamp Life – 2-4,000 hours

Advantages	**Disadvantages**
▪ More compact	▪ Cost more
▪ Longer life	▪ Increased IR
▪ More light	▪ Increased UV
▪ Whiter light (higher color temp.)	▪ Handling problem

2.3 Fluorescent Lamps

2.3.1 Features of fluorescent lamps

Fluorescent Lamps are about 3 to 5 times as efficient as standard incandescent lamps and can last about 10 to 20 times longer. Passing electricity through a gas or metallic vapour will cause electromagnetic radiation at specific wavelengths according to the chemical constitution and the gas pressure. The fluorescent tube has a low pressure of mercury vapour, and will emit a small amount of blue/green radiation, but the majority will be in the UV at 253.7nm and 185nm.

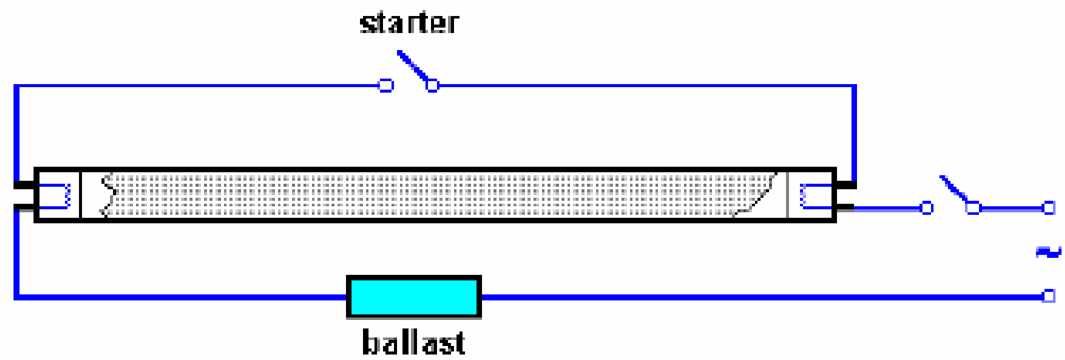


Figure 4a. Fluorescent lamp

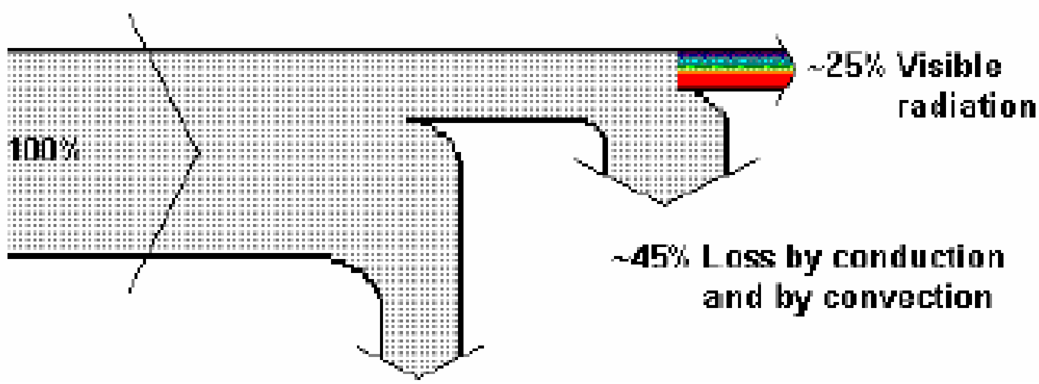


Figure 4b. Energy flow diagram of a fluorescent lamp

The inside of the glass wall has a thin phosphor coating, selected to absorb the UV radiation and transmit it in the visible region. This process is approx. 50% efficient. Fluorescent tubes are 'hot cathode' lamps, since the cathodes are heated as part of the starting process. The cathodes are tungsten filaments with a layer of barium carbonate. When heated, this coating will provide additional electrons to help start the discharge. This emissive coating must not be over-heated, as lamp life will be reduced. The lamps use a soda lime glass, which is a poor transmitter of UV. The amount of mercury is small, typically 12mg. The latest lamps are using a mercury amalgam, which enables doses closer to 5mg. This enables the optimum mercury pressure to be sustained over a wider temperature range. This is useful for exterior lighting as well as compact recessed fittings.

2.3.2 How do T12, T10, T8, and T5 fluorescent lamps differ?

These four lamps vary in diameter (ranging from 1.5 inches, which is 12/8 of an inch for T12 to 0.625 or 5/8 of an inch in diameter for T5 lamps). Efficacy is another area that distinguishes one from another. T5 & T8 lamps offer a 5-per cent increase in efficacy over 40-watt T12 lamps, and have become the most popular choice for new installations.

2.3.3 Effect of temperature

The most efficient lamp operation is achieved when the ambient temperature is between 20 and 30°C for a fluorescent lamp. Lower temperatures cause a reduction in mercury pressure, which means that less ultraviolet energy is produced; therefore, less UV energy is available to act on the phosphor and less light is the result. High temperatures cause a shift in the wavelength of UV produced so that it is nearer to the visual spectrum. The longer wavelengths of UV have less effect on the phosphor, and therefore light output is also reduced. The overall effect is that light output falls off both above and below the optimum ambient temperature range.

Features

Halophosphate

- Efficacy – 80 lumens/Watt (HF gear increases this by 10%)
- Color Rendering Index –2-3
- Color Temperature – Any
- Lamp Life – 7-15,000 hours

Tri-phosphor

- Efficacy – 90 lumens/Watt
- Color Rendering Index –1A-1B
- Color Temperature – Any
- Lamp Life – 7-15,000 hours

2.3.4 Compact fluorescents lamps

The recent compact fluorescent lamps open up a whole new market for fluorescent sources. These lamps permit design of much smaller luminaries, which can compete with incandescent and mercury vapour in the market of lighting fixtures having round or square shapes. Products in the market are available with either built in control gear (CFG) or separate control gear (CFN).

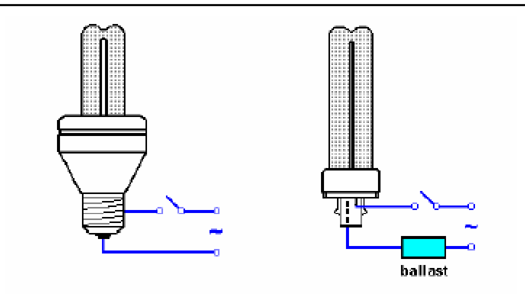


Fig 5 : CFL

Features
Efficacy – 60 lumens/Watt
Color Rendering Index – 1B
Color Temperature – Warm, Intermediate
Lamp Life – 7-10,000 hours

2.4 Sodium Lamps

2.4.1 High pressure sodium lamps

The high pressure sodium (HPS) lamp is widely used for outdoor and industrial applications. Its higher efficacy makes it a better choice than metal halide for these applications, especially when good color rendering is not a priority. HPS lamps differ from mercury and metal-halide lamps in that they do not contain starting electrodes; the ballast circuit includes a high-voltage electronic starter. The arc tube is made of a ceramic material, which can withstand temperatures up to 2372F. It is filled with xenon to help start the arc, as well as a sodium-mercury gas mixture.

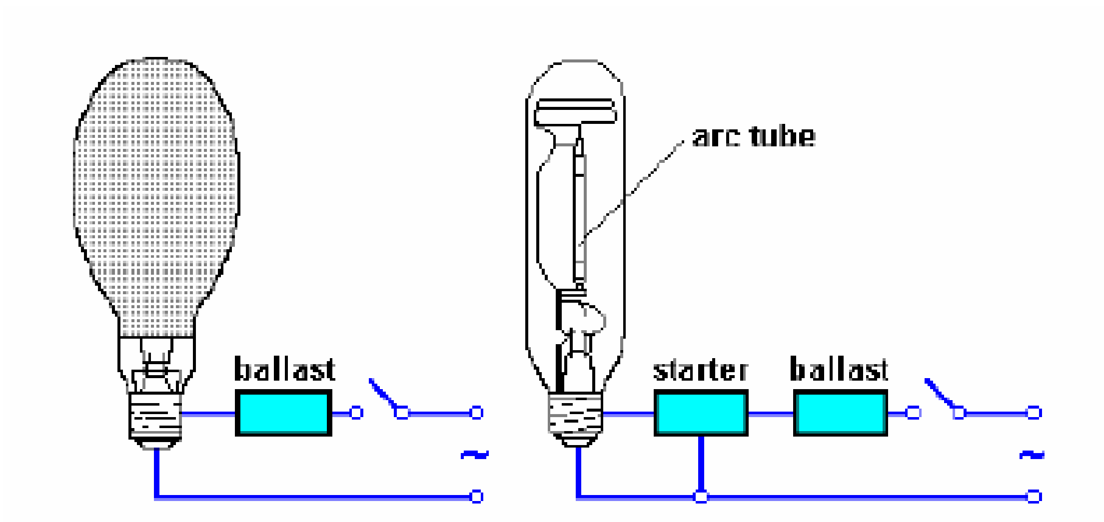
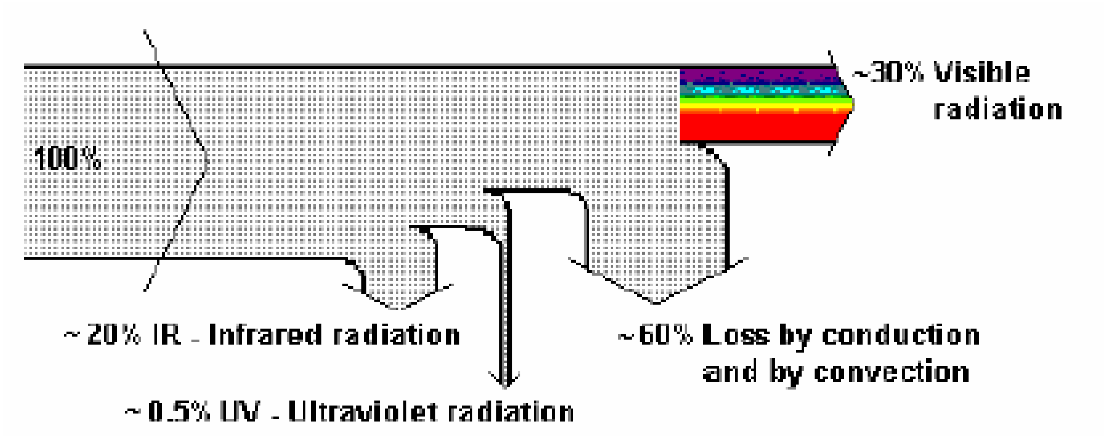


