8. LIGHTING SYSTEM

Light Source, T5, T8, T12 Definitions, CFL, LEDs, Metal Halides, Choice of Lighting, Luminance Requirements and Energy Conservation Avenues, Electronic Ballast, Energy Efficient Lighting Controls, Occupancy Sensors, High Efficiency Street Lighting, Labeling Scheme.

8.1 Introduction

Most natural light comes from the sun, including moon light. Its origin makes it completely clean and it consumes no natural resources. But man-made sources generally require consumption of resources, such as fossil fuels, to convert stored energy into light energy.

Light is usually described as the type of electromagnetic radiation that has a wavelength visible to the human eye, roughly 400 to 700 nanometers. Light exists as tiny "packets" called photons and exhibits the properties of both particles and waves. Visible light, as can be seen on the electromagnetic spectrum, as given in Figure 8.1, 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.

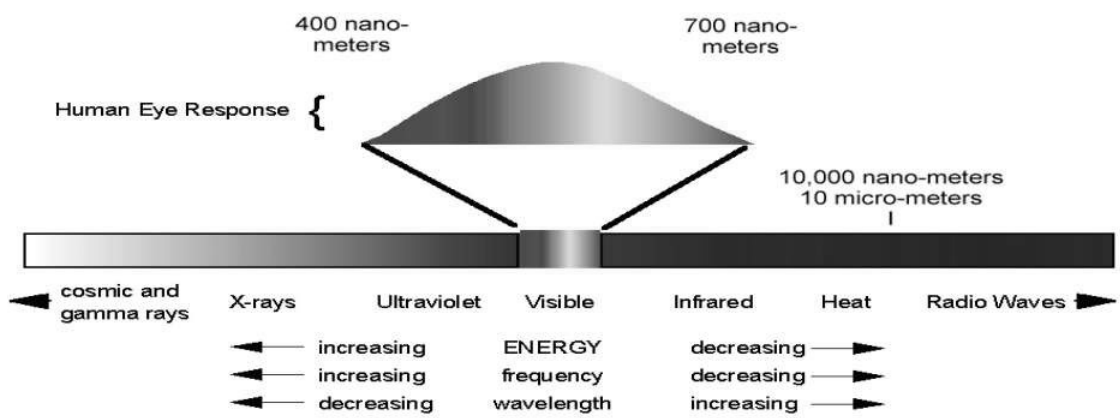


Figure 8.1 Visible Radiation

The lumen (lm) is the photometric equivalent of the Watt, weighted to match the eye response of the "standard observer". Yellowish-green light receives the greatest weight because it stimulates the eye more than blue or red light of equal radiometric power:

1 Watt = 683 lumens at 555 nm wavelength

The best eye sensitivity, as seen from Figure 8.2 is at 555 nm wavelength having greenish yellow colour with a luminous efficacy of 683 lm/Watt.

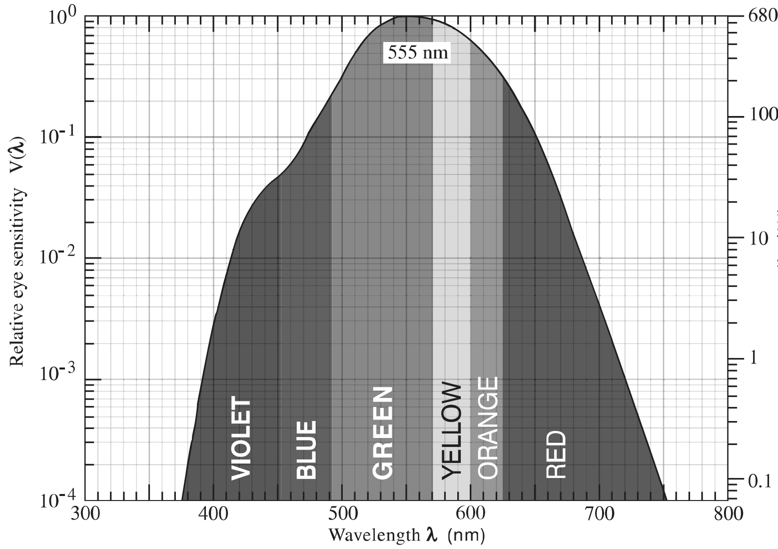


Figure 8.2 Relative Eye Sensitivity and Luminous Efficacy

Three primary considerations to ensure energy efficiency in lighting systems are:

i. Selection of the most efficient light source possible in order to minimize electricity consumption and cost.

ii. Matching the proper lamp type to the intended work task or aesthetic application, consistent with color, brightness control and other requirements.

iii. Establishing adequate light levels without compromising productivity improve security and increase safety.