Figure 6. Sodium Vapor Lamp



Energy Flow Diagram of High Pressure Sodium Lamp

Features

- Efficacy – 50 - 90 lumens/Watt (better CRI, lower Efficacy)
- Color Rendering Index – 1 – 2
- Color Temperature – Warm
- Lamp Life – 24,000 hours, excellent lumen maintenance
- Warm up – 10 minutes, hot re-strike – within 60 seconds
- Operating sodium at higher pressures and temperatures makes it highly reactive.
- Contains 1-6 mg sodium and 20mg mercury
- The gas filling is Xenon. Increasing the amount of gas allows the mercury to be reduced, but makes the lamp harder to start
- The arc tube is contained in an outer bulb that has a diffusing layer to reduce glare.
- The higher the pressure, the broader the wavelength band, and the better CRI, lower efficacy.

2.4.2 Low pressure sodium lamps

Although low pressure sodium (LPS) lamps are similar to fluorescent systems (because they are low pressure systems), they are commonly included in the HID family. LPS lamps are the most successful light sources, but they produce the poorest quality light of all the lamp types. Being a monochromatic light source, all colors appear black, white, or shades of gray under an LPS source. LPS lamps are available in wattages ranging from 18-180. LPS lamp use has been generally limited to outdoor applications such as security or street lighting and indoor, low-wattage applications where color quality is not important (e.g. stairwells). However, because the color rendition is so poor, many municipalities do not allow them for roadway lighting.

Features

- Efficacy – 100 – 200 lumens/Watt
- Color Rendering Index – 3
- Color Temperature – Yellow (2,200K)
- Lamp Life – 16,000 hours
- Warm up – 10 minutes, hot re-strike – up to 3 minutes

2.5 Mercury Vapour Lamps

Mercury vapor lamps are the oldest style of HID lamp. Although they have long life and low initial cost, they have poor efficacy (30 to 65 lumens per watt, excluding ballast losses) and exude a pale green color. Perhaps the most important issue concerning mercury vapor lamps is how to best avoid them by using other types of HID or fluorescent sources that have better efficacy and color rendering. Clear mercury vapor lamps, which produce a blue-green light, consist of a mercury-vapor arc tube with tungsten electrodes at both ends. These lamps have the lowest efficacies of the HID family, rapid lumen depreciation, and a low color rendering index. Because of these characteristics, other HID sources have replaced mercury vapor lamps in many applications. However, mercury vapor lamps are still popular sources for landscape illumination because of their 24,000 hour lamp life and vivid portrayal of green landscapes. The arc is contained in an inner bulb called the arc tube. The arc tube is filled with high purity mercury and argon gas. The arc tube is enclosed within the outer bulb, which is filled with nitrogen.

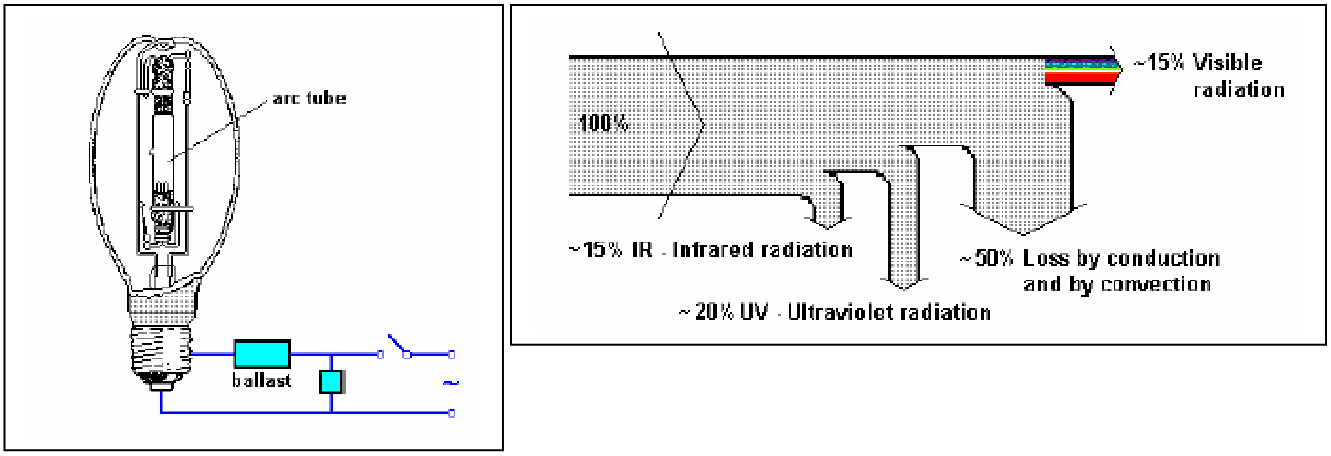


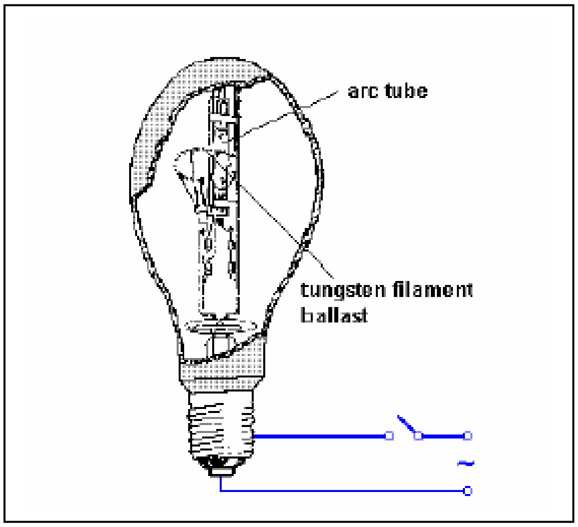
Figure 7. Mercury vapor lamp and its energy flow diagram

Features

- Efficacy – 50 - 60 lumens/Watt (excluded from part L)
- Color Rendering Index – 3
- Color Temperature –Intermediate
- Lamp Life – 16,000 - 24,000 hours, poor lumen maintenance
- Third electrode means control gear is simpler and cheaper to make. Some countries has used MBF for road lighting where the yellow SOX lamp was considered inappropriate
- Arc tube contains 100 mg mercury and argon gas. Envelope is quartz
- No cathode pre-heating; third electrode with shorter gap to initiate discharge
- Outer phosphor coated bulb. It provides additional red light using UV, to correct the blue/green bias of the mercury discharge
- The outer glass envelope prevents UV radiation escaping

2.6 Blended Lamps

Blended lamps are often described as two-in-one lamps. This combines two sources of light enclosed in one gas filled bulb. One source is a quartz mercury discharge tube (like a mercury lamp) and the other is a tungsten filament connected in series to it. This filament acts as a ballast for the discharge tube to stabilize the lam current; hence no other ballast is needed. The tungsten filament coiled in construction encircles the discharge tube and is connected in series with it. The fluorescent powder coating is given on the inside of the bulb wall to convert the emitted ultraviolet rays from the discharge tube to visible light.. At ignition, the lamp emits only light from the tungsten filament, and during the course of about 3 minutes, the arc in the discharge tube runs up to reach full light output. These lamps are suitable for flame proof areas and can fit into incandescent lamp fixtures without any modification.



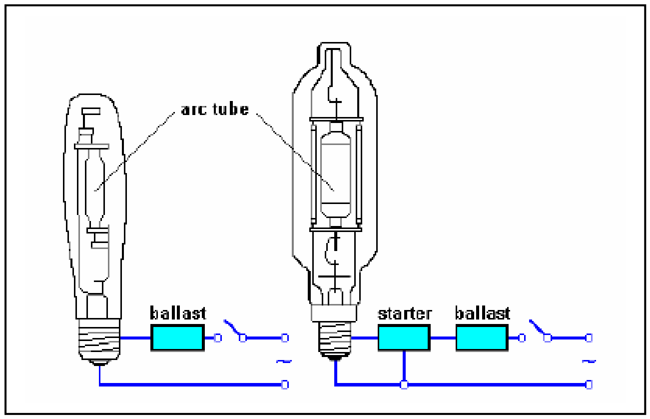
Features
- Typical rating 160 W
- Efficacy of 20 to 30 Lm/W
- High power factor of 0.95
- Life of 8000 hours

Figure 8. Blended lamps

2.7 Metal Halide Lamps

The halides act in a similar manner to the tungsten halogen cycle. As the temperature increases there is disassociation of the halide compound releasing the metal into the arc. The halides prevent the quartz wall getting attacked by the alkali metals.

Features
- Efficacy – 80 lumens/Watt
- Color Rendering Index – 1A –2 depends on halide mix
- Color Temperature – 3,000K – 6,000K
- Lamp Life – 6,000 - 20,000 hours, poor lumen maintenance
- Warm-up – 2-3 minutes, hot re-strike 10-20 minutes
- The choice of color, size and rating is greater for MBI than any other lamp type They are a developed version of the two other high intensity discharge lamps, as they tend to have a better efficacy
- By adding other metals to the mercury different spectrum can be emitted
- Some MBI lamps use a third electrode for starting, but other, especially the smaller display lamps, require a high voltage ignition pulse



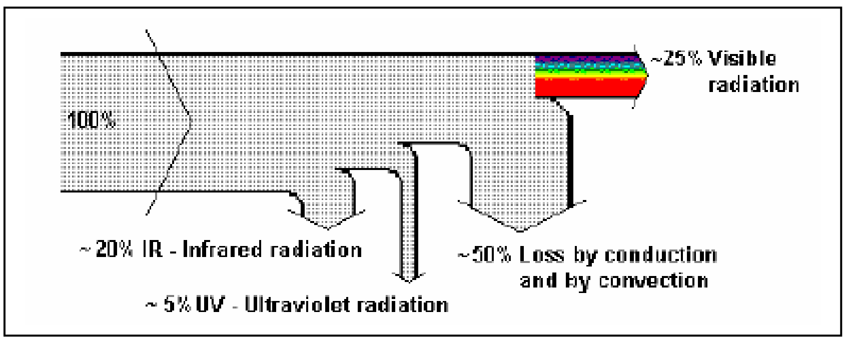


Figure 9. Metal halide lamp and its energy flow diagram

2.8 LED Lamps

LED lamps are the newest addition to the list of energy efficient light sources. While LED lamps emit visible light in a very narrow spectral band, they can produce "white light". This is accomplished with either a red-blue-green array or a phopshor-coated blue LED lamp. LED lamps last from 40,000 to 100,000 hours depending on the color. LED lamps have made their way into numerous lighting applications including exit signs, traffic signals, under-cabinet lights, and various decorative applications. Though still in their infancy, LED lamp technologies are rapidly progressing and show promise for the future. In traffic signal lights, a strong market for LEDs, a red traffic signal head that contains 196 LEDs draws 10W versus its incandescent counterpart that draws 150W. Various estimates of potential energy savings range from 82% to 93%. LED retrofit products, which come in various forms including light bars, panels and screw in LED lamps, typically draw 2-5W per sign, resulting in significant savings versus incandescent lamps with the bonus benefit of much longer life, which in turn reduces maintenance requirements.

2.9 Lighting Components

2.9.1 Luminaries/ Reflectors

The most important element in a light fitting, apart from the lamp(s), is the reflector. Reflectors impact on how much of the lamp's light reaches the area to be lit as well as the lighting distribution pattern. Reflectors are generally either diffuse (painted or powder coated white finish) or specular (polished or mirror-like). The degree of reflectance of the reflector material and the reflector's shape directly influence the effectiveness and efficiency of the fitting. Conventional diffuse reflectors have a reflectance of 70-80% when new. Newer high reflectance or semi-diffuse materials have reflectances as high as 85%. Conventional diffusers absorb much of the light and scatter it rather than reflecting it to the area required. Over time the reflectance values can decline due to the accumulation of dust and dirt as well as yellowing caused by the UV light. Specular reflectors are much more effective in that they maximise optics and specular reflectivity thus allowing more precise control of light and sharper cutoffs. In new-condition they have total reflectance values in the range of 85-96%. These values do not deteriorate as much as they do for conventional reflectors as they age. The most common materials used are anodized aluminium (85-90% reflectance) and silver film laminated to a metal substrate (91-95% reflectance). Enhanced (or coated) aluminium is used to a lesser extent (88-96% reflectance) Since they must remain clean to be effective, mirror optics reflectors should not be used in industrial-type open strip fixtures where they are likely to be covered with dust.

Figure 10. Mirror Optics Luminaire

2.9.2 Gear

The gears used in the lighting equipment are as follows:

- ***Ballast:*** A current limiting device, to counter negative resistance characteristics of any discharge lamps. In case of fluorescent lamps, it aids the initial voltage build-up, required for starting.
- ***Ignitors:*** These are used for starting high intensity Metal Halide and Sodium vapour lamps.

The following Table gives the performance characteristics of the commonly used luminaries:

Table 2. Luminous Performance Characteristics of Commonly Used Luminaries

Type of Lamp	Lum / Watt		Color Rendering Index	Typical Application	Life (Hours)
	Range	Avg.			
Incandescent	8-18	14	Excellent	Homes, restaurants, general lighting, emergency lighting	1000
Fluorescent Lamps	46-60	50	Good w.r.t. coating	Offices, shops, hospitals, homes	5000
Compact fluorescent lamps (CFL)	40-70	60	Very good	Hotels, shops, homes, offices	8000-10000
High pressure mercury (HPMV)	44-57	50	Fair	General lighting in factories, garages, car parking, 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, ware houses, street lighting	6000-12000
Low pressure sodium (LPSV) SOX	101-175	150	Poor	Roadways, tunnels, canals, street lighting	6000-12000

3. ASSESSMENT OF LIGHTING SYSTEMS

This section includes the designing of a lighting system for interiors and also the methodology of a lighting system energy efficiency study. It also gives the recommended values of the illuminance required for various types of work as per the Indian standard.

3.1 Designing of Lighting System

3.1.1 How much light is needed?

Every task requires some lighting level on the surface of the body. Good lighting is essential to perform visual tasks. Better lighting permits people to work with more productivity. Typical book reading can be done with 100 to 200 lux. The question before the designer is hence, firstly, to choose the correct lighting level. CIE (Commission International de l'Eclairage) and IES (Illuminating Engineers Society) have published recommended lighting levels for various tasks. These recommended values have since made their way into national and international standards for lighting design (see Table given below). The second question is about the quality of light. In most contexts, quality is read as color rendering. Depending on the type of task, various light sources can be selected based on their color-rendering index.

Table 3. Illuminance Levels for different Areas of Activity

	Illuminance level (lux)	**Examples of Area of Activity**
General Lighting for rooms and areas used either infrequently and/or casual or simple visual tasks	20	Minimum service illuminance in exterior circulating areas, outdoor stores , stockyards
	50	Exterior walkways & platforms.
	70	Boiler house.
	100	Transformer yards, furnace rooms etc.
	150	Circulation areas in industry, stores and stock rooms.
General lighting for interiors	200	Minimum service illuminance on the task
	300	Medium bench & machine work, general process in chemical and food industries, casual reading and filing activities.
	450	Hangers, inspection, drawing offices, fine bench and machine assembly, color work, critical drawing tasks.
	1500	Very fine bench and machine work, instrument & small precision mechanism assembly; electronic components, gauging & inspection of small intricate parts (may be partly provided by local task lighting)
Additional localized lighting for visually exacting tasks	3000	Minutely detailed and precise work, e.g. very small parts of instruments, watch making, engraving

3.1.2 Lighting design for interiors

The step by step process of lighting design is illustrated below with the help of an example. The following figure shows the parameters of a typical space.