8.2 Basic Parameters and Terms in Lighting System

Luminous flux: The luminous flux describes the quantity of light emitted by a light source. It is a measure of a lamp's economic efficiency.

The most common measurement or unit of luminous flux is the **lumen (lm)**. The lumen rating of a lamp is a measure of the total light output of the lamp. Light sources are labeled with an output rating in lumens.

Illuminance (E): is the quotient of the luminous flux incident on an element of the surface at a point of surface containing the point, by the area of that element.

The lighting level produced by a lighting installation is usually qualified by the illuminance produced on a specified plane. In most cases, this plane is the major plane of the tasks carried out in the interior and is commonly called the working plane. The illuminance provided by an installation affects both the performance of the tasks and the appearance of the space. **Lux (lx) is** the metric unit of measure for illuminance of a surface. One lux is equal to one lumen per square meter. Illuminance decreases by the square of the distance (inverse square law).

The inverse square law defines the relationship between the illuminance 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).

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

Where, E = Illuminance in lux (lm/m^2), I = Luminous flux in lumen (lm) and d = distance in m

An alternate form of this equation which is sometimes more convenient is:

$$E_1 d_1^2 = E_2 d_2^2$$

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.

Example:

The illuminance is 10 lm/m^2 from a lamp at 1 meter distance. What will be the illuminance at half the distance?

Solution:

$$E_{(1m)} = (d_2 / d_1)^2 * E_2$$
$$= (1.0 / 0.5)^2 * 10.0$$
$$= 40\ lm/m^2$$

Average maintained illuminance: is the average of illuminance (lux) levels measured at various points in a defined area.

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

Luminous Efficacy (lm/W): is the ratio of luminous flux emitted by a lamp to the power consumed by the lamp. It is a reflection of efficiency of energy conversion from electricity to light form. **Unit: lumens per lamp Watt (lm/W).**

Lamp Circuit Efficacy: 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. This is a more meaningful measure for those lamps that require control gear. **Unit: lumens per circuit Watt (lm/W).**

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 metre ($lux/W/m^2$).**

Installed Power Density: The installed power density per 100 lux is the power needed per square metre 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 metre per 100 lux ($W/m^2/100$ lux)**

Color rendering index (CRI): is a measure of the effect of light on the perceived color of objects. To determine the CRI of a lamp, the color appearances of a set of standard color chips are measured with special equipment under a reference light source with the same correlated color temperature as the lamp being evaluated. If the lamp renders the color of the chips identical to the reference light source, its CRI is 100. If the color rendering differs from the reference light source, the CRI is less than 100. A low CRI indicates that some colors may appear unnatural when illuminated by the lamp.

Luminaire: is a device that distributes filters or transforms the light emitted from one or more lamps. The luminaire includes all the parts necessary for fixing and protecting the lamps, except the lamps themselves. In some cases, luminaires also include the necessary circuit auxiliaries, together with the means for connecting them to the electric supply. The basic physical principles used in optical luminaire are reflection, absorption, transmission and refraction.

Control gear: The gears used in the lighting equipment are as follows:

- **Ballast** is 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. In an electric circuit the ballast acts as a stabilizer. Fluorescent lamp is basically an electric discharge lamp with two electrodes separated inside a tube with no apparent connection between them. When sufficient voltage is impressed on these electrodes, electrons are driven from one electrode and attracted to the other. The current flow takes place through an atmosphere of low-pressure mercury vapour.
- Since the fluorescent lamps cannot produce light by direct connection to the power source, they need an ancillary circuit and device to get started and remain illuminated. The auxiliary circuit housed in a casing is known as ballast.
- **Ignitors** are used for starting high intensity discharge lamps such as metal halide and sodium vapour lamps. Ignitors generate a high voltage pulse or a series of pulses to initiate the discharge.

8.3 Light Source and Lamp Types

Lamp is equipment, which produces light. Light is that part of the electromagnetic spectrum that is perceived by our eyes. A number of light sources are available, each with its own unique combination of operating characteristics viz., efficacy, colour, lamp life, and the percent of output that a lamp loses over its life.

Based on the construction and operating characteristics, the lamps can be categorized into three groups: incandescent, fluorescent and high intensity discharge (HID) lamps. HID lamps can be further classified as sodium vapour, mercury vapour and metal halide lamps. The most commonly used lamps are described briefly as follows:

1) Incandescent lamp

The principal parts of an incandescent lamp also known as GLS lamp (General Lighting Service lamp) include the filament, the bulb, the fill gas or vacuum and the cap. Incandescent lamps (Figure 8.3 A&B) produce light by means of a wire or filament heated to incandescence by the flow of electric current through it. The filament is enclosed in an evacuated glass bulb filled with inert gas such as argon, krypton, or nitrogen that helps to increase the brilliance of lamp and to prevent the filament from burning out.

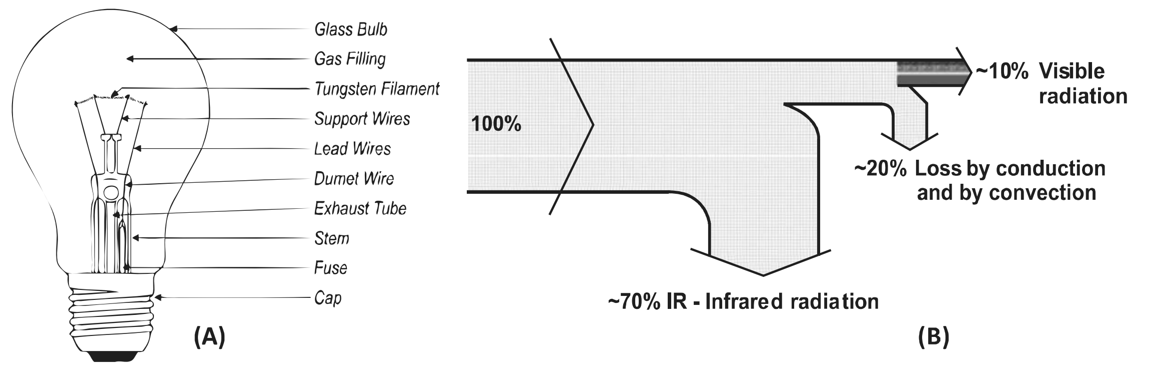


Figure 8.3 Incandescent Lamp and Energy Flow Diagram

Reflector lamps: Reflector lamps are basically incandescent, provided with a high quality internal mirror, which follows exactly the parabolic shape of the lamp. The reflector is resistant to corrosion, thus making the lamp maintenance free and output efficient.

2) Halogen lamp

It has a tungsten filament and the bulb filled with halogen gas (Figure 8.4). Current flows through the filament and heats it up, as in incandescent lamps. These lamps therefore generate a relatively large amount of heat. The use of halogen increases the efficiency and extends the service life compared with traditional incandescent lamps. Low-voltage types are very small and are ideal for precise direction of light, but they require a transformer.

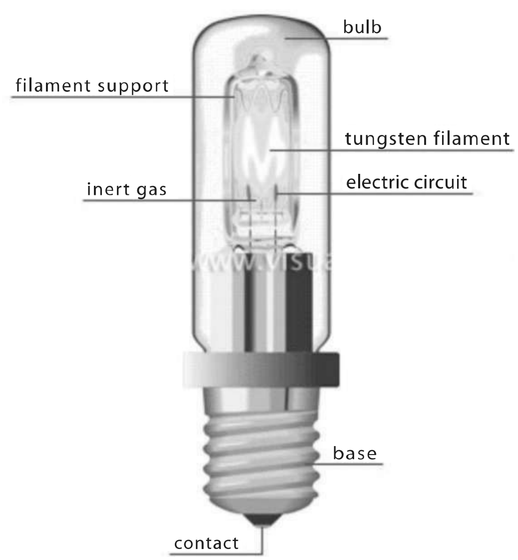


Figure 8.4 Halogen Lamp

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.