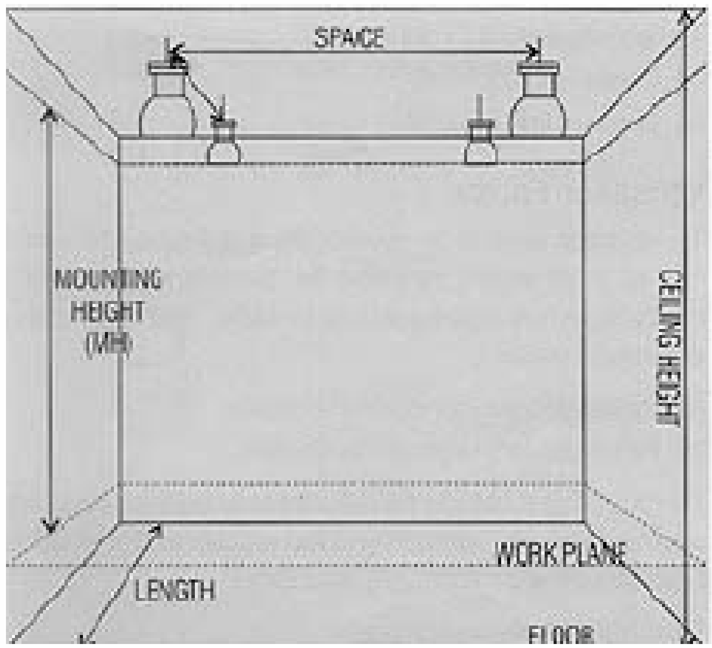


Figure 11. Room with dimensions

Step 1: Decide the required illuminance on work plane, the type of lamp and luminaire

A preliminary assessment must be made of the type of lighting required, a decision most often made as a function of both aesthetics and economics. For normal office work, illuminance of 200 lux is desired.

For an air-conditioned office space under consideration, we choose 36 W fluorescent tube lights with twin tube fittings. The luminaire is porcelain-enamelled, suitable for the above lamp. It is necessary to procure utilisation factor tables for this luminaire from the manufacturer for further calculations.

Step 2: Collect the room data in the format given below

Room dimensions	Length	L1	10	m
	Width	L2	10	m
	Floor area	L3	100	m 2
	Ceiling Height	L4	3.0	m
Surface reflectance	Ceiling	L5	0.7	p.u

	Wall	L6	0.5	p.u
	Floor	L7	0.2	p.u
Work plane height from floor		L8	0.9	m
Luminaire height from floor		L9	2.9	m

Typical reflectance values for using in L5, L6, L7 are:

	Ceiling	**Walls**	**Floor**
Air Conditioned Office	0.7	0.5	0.2
Light Industrial	0.5	0.3	0.1
Heavy Industrial	0.3	0.2	0.1

Step 3: Calculate room index

$$\text{Room Index} = \frac{\text{Length} \times \text{Width}}{\text{Hight} \times (\text{Length} + \text{Width})}$$

= 10 X 10 / [2 *(10 + 10)] = 2.5

Step 4: Calculating the Utilization factor

Utilization factor is defined as the per cent of rated bare-lamp lumens that exit the luminaire and reach the work plane. It accounts for light directly from the luminaire as well as light reflected off the room surfaces. Manufacturers will supply each luminaire with its own CU table derived from a photometric test report. Using tables available from manufacturers, it is possible to determine the utilization factor for different light fittings if the reflectance of both the walls and ceiling is known, the room index has been determined and the type of luminaire is known. For twin tube fixture, utilization factor is 0.66, corresponding to room index of 2.5.

Step 5: Calculate the number of fittings required by applying the following formula:

$$N = \frac{E \times A}{F \times UF \times LLF}$$

Where:
N = Number of fittings
E = Lux level required on working plane
A = Area of room (L x W)
F = Total flux (Lumens) from all the lamps in one fitting
UF = Utilisation factor from the table for the fitting to be used
LLF = Light loss factor. This takes account of the depreciation over time of lamp output and dirt accumulation on the fitting and walls of the building.

LLF = Lamp lumen $_{MF}$ x Luminaire $_{MF}$ x Room surface $_{MF}$

Typical LLF Values

Air Conditioned Office	0.8
Clean Industrial	0.7
Dirty Industrial	0.6

$$N = \frac{200 \times 100}{2 \times 3050 \times 0.66 \times 0.8}$$

= 6.2; So, 6 nos twin tube fixtures are required. Total number of 36-Watt lamps is 12.

Step 6: Space the luminaires to achieve desired uniformity

Every luminaire will have a recommended space to height ratio. In earlier design methodologies, the uniformity ratio, which is the ratio of minimum illuminance to average illuminance was kept at 0.8 and suitable space to height ratio is specified to achieve the uniformity. In modern designs incorporating energy efficiency and task lighting, the emerging concept is to provide a uniformity of 1/3 to 1/10 depending on the tasks. Recommended value for the above luminaire is 1.5. If the actual ratio is more than the recommended values, the uniformity of lighting will be less. For a sample of arrangement of fittings, refer fig 12. The luminaire closer to a wall should be one half of a spacing or less.

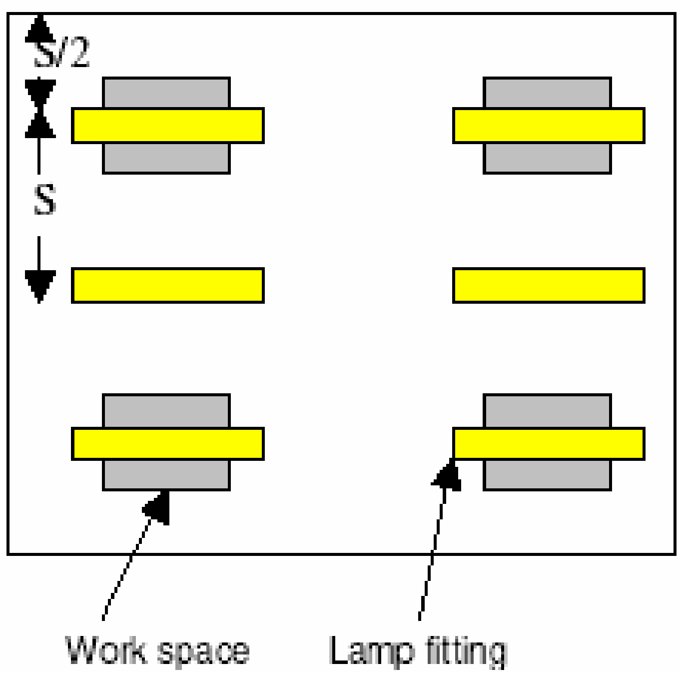


Figure 12. Luminaire spacing

- Spacing between luminaires = 10/3 = 3.33 meters
- Mounting height = 2.0 m
- Space to height ratio = 3.33/2.0 = 1.66
- This is close to the limits specified and hence accepted.

It is better to choose luminaires with larger SHR. This can reduce the number of fittings and connected lighting load.

3.2 Recommended Illuminance Levels For Various Tasks / Activities / Locations

3.2.1 Recommendations on illuminance

Scale of Illuminance: The minimum illuminance for all non-working interiors, has been mentioned as 20 Lux (**as per IS 3646**). A factor of approximately 1.5 represents the smallest significant difference in subjective effect of illuminance. Therefore, the following scale of illuminances is recommended.

20–30–50–75–100–150–200–300–500–750–1000–1500–2000, …Lux

Illuminance ranges: Because circumstances may be significantly different for different interiors used for the same application or for different conditions for the same kind of activity, a range of illuminances is recommended for each type of interior or activity intended of a single value of illuminance. Each range consists of three successive steps of the recommended scale of illuminances. For working interiors the **middle value (R**) of each range represents the recommended service illuminance that would be used unless one or more of the factors mentioned below appllies.

The **higher value (H)** of the range should be used at exceptional cases where low reflectances or contrasts are present in the task, errors are costly to rectify, visual work is critical, accuracy or higher productivity is of great importance and the visual capacity of the worker makes it necessary.

Similarly, **lower value (L)** of the range may be used when reflectances or contrasts are unusually high, speed & accuracy is not important and the task is executed only occasionally.

<u>Recommended Illumination</u>
The following table gives the recommended illuminance range for different tasks and activities. The values are related to the visual requirements of the task, to user's satisfaction, to practical experience and to the need for cost effective use of energy**.**

3. Metal Manufacture & Iron making	
Sinter plant:	
Plant floor	150-200-300
Mixer drum, fan house, screen houses, coolers, transfer stations	100-150-200
Furnaces, cupola:	
General	100-150-200
Control platforms	200-300-500
Conveyor galleries, walkways	30-50-100
Steel Making	
Electric melting shops	150-200-300
Basic oxygen steel making plants	
General	100-150-200
Converter floor, teeming bay	150-200-300
Control platforms	200-300-500
Scrap bays	100-150-200
Metal forming and treatment	
Ingot stripping, soaking pits, annealing and heat treatment bays, acid recovery plant	150-200-300
Pickling and cleaning bays, roughing mills, cold mills finishing mills, tinning and galvanizing lines, cut up and rewind lines	
General	100-150-200
Control platforms	200-300-500
Wire mills, product finishing, steel inspection & treatment	200-300-500
Plate/strip inspection	300-500-700
Foundries	
Automatic plant	
Without manual operation	30-50-100
With occasional manual operation	100-150-200
With continuous manual operation	200-300-500
Control room	200-300-500
Control platforms	200-300-500
Non-automatic plants	
Charging floor, pouring, shaking out, cleaning, grinding fettling	200-300- 500
Rough molding, rough core making	200-300-500
Fine molding, fine core making	300-500-750
Inspection	300-500-750
Forges (severe vibration is likely to occur)	
General	200-300-500
Inspection	300-500-750
4. Ceramics Concrete products	
Mixing, casting, cleaning	150-200-300
Potteries	
Grinding, molding, pressing, cleaning, trimming, glazing, firing	200-300- 500
Enamelling, coloring	500-750-1000