3) Fluorescent tube lamp (FTL)

It works by the fluorescence principle. A fluorescent lamp (Figure 8.5 A&B) is a glass tube containing a small trace of a gas such as mercury vapor (for a white color), carbon dioxide (for green), neon (for red color), etc., with a special fluorescent / phosphorescent coating on the interior surface of the tube. It contains two filaments, one at each end of the tube and when the electrical supply is switched ON, the contacts of the starter open and the filaments glow to heat up the gas contained inside the tube.

This action provides a voltage across its electrodes that set off an electric (gaseous mercury) arc discharge in the tube. This generates invisible UV radiation that is high enough to ionise the warmed-up gas inside the tube. This ionised gas also called as "plasma", excites the fluorescent coating so that it gives out visible light. Ballast is needed to start and operate fluorescent lamps, because of the characteristics of a gaseous arc. The luminous flux is highly dependent on the ambient temperature. Fluorescent Lamps are about 3 to 5 times as efficient as standard incandescent lamps and can last about 10 to 20 times longer.

The different types of fluorescent lamps and their reference are given below:

Linear tubes

- T12 - 38 mm (1.5"diameter)
- T8 - 25 mm (1"diameter)
- T5 - 16mm (5/8"diameter)
- T2 - 6 mm (1/4"diameter)

U-bent tubes

- T12- 38 mm (1.5"diameter)
- T8 - 25 mm (1" diameter)

Circular tubes

- T9 - 38 mm (1.5"diameter)
- T5 - 16 mm (5/8"diameter)

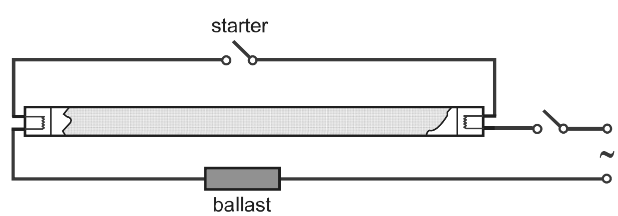


Figure 8.5 (A) Fluorescent Tube Lamp

These four lamps vary in diameter (ranging from 1.5 inches that 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-percent increase in efficacy over 40-watt T12 lamps, and have become the most popular choice for new installations.

4) Compact fluorescent lamp (CFL)

Compact Fluorescent lamps (Figure 8.6) are compact / miniature versions of the linear or circular fluorescent lamps and operate in a very similar way. The luminous flux depends on temperature. CFL's use less power and have a longer rated life compared to an incandescent lamp.

Figure 8.6 Compact Fluorescent Lamp

They are designed to replace an incandescent lamp and can fit into most existing light fixtures formerly used for incandescent. CFL's are available in screw type/ pin type which fit into standard sockets, and gives off light that is similar to common fluorescent lamps.

5) Sodium vapour lamp

Low pressure sodium vapour lamp

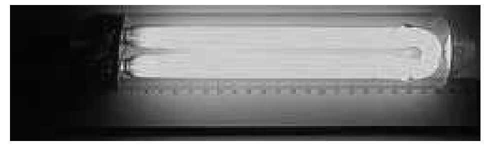


Figure 8.7 Low Pressure Sodium Vapour Lamp

Although low pressure sodium vapour (LPSV) lamps (Figure 8.7) are similar to fluorescent systems (because they are low pressure systems), they are commonly included in the HID family. LPSV lamps are the most efficacious light sources, but they produce the poorest quality light of all the lamp types. Being a monochromatic light source, all colours appear black, white, or shades of gray under an LPSV source. LPSV lamps are available in wattages ranging from 18-180.

LPSV 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.

High pressure sodium vapour lamp

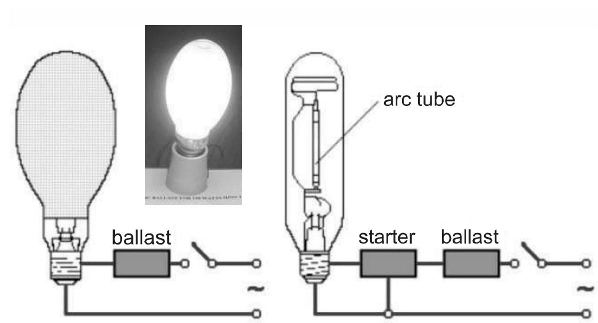


Figure 8.8 (A) High Pressure Sodium Vapour Lamp

The high pressure sodium vapour (HPSV) lamp (Figure 8.8 A&B) is widely used for outdoor and industrial applications as the light is yellowish. Its higher efficacy makes it a better choice than metal halide for these applications, especially when good color rendering is not a priority. HPSV 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 1300 ^{o}C. It is filled with xenon to help start the arc, as well as a sodium-mercury gas mixture.