Glass works	
Furnace rooms, bending, annealing	100-150-200
Mixing rooms, forming, cutting, grinding, polising, toughening	200-300-500
Bevelling, decorative cutting, etching, silvering	300-500-750
Inspection	300-500-750
5. Chemicals, petroleum, and chemical and petrochemical works	
Exterior walkways, platforms, stairs and ladders	30-50-100
Exterior pump and valve areas	50-100-150
Pump and compressor houses	100-150-200
Process plant with remote control	30-50-100
Process plant requiring occasional manual intervention	50-100-150
Permanently occupied work stations in process plant	150-200-300
Control rooms for process plant	200-300-500
Pharmaceuticals Manufacturer and Fine chemicals manufacturer	
Pharmaceutical manufacturer	
Grinding, granulating, mixing, drying, tableting, sterilising, washing, preparation of solutions, filling, capping, wrapping, hardening	300-500-750
Fine chemical manufacturers	
Exterior walkways, platforms, stairs and ladders	30-50-100
Process plant	50-100-150
Fine chemical finishing	300-500-750
Inspection	300-500-750
Soap manufacture	
General area	200-300-500
Automatic processes	100-200-300
Control panels	200-300-500
Machines	200-300-500
Paint works	
General	200-300-500
Automatic processes	150-200-300
Control panels	200-300-500
Special batch mixing	500-750-1000
Color matching	750-100-1500
6. Mechanical engineering & Structural steel fabrication	
General	200-300-500
Marking off	300-500-750
Sheet metal works	
Pressing, punching shearing, stamping, spinning, folding	300-500-750
Benchwork, scribing, inspection	500-750-1000
Machine and tool shops	
Rough bench and machine work	200-300-500
Medium bench and machine work	300-500-700
Fine bench and machine work	500-750-1000

Gauge rooms	750-1000-1500
Die sinking shops	
General	300-500-750
Fine work	1000-1500-2000
Welding and soldering shops	
Gas and arc welding, rough spot welding	200-300-500
Medium soldering, brazing, spot welding	300-500-750
Fine soldering, fine spot welding	750-1000-1500
Assembly shops	
Rough work e.g., frame and heavy machine assembly	200-300-500
Medium work, e.g., engine assembly, vehicle body assembly	300-500-750
Fine work, e.g., office machinery assembly	500-750-1000
Very fine work, e.g., instrument assembly	750-1000-1500
Minute work, e.g., watch making	1000-1500-2000
Inspection and testing shops	
Coarse work, e.g., using go/no go gauges, inspection of large sub-assemblies	300-500-750
Medium work, e.g., inspection of painted surfaces	500-750-1000
Fine work, e.g., using calibrated scales, inspection of precision mechanisms	750- 1000-1500
Very fine, e.g., inspection of small intricate parts	1000-1500-2000
Minute work, e.g., inspection of very small instruments	2000
Paints shops and spray booths	
Dipping, rough spraying	200-300-500
Preparation, ordinary painting, spraying and finishing	200-500-750
Fine painting, spraying and finishing	500-750-1000
Inspection, retouching and matching	750-1000-1500
Plating shops	
Vats and baths	200-300-500
Buffing, polishing, burnishing	300-500-750
Final buffing and polishing	500-750-1000
Inspection -	
7. Electrical and electronic engineering, and electrical equipment manufacture	
Manufacture of cables and insulated wires, winding varnishing and immersion of coils, assembly of large machines, simple assembly work	200-300-500
Medium assembly, e.g., telephones, small motors	300-500-750
Assembly of precision components, e.g., telecommunications equipment, adjustment, inspection and calibration	750-1000-1500
Assembly of high precision parts	1000-1500-2000
Electronic equipment manufacture	
Printed circuit board	
Silk screening	300-500-750
Hand insertion of components, soldering	500-750-1000
Inspection	750-1000-1500

Assembly of wiring harness, cleating harness, testing and calibration	500-750- 1000
Chassis assembly	750-1000-1500
Inspection and testing	
Soak test	150-200-300
Safety and functional tests	200-300-500
8. Food, drink, tobacco, and slaughter houses	
General	200-300-500
Inspection	300-500-750
Canning, preserving and freezing	
Grading and sorting of raw materials	500-750-1000
Preparation	300-500-750
Canned and bottled goods	
Retorts	200-300-500
Automatic processes	150-200-300
Labeling and packaging	200-300-500
Frozen foods	
Process area	200-300-500
Packaging and storing	200-300-500
Bottling, brewing and distilling	
Key washing and handling, bottle washing	150-200-300
Key inspection	200-300-500
Bottle inspection	
Process areas	200-300-500
Bottle filling	500-750-1000
Edible oils and fats processing	
Refining and blending	200-300-500
Production	300-500-750
Mills-milling, filtering and packing	200-300-500
Bakeries	
General	200-300-500
Hand decorating, icing	300-500-750
Chocolate and confectionery manufacture General	200-300-500
Automatic processes	150-200-300
Hand decoration, inspection, wrapping and packing	300-500-750
Tobacco processing	
Material preparation, making and packing	300-500-750
Hand processes	500-750-1000
9. Textiles & Fiber preparation	
Bale breaking, washing	200-300-500
Stock dyeing, tinting	200-300-500
Yarn manufacture	
Spinning, roving, winding, etc.	300-500-750
Healding (drawing in)	750-1000-750
Fabric production	
Knitting	300-500-750

Weaving	
Jute and hemp	200-300-500
Heavy woollens	300-500-750
Medium worsteds, fine woollens, cottons	500-750-1000
Fine worsteds, fine linens, synthetics	750-1000-1500
Mending	1000-1500-2000
Inspection	1000-1500-2000
Fabric finishing	
Dyeing	200-300-500
Calendaring, chemical treatment, etc.	300-500-750
Inspection	
Grey cloth	750-1000-1500
Final	1000-1500-2000
Carpet manufacture	
Winding, beaming	200-300-500
Setting pattern, tufting cropping, trimming, fringing, latexing and latex drying	300-500-750
Designing, weaving, mending	500-750-1000
Inspection	
General	750-1000-1500
Piece dyeing	500-750-1000
10. Leather industry & Leather manufacture	
Cleaning, tanning and stretching, vats, cutting, fleshing, stuffing	200-300- 500
Finishing, scarfing	300-500-750
Leather working	
General	200-300-500
Pressing, glazing	300-500-750
Cutting, splitting, scarfing, sewing	500-750-1000
Grading, matching	
11. Clothing, footwear, and clothing manufacture	
Preparation of cloth	200-300-500
Cutting	500-750-1000
Matching	500-750-1000
Sewing	750-1000-1500
Pressing	300-500-750
Inspection	1000-1500-2000
Hand tailoring	1000-1500-2000
Hosiery and knitwear manufacture	
Flat bed knitting machines	300-500-750
Circular knitting machines	500-700-1000
Lockstitch and over locking machine	750-1000-1500
Linking or running on	750-1000-1500
Mending, hand finishing	1000-1500-3000
Inspection	1000-1500-2000
Glove manufacture	

Sorting and grading	500-750-1000
Pressing, knitting, cutting	300-500-750
Sewing	500-750-1000
Inspection	1000-1500-2000
Hat manufacture	
Stiffening, braiding, refining, forming, sizing, pounding, ironing	200- 300-500
Cleaning, flanging, finishing	300-500-750
Sewing	500-750-1000
Inspection	1000-1500-2000
Boot and shoe manufacture	
Leather and synthetics	
Sorting and grading	750-1000-1500
Clicking, closing	750-1000-1500
Preparatory operations	750-1000-1500
Cutting tables and pressure	1000-1500-2000
Button stock preparation, lasting, bottoming finishing, shoe rooms	750-1000- 1500
Rubber	
Washing, compounding, coating, drying, varnishing, vulcanizing, calendaring, cutting	200-300-500
Lining, making and finishing	300-500-750
12. Timber and Furniture Sawmills	
General	150-200-300
Head saw	300-500-750
Grading	500-750-1000
Woodwork shops	
Rough sawing, bench work	200-300-500
Sizing, planning, sanding, medium machining and bench work	300-500-750
Fine bench and machine work, fine sanding, finishing	500-750-1000
Furniture manufacture	
Raw material stores	50-100-150
Finished goods stores	100-150-200
Wooe matching and assembly, rough sawing, cutting	200-300-500
Machining, sanding and assembly, polishing	300-500-750
Tool rooms	300-500-750
Spray booths	
Color finishing	300-500-750
Clear finishing	200-300-500
Cabinet making	
Veneer sorting and grading	750-1000-1500
Marquetry, pressing, patching and fitting	300-500-750
Final inspection	500-750-1000
Upholstery manufacture	
Cloth inspection	1000-1500-2000
Filling, covering	300-500-750
Slipping, cutting, sewing	500-750-1000