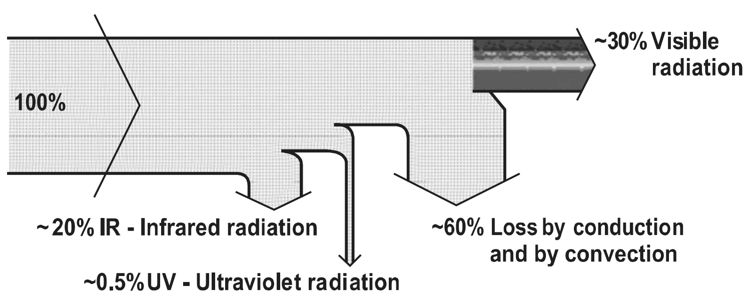


Figure 8.8 (B) Energy Flow diagram of High Pressure Sodium Vapour Lamp

6) Mercury vapour lamp

In a mercury vapour lamp (Figure 8.9) electromagnetic radiation is created from discharge within mercury vapour, but the regime is different than that found in the normal fluorescent lamp. During operation, the pressure within the lamp is in the range of 200 – 400 kPa (compared with only 1 Pa). It is not possible to achieve the mercury vapour discharge in a cold lamp. For this reason, the lamp also includes argon, and the initial arc is struck as an argon arc. The energy from this discharge vapourises the mercury to get the main discharge going.

The mercury vapour lamp produces a much greater proportion of visible light than fluorescent lamp and gives off a bluish white light. Phosphor coating can be given to improve the colour rendering index.

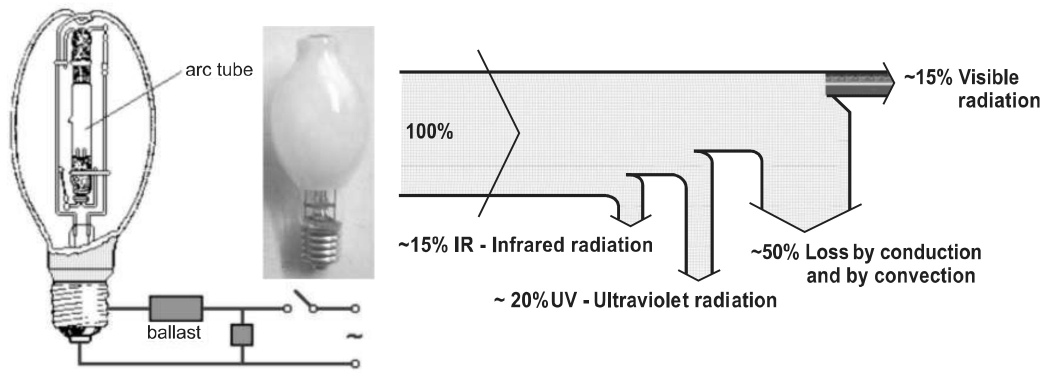


Figure 8.9 Mercury Vapour Lamp and Energy Flow Diagram

7) Metal halide lamp:

Metal halide lamp (Figure 8.10 A&B) can be considered as a variant of high pressure mercury vapour lamp (HPMV). In addition to mercury vapour and argon, this lamp contains metal halide. The halides can be a mixture of rare earth halides, usually iodides or a mixture of sodium and scandium iodide. The mercury vapour radiation is augmented by that of the metals.