Mattress making -	
Assembly	300-500-750
Tape edging	750-1000-1500
13. Paper and Printing Paper mills	
Pulp mills, preparation plants	200-300-500
Paper and board making	
General	200-300-500
Automatic process	150-200-300
Inspection, sorting	300-500-750
Paper converting process	
General	200-300-750
Associated printing	300-500-750
Printing works	
Type foundries	
Matrix making, dressing type, hand and machine coating	200-300-500
Front assembly, sorting	500-750-1000
Composing rooms	
Hand composing, imposition and distribution	500-750-1000
Hot metal keyboard	500-750-1000
Hot metal casting	200-300-500
Photo composing keyboard or setters	300-500-750
Paste up	500-750-1000
Illuminated tables -- general lighting	200-300-500
Proof presses	300-500-750
Proof reading	500-750-1000
Graphic reproduction	
General	300-500-750
Precision proofing, retouching, etching	750-1000-1500
Color reproduction and inspection	750-1000-1500
Printing machine room	
Presses	300-500-750
Premake ready	300-500-750
Printed sheet inspection	750-1000-1500
Binding	
Folding, pasting, punching and stitching	300-500-750
Cutting, assembling, embossing	500-750-1000
14. Plastics & Rubber plastic products	
Automatic plant	
Without manual control	30-50-100
With occasional manual control	50-100-150
With continuous manual control	200-300-500
Control rooms	200-300-500
Control platforms	200-300-500
Non-automatic plant	
Mixing, calendaring, extrusion, injection,	200-300-500

compression and blow moulding, sheet fabrication Trimming, cutting, polishing, cementing	300-500-750
Printing, inspection	750-1000-1500
Rubber production	
Stock preparation -- plasticising, milling	150-200-300
Calendaring, fabric preparation, stock-cutting	300-500-750
Extruding, moulding	300-500-750
Inspection	750-1000-1500

3.3 Methodology of Lighting System Energy Efficiency Study

A step by step approach to assessment of improvement options in lighting at any facility would involve the following likely steps.

Step 1: Inventory the lighting system elements, & transformers in the facility as per following typical format.

Device rating, population and use profile:

S. No.	Plant Location	Lighting Device & Ballast Type	Rating in Watts Lamp & Ballast	Population Numbers	Use / Shifts as I / II / III shifts / Day

Lighting transformer / rating and population profile :

S. No.	Plant Location	Lighting Transformer Rating (kVA)	Numbers Installed	Measurement Provisions Available Volts / Amps / kW/ Energy

In case of distribution boards being available, instead of transformers, fuse ratings may be inventoried along the above pattern in place of transformer kVA.

Step 2: With the aid of a lux meter, measure and document the lux levels at various plant locations at working level, as daytime lux and night time lux values alongside the number of lamps "ON" during measurement.

Step 3: With the aid of portable load analyzer, measure and document the voltage and power consumption at various input points, namely the distribution boards or the lighting voltage transformers at the same as that of the lighting level audit.

Step 4: Compare the measured lux values with the standard. Use the values as a reference and identify locations of under lit and over lit areas.

Step 5: Analyze the failure rates of lamps, ballasts and the actual life expectancy levels from the past data.

Step 6: Based on careful assessment and evaluation, identify improvement options, which could include:

- Maximum sunlight use options through transparent roof sheets, north light roof, etc.
- Replacements of lamps by more energy efficient lamps, with due consideration to luminaire, color rendering index color rendering index and lux level as well as expected life comparison.
- Replacements of ballasts by more energy efficient ballasts, with due consideration to life and power factors apart from watt loss.
- Selecting interior colors for light reflection.
- Modify the layout as per needs.
- Providing individual / group controls for lighting for energy efficiency such as:
- On / off type voltage regulation type (for illuminance control)
- Group control switches / units
- Occupancy sensors
- Photovoltaic controls
- Mechanical timer operated controls
- Pager operated controls
- Computerized lighting control programmes
- Installation of input voltage regulators / controllers for energy efficiency as well as longer life expectancy of lamps where higher voltages, fluctuations are expected.
- Instances of energy efficient displays like LED's in place of lamp type displays in control panels / instrumentation areas, etc.

4. ENERGY EFFICIENCY OPPORTUNITIES

This section gives the various means and ways by which energy could be conserved by applying good lighting practices.

4.1 Use Natural Day Lighting

The utility of using natural day lighting instead of electric lighting during the day is well known, but is being increasingly ignored especially in modern air-conditioned office spaces and commercial establishments like hotels, shopping plazas etc. Industrial plants generally use daylight in some fashion, but improperly designed day lighting systems can result in complaints from personnel or supplementary use of electric lights during daytime. Consider an application that needs an illumination level of 500 lux. To account for losses in reflection and diffusion within the skylight assembly, assume that 40% of the sunlight entering the skylight makes its way into the space. Thus, on a bright day, about 2% of the ceiling area needs to be skylights. To compensate for low sun angles, hazy conditions, dirty skylights, etc., double this to about 4%. To account for average cloudy conditions, increase this to 10% or 15%. Some of the methods to incorporate day lighting are:

- North lighting by use if single-pitched truss of the saw-tooth type is a common industrial practice; this design is suitable for latitudes north of 23 i.e. in North India. In South India, north lighting may not be appropriate unless diffusing glasses are used to cut out the direct sunlight.
- Innovative designs are possible which eliminates the glare of daylight and blend well with the interiors. Glass strips, running continuously across the breadth of the roof at regular intervals, can provide good, uniform lighting on industrial shop floors and storage bays.
- A good design incorporating sky lights with FRP material along with transparent or translucent false ceiling can provide good glare-free lighting; the false ceiling will also cut out the heat that comes with natural light.
- Use of atrium with FRP dome in the basic architecture can eliminate the use of electric lights in passages of tall buildings.
- Natural light from windows should also be used. However, it should be well designed to avoid glare. Light shelves can be used to provide natural light without glare.

Figure 13. Day lighting with poly carbonated sheets

Figure 14. Atrium with FRP dome

4.2 De-lamping to reduce excess lighting

De-lamping is an effective method to reduce lighting energy consumption. In some industries, reducing the mounting height of lamps, providing efficient luminaires and then de-lamping has ensured that the illuminance is hardly affected. De-lamping at empty spaces where active work is not being performed is also a useful concept. There are some issues rated to de-lamping with reference to the connection of lamps and ballasts in a multi-lamp fixture. There are series and parallel-wired ballasts. Most magnetic ballasts are series wired. It is about 50/50, series to parallel when using electronic ballasts. With series wired ballasts, when one lamp is removed from the ballast the other lamp will not light properly and will fail if left running. The non-removed lamp will probably not light or will flicker or produce very little light. So, in a series wired ballast we need to remove all of the lamps from the ballast. The ballast will continue to use energy, 10 to 12 watts for magnetic and 1 to 2 watts for electronic. Parallel wired ballasts can be decamped without too many problems and are often rated by the manufacturer to run one less lamp than the label rating.

4.3 Task Lighting

Task lighting implies providing the required good illuminance only in the actual small area where the task is being performed, while the general illuminance of the shop floor or office is kept at a lower level; e.g. Machine mounted lamps or table lamps. Energy saving takes place because good task lighting can be achieved with low wattage lamps. The concept of task lighting if sensibly implemented, can reduce the number of general lighting fixtures, reduce the wattage of lamps, save considerable energy and provide better illuminance and also provide aesthetically pleasing ambience. In some textile mills, lowering of tube light fixtures has resulted in improved illuminance and also elimination of almost 40% of the fixtures. The dual benefit of lower energy consumption and lower replacement cost has been realized. In some engineering industries, task lighting on machines is provided with CFLs. Even in offices, localised table lighting with CFLs may be preferred instead of providing a large number of fluorescent tube lights of uniform general lighting.

4.4 Selection of High Efficiency Lamps and Luminaries

Details of common types of lamps are summarized below. From this list, it is possible to identify energy saving potential for lamps by replacing with more efficient types.

Table 3. Information on Commonly Used Lamps

Lamp Type	**Lamp Rating in Watts** (Total Power including ballast losses in Watts)	**Efficacy in Lumens/Watt** (including ballast losses, where applicable)	**Color Rendering Index**	**Lamp Life**
General Lighting Service (GLS) (Incandescent bulbs)	15,25,40,60,75,100,150,200, 300,500 (no ballast)	8 to 17	100	1000
Tungsten Halogen (Single ended)	75,100,150,500,1000,2000 (no ballast)	13 to 25	100	2000

Lamp Type	**Lamp Rating in Watts** (Total Power including ballast losses in Watts)	**Efficacy in Lumens/Watt** (including ballast losses, where applicable)	**Color Rendering Index**	**Lamp Life**
Tungsten Halogen (Double ended)	200,300,500,750,1000,1500, 2000 (no ballast)	16 to 23	100	2000
Fluorescent Tube lights (Argon filled)	20,40,65 (32,51,79)	31 to 58	67 to 77	5000
Fluorescent Tube lights (Krypton filled)	18,36,58 (29,46,70)	38 to 64	67 to 77	5000
Compact Fluorescent Lamps (CFLs) (without prismatic envelope)	5, 7, 9,11,18,24,36 (8,12,13,15,28,32,45)	26 to 64	85	8000
Compact Fluorescent Lamps (CFLs) (with prismatic envelope)	9,13,18,25 (9,13,18,25) i.e. rating is inclusive of ballast cons.	48 to 50	85	8000
Mercury Blended Lamps	160 (internal ballast, rating is inclusive of ballast consumption)	18	50	5000
High Pressure Mercury Vapour (HPMV)	80,125,250,400,1000,2000 (93,137,271,424,1040,2085)	38 to 53	45	5000
Metal Halide Lamps (Single ended)	250,400,1000,2000 (268,427,1040,2105)	51 to 79	70	8000
Metal Halide Lamps (Double ended)	70,150,250 (81,170,276)	62 to 72	70	8000
High Pressure Sodium Vapour Lamps (HPSV)	70,150,250,400,1000 (81,170,276,431,1060)	69 to 108	25 to 60	>1200 0
Low Pressure Sodium Vapour Lamps (LPSV)	35,55,135 (48,68,159)	90 to 133		>1200 0

The following examples of lamp replacements are common.