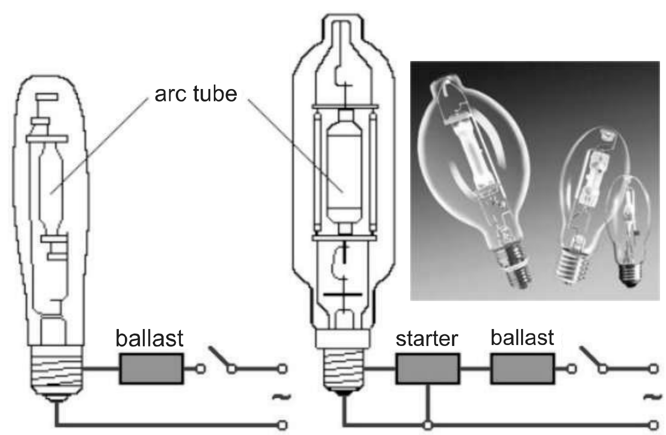


Figure 8.10 (A) Metal Halide Lamp

A highly compact electric arc is produced in a discharge tube. A starter is needed to switch on the lamp. The use of ceramic discharge tubes further improves the lamp properties. 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. By adding other metals to the mercury different spectrum can be emitted. Some lamps use a third electrode for starting, but others, especially the smaller display lamps, require a high voltage ignition pulse.

Metal halide lamps have a significantly better colour rendering index than mercury vapour and can be tailored by the choice of halides.

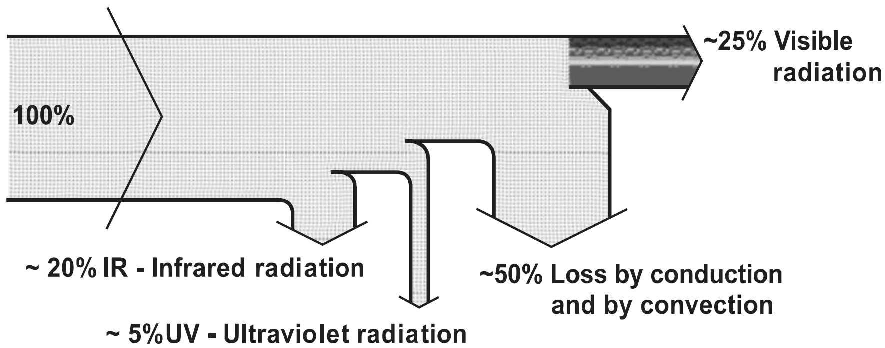


Figure 8.10 (B) Energy Flow Diagram of Metal Halide Lamp

8) Light emitting diode (LED) lamp

LEDs produce light in a very unique way; they produce light via a process called electro-luminescence (Figure 8.11), a process that starts by turning a semiconductor material into a conducting material. A semiconductor with extra electrons is called N-type (negative) material, since it has extra negatively-charged electrons. In N-type material, free electrons can move from a negatively-charged area to a positively charged area. A semiconductor with extra holes is called P-type (positive) material since it has extra positively-charged gaps called holes. When excited with current the negative electron leaves its atom and the P-type material's positive attraction draws the free negative electron into its hole, and the hole also moves toward the electron, so on and so forth.

As an electron travels to a hole, it carries energy, but in order to fit into the hole it must release any extra energy, and when it does, the extra energy is released in the form of light. When we maintain a steady flow of electrical current to the diode, it continues the process of allowing electrons to flow from the negative charged material and fall into the positive charged holes which maintains a steady stream of light out of the LED. The actual LED is quite small in size, usually less than one square millimeter. Additional optical components are added to shape and direct the light. LED's are made of number of inorganic semiconductor materials, many of which produce different colour of light.