- Installation of metal halide lamps in place of mercury / sodium vapour lamps. Metal halide lamps provide a high color rendering index when compared with mercury & sodium vapour 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 lines, inspection areas, painting shops, etc. It is recommended to install metal halide lamps where color rendering is more critical.
- Installation of High Pressure Sodium Vapour (HPSV) lamps for applications where color rendering is not critical. High pressure sodium vapour (HPSV) lamps offer more efficacy. 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 LED panel indicator lamps in place of filament lamps. Panel indicator lamps are used widely in industries for monitoring, fault indication, signaling, etc.

Conventionally filament lamps are used for the purpose, which has got the following disadvantages:

- High energy consumption (15 W/lamp)
- Failure of lamps is high (Operating life less than 10,000 hours)
- Very sensitive to voltage fluctuations

The LEDs have the following merits over filament lamps.

- Lesser power consumption (Less than 1 W/lamp)
- Withstand high voltage fluctuation in power supply.
- Longer operating life (more than 1,00,000 hours)

It is recommended to install LEDs for panel indicator lamps at the design stage.

The types of lamps used depends on the mounting height, color rendering may also be a guiding factor. The table below summarizes the replacement possibilities with the potential savings.

Table 4. Savings by Use of More Efficient Lamps

Existing Lamp	**Replace by**	**Potential Energy Savings, %**
GLS (Incandescent)	Compact Fluorescent Lamp (CFL)	38 to 75
	High Pressure Mercury Vapour (HPMV)	45 to 54
	Metal Halide	66
	High Pressure Sodium Vapour (HPSV)	66 to 73
Standard Tube light (Argon)	Slim Tube light (Krypton)	9 to 11
Tungsten Halogen	Tube light (Krypton)	31 to 61
	High Pressure Mercury Vapour (HPMV)	54 to 61
	Metal Halide	48 to 73
	High Pressure Sodium Vapour (HPSV)	48 to 84
Mercury Blended Lamp	High Pressure Mercury Vapour (HPMV)	41
High Pressure Mercury Vapour (HPMV)	Metal Halide	37
	High Pressure Sodium Vapour (HPSV)	34 to 57
	Low Pressure Sodium Vapour (LPSV)	62
Metal Halide	High Pressure Sodium Vapour (HPSV)	35
	Low Pressure Sodium Vapour (LPSV)	42
High Pressure Sodium Vapour (HPSV)	Low Pressure Sodium Vapour (LPSV)	42

There may be some limitations if color rendering is an important factor. It may be noted that, in most cases, the luminaires and the control gear would also have to be changed. The savings are large if the lighting scheme is redesigned with higher efficacy lamps and luminaires.

Considerable development work is being done to improve the effectiveness of luminaires. For tube lights in dust-free areas, luminaires with mirror optics may be used in place of the conventional stove enamel painted trough type luminaires or recessed luminaires with acrylic covers. This measure is well accepted and has been implemented in a large number of offices and commercial buildings.

4.5 Reduction of Lighting Feeder Voltage

Figure 15 shows the effect of variation of voltage on light output and power consumption for fluorescent tube lights. Similar variations are observed on other gas discharge lamps like mercury vapour lamps, metal halide lamps and sodium vapour lamps; table below summarizes the effects. Hence, reduction in lighting feeder voltage can save energy, provided the drop in light output is acceptable. In many areas, night time grid voltages are higher than normal; hence reduction in voltage can save energy and also provide the rated light output. Some manufacturers are supplying reactors and transformers as standard products. A large number of industries have used these devices and have reported saving to the tune of 5% to 15%. Industries having a problem of higher night time voltage can get an additional benefit of reduced premature lamp failures.

Table 5. Variation in Light Output and Power Consumption

Particulars	10% lower voltage	10% higher voltage
Fluorescent lamps		
Light output	Decreases by 9 %	Increases by 8 %
Power input	Decreases by 15 %	Increases by 8 1%
HPMV lamps		
Light output	Decreases by 20 %	Increases by 20 %
Power input	Decreases by 16 %	Increases by 17 %
Mercury blended lamps		
Light output	Decreases by 24 %	Increases by 30 %
Power input	Decreases by 20 %	Increases by 20 %
Metal halide lamps		
Light output	Decreases by 30 %	Increases by 30 %
Power input	Decreases by 20 %	Increases by 20 %
HPSV lamps		
Light output	Decreases by 28 %	Increases by 30 %
Power input	Decreases by 20 %	Increases by 26 %
LPSV lamps		
Light output	Decreases by 4 %	Increases by 2 %
Power input	Decreases by 8 %	Increases by 3 %

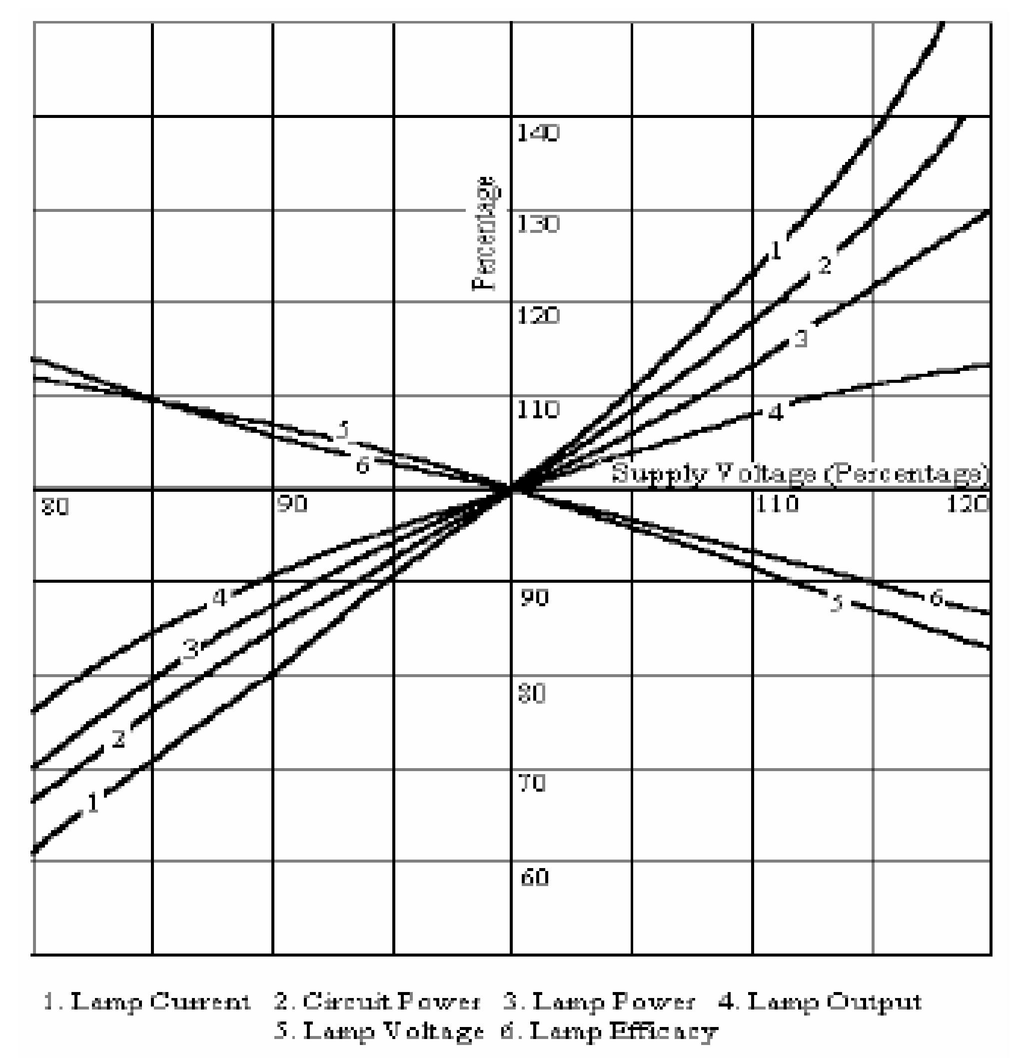


Figure 15. Effect of voltage variation of fluorescent tube light parameters

4.6 Electronic Ballasts instead of electromagnetic ballasts

Conventional electromagnetic ballasts (chokes) are used to provide higher voltage to start the tube light and subsequently limit the current during normal operation. *Electronic ballasts* are oscillators that convert the supply frequency to about 20,000 Hz to 30,000 Hz.