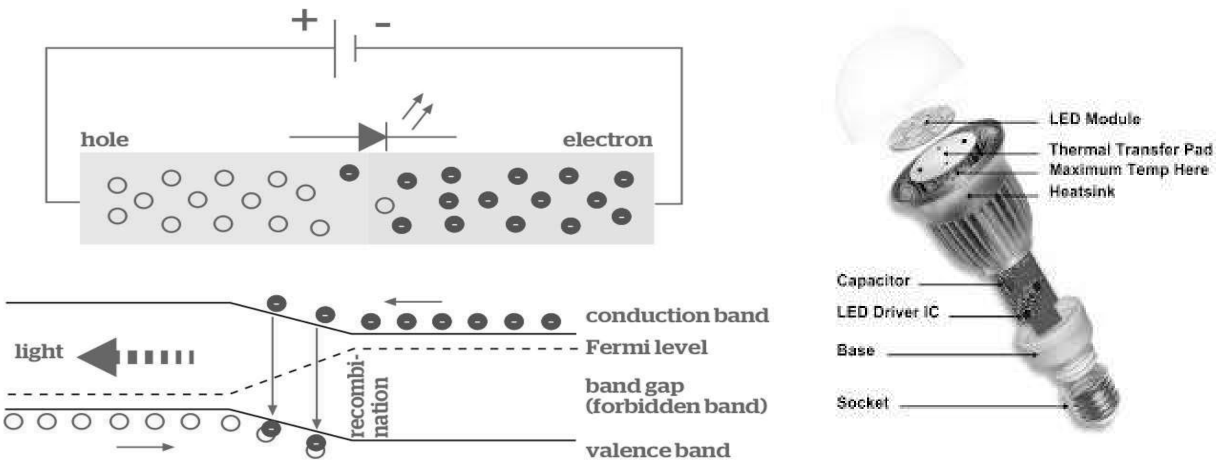


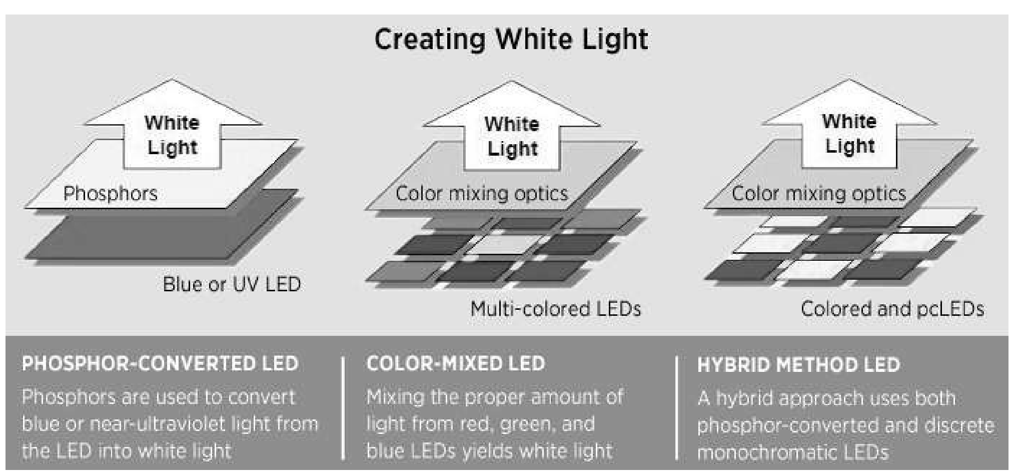
Figure 8.11(A) Representation of LED light

The efficiency of LED’s has now risen sharply and is currently up to 200 lumens per watt in the laboratory and in some products available on the market (although more typical LED’s average output varies from 50 to 130 lumens per watt).

Because of the low power requirement for LED’s, using solar panels becomes more practical and less expensive than running an electrical wire or using a generator. Hence LED with battery backup for remote application is very economical. They do not radiate light in 360 degrees as an incandescent does. The light will be bright wherever it is focused.

Unlike incandescent and fluorescent lamps, LEDs are not inherently white light sources. Instead, LEDs emit nearly monochromatic light, making them highly efficient for colored light applications such as traffic lights and exit signs. However, to be used as a general light source, white light is needed. White light can be achieved with LEDs in three ways:

Phosphor conversion, in which a phosphor is used on or near the LED to convert the colored light to white light; RGB systems, in which light from multiple monochromatic LEDs (red, green, and blue) is mixed, resulting in white light; and a hybrid method, which uses both phosphor-converted and monochromatic LEDs.



Advantages of LED technology is as follows Low power consumption, Directional light output, High efficiency level, Long life: upto ~100,000 hour life if junction temperature can be controlled, Instant switching on with no warm up time, High resistance to switching cycles, High impact and vibration resistance, No UV or IR radiation, Color control ability, allows dimming and Mercury free

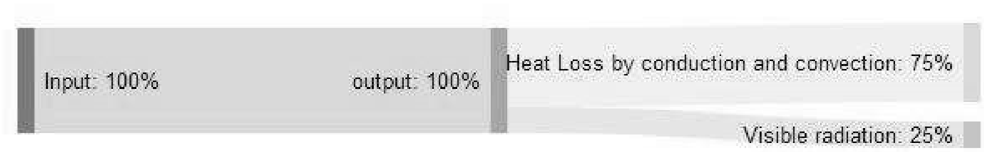


Figure 8.11 (B) Energy Flow diagram of LED Lamp

LED's also offer a number of promising environmental benefits, and they are often viewed as the future of green lighting.