Industries have installed electronic ballasts for tube lights in large numbers. The operation is reliable, provided the ballasts are purchased from established manufacturers. Electronic ballasts have been developed for 20W, 40 W and 65W fluorescent tube lights, 9W & 11W CFLs, 35W LPSV lamps and 70W HPSV lamps. These are now commercially available.

Benefits of using electronic ballasts for fluorescent tube lights instead of electromagnetic ballasts are:

- Reduced power loss: only about 1 Watt, in place of 10 to 15 Watts in standard electromagnetic chokes. Table 6 shows the approximate savings by use of electronic ballasts.
- Improved efficacy of tube lights at higher frequencies, resulting in additional savings if the ballast is optimized to provide the same light output as with the conventional choke. Hence a total saving of about 15 to 20 Watts per tube light can be achieved by electronic ballasts.
- The starter is eliminated and the tube light lights up instantly without flickering.

Table 6. Savings by use of Electronic Ballasts

Type of Lamp	With Conventional Electromagnetic ballast	With Electronic Ballast	Power Savings, Watts
40W Tube light	51	35	16
35W Low Pressure Sodium	48	32	16
70W High Pressure Sodium	81	75	6

4.7 Low Loss Electromagnetic Ballasts for Tube Lights

The loss in standard electromagnetic ballast of a tube light is likely to be 10 to 15 Watts. Use of *low loss electromagnetic chokes* can save about 8 to 10 Watts per tube light. The saving is due to the use of more copper and low loss steel laminations in the choke, leading to lower losses. A number of industries have implemented this measure

4.8 Timers, Twilight Switches & Occupancy Sensors

Automatic control for switching off unnecessary lights can lead to good energy savings. Simple timers or programmable timers can be used for this purpose. The timings may have to change, once in about two months, depending upon the season. Use of timers is a very reliable method of control.

Twilight switches can be used to switch the lighting depending on the availability of daylight. Care should be taken to ensure that the sensor is installed in a place, which is free from shadows, light beams of vehicles and interference from birds. Dimmers can also be used in association with photo-control; however, electronic dimmers normally available in India are suitable only for dimming incandescent lamps. Dimming of fluorescent tube lights is possible, if these are operated with electronic ballasts; these can be dimmed using motorized autotransformers or electronic dimmers (suitable for dimming fluorescent lamps; presently, these have to be imported).

Infrared and *Ultrasonic occupancy sensors* can be used to control lighting in cabins as well as in large offices. Simple infrared occupancy sensors are now available in India. However ultrasonic occupancy sensors have to be imported. It may be noted that more sophisticated occupancy sensors used abroad have a combination of both infrared and ultrasonic detection; these sensors incorporate a microprocessor in each unit that continuously monitors the sensors, adjusting the sensitivity levels to optimize performance. The microprocessor is programmed to memorize the static and changing features of its environment; this ensures that the signals received from repetitive heat and motion equipment like fans is filtered out.

In developed countries, the concept of tube light fixtures with in-built electronic ballast, photo-controlled dimmer and occupancy sensor is being promoted as a package. The following control methodologies are useful.

General areas

- Where day lighting is available, provide day lighting controls. Use continuous dimming for spaces with minor motion activity such as reading, writing, and conferencing. Use stepped dimming (on/off switching) for spaces with major motion activity such as walking and shelf stocking.
- Always mount ultrasonic occupancy sensors at least 6 to 8 ft. away from HVAC ducts on vibration free surfaces and place so there is no detection out the door or opening of the space.
- In spaces of high occupant ownership such as private offices and conference rooms, always include switches for manual override control of the lighting.
- If there is concern that lighting could be turned off automatically or manually when people are still in the space, put in night lighting for safe egress.
- Many lighting control devices have specific voltage and load ratings requirements. Be sure to specify the device model that matches the correct voltage and load rating for the application.

Conference Rooms

- Use dual technology occupancy sensors in larger conference rooms for optimal detection of both small hand motion and larger body movement.
- Ceiling or corner-mounted passive infrared occupancy sensors are used for medium and small conference rooms.
- Always include switches that provide manual override control of the lighting.

Cubicles

- Control plug loads such as task lighting, computer monitors, portable fans and heaters with an occupancy sensor controlled plug strip.
- Mount a personal occupancy sensor beneath binder bin or desk and position so that it cannot detect motion outside the cubicle area.

Restrooms

- Use ceiling mounted ultrasonic sensors for restrooms with stalls.

Exterior Lighting Control

- Use a lighting control panel with time clock and photocell to control exterior lighting to turn on at dusk and off at dawn and turn non-security lighting off earlier in the evening for energy savings.

4.9 T5 Fluorescent Tube Light

The fluorescent tube lights in use presently in India are of the T12 (40W) and T8 (36W). T12 implies that the tube diameter is 12/8” (33.8mm), T8 implies diameter of 8/8” (26mm) and T5 implies diameter of 5/8” (16mm). This means that the T5 lamp is slimmer than the 36W slim tube light. These lamps are available abroad in ratings of 14W, 21W, 28W and 35W.

The efficiency of the 35W T5 lamp is about 104 lm/W (lamp only) and 95 lm/W (with electronic ballasts), while that of the 36W T8 lamp is about 100 lm/W (lamp only) and 89 lm/W (with electronic ballast). This may appear to be a small improvement of about 7%, but with the use of super-reflective aluminum luminaire of higher efficiency, T5 lamps can effect an overall efficiency improvement ranging from 11% to 30%.

T5 lamps have a coating on the inside of the glass wall that stops mercury from being absorbed into the glass and the phosphors. This drastically reduces the need for mercury from about 15 milligrams to 3 milligrams per lamp. This may be advantageous in countries with strict waste disposal laws.

However, these lamps are about 50mm shorter in length than T12 and T8 lamps, which implies that the existing luminaires cannot be used. In addition, T5 lamp can be operated only with electronic ballast.

In Europe, the T5 lamps are being used in good numbers in place of 4 foot, 36W T8 lamps. Their shorter lengths permit integration in standard building modules. With new miniature ballasts, luminaires are light and flat, saving space and also resources used for their production. The USA has been slow in accepting this technology, as the 4 foot, T8 lamps consume only about 35 Watts. The focus in the USA has generally been on better optic control, rather than on lamp efficiency.

4.10 Lighting Maintenance

Maintenance is vital to lighting efficiency. Light levels decrease over time because of aging lamps and dirt on fixtures, lamps and room surfaces. Together, these factors can reduce total illumination by 50 percent or more, while lights continue drawing full power. The following basic maintenance suggestions can help prevent this.

- Clean fixtures, lamps and lenses every 6 to 24 months by wiping off the dust.
- Replace lenses if they appear yellow.
- Clean or repaint small rooms every year and larger rooms every 2 to 3 years. Dirt collects on surfaces, which reduces the amount of light they reflect.
- Consider group re-lamping. Common lamps, especially incandescent and fluorescent lamps, lose 20 per cent to 30 per cent of their light output over their service life. Many lighting experts recommend replacing all the lamps in a lighting system at once. This saves labor, keeps illumination high and avoids stressing any ballasts with dying lamps.

5. OPTION CHECK LIST

This section includes the most important energy efficiency options

- Reduce excessive illumination levels to standard levels using switching, delamping, etc. (Know the electrical effects before doing delamping.)
- Aggressively control lighting with clock timers, delay timers, photocells, and/or occupancy sensors.
- Install efficient alternatives to incandescent lighting, mercury vapor lighting, etc. Efficiency (lumens/watt) of various technologies range from best to worst approximately as follows: low pressure sodium, high pressure sodium, metal halide, fluorescent, mercury vapor, incandescent.
- Select ballasts and lamps carefully with high power factor and long-term efficiency in mind. obsolete fluorescent systems to Compact fluorescents and electronic ballasts
- Consider lowering the fixtures to enable using less of them.
- Consider day lighting, skylights, etc.
- Consider painting the walls a lighter color and using less lighting fixtures or lower wattages.
- Use task lighting and reduce background illumination.
- Re-evaluate exterior lighting strategy, type, and control. Control it aggressively.
- Change exit signs from incandescent to LED.

6. WORKSHEETS

This module does not have any worksheets separately. The work tables for conducting energy audits are explained in the section on the methodology to conduct a "Lighting System Energy Efficiency Study".

7. REFERENCES

This module is largely adapted from the "Best Practice Manual – Lighting" published by the Bureau of Energy Efficiency, Ministry of Power, India, in 2005. www.bee-india.nic.in. UNEP would like to thank the BEE for the kind permission to make use of its information for this Guide.

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- GE lighting, USA
- Watt Stopper Inc, USA
- Vergola India Ltd
- Lighting reasearch centre, USA
- LBNL , USA

Disclaimer:

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