9) Induction lamp

Induction lamp is noted for 'crisp white light output'. Uses a magnetic field to excite gases – has no lamp parts to wear out. It consists of two main components: ballast and a sealed gas-filled bulb. Light is produced via electromagnetic induction, without an electrode or any electrical connection inside the bulb. Instead, high frequency electromagnetic fields are induced from outside the sealed chamber.

To produce light, the ballast supplies the electric coils with high frequency electrical current. The ferrite magnets on either side of the bulb then emit electromagnetic fields which excite electrons within the bulb.

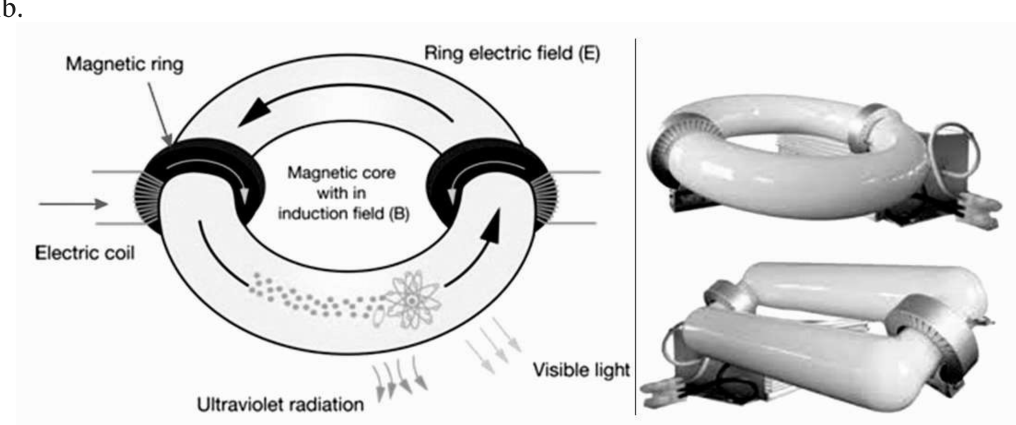


Figure 8.12 Representation of Induction Lamp

As the electrons accelerate inside the bulb, they collide with mercury atoms and produce ultraviolet (UV) light radiation. The UV light then causes the special phosphor coating inside the glass to react in a way that produces fluorescent light within the visible spectrum. The light produced by Induction Lighting (Figure 8.12) achieves good Color Rendering Index (CRI), with a Correlated Color Temperature.

Advantages of Induction lamps is as follows long burning hours, very less maintenance required, instant on/ instant re-strike and energy efficient lighting.

Lamp features: The Table 8.1 shows the lamp features of different lamps.

Table 8.1 Luminous Performance Characteristics of Commonly Used Luminaries

Type of Lamp	Lumens / Watt		Colour Rendering Index	Typical Application	Typical Life (hours)
	Range	Avg.			
Incandescent	8-18	14	Excellent (100)	Homes, restaurants, general lighting, emergency lighting	1000
Fluorescent lamps	46-60	50	Good w.r.t. coating (67-77)	Offices, shops, hospitals, homes	5000
Compact fluorescent lamps (CFL)	40-70	60	Very good (85)	Hotels, shops, homes, offices	8000-10000
High pressure mercury (HPMV)	44-57	50	Fair (45)	General lighting in factories, garages, car parking, flood lighting	5000
Halogen lamps	18-24	20	Excellent (100)	Display, flood lighting, stadium exhibition grounds, construction areas	2000-4000
High pressure sodium (HPSV) SON	67-121	90	Fair (22)	General lighting in factories, ware houses, street lighting	6000-12000
Low pressure sodium (LPSV) SOX	101-175	150	Poor (10)	Roadways, tunnels, canals, street lighting	6000-12000
Metal halide lamps	75-125	100	Good (70)	Industrial bays, spot lighting, flood lighting, retail stores	8000
LED lamps	50-130	90	Very good (80)	Office, industry, outdoor, retail, hospitality, etc	30,000-60,000
Induction Lamps	65-90	75	Very good (80)	General lighting, factories, warehouse, street lighting, flood lighting, etc	60,000-1,00,000

8.4 Recommended Illuminance Levels for Various Tasks / Activities / Locations

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 apply.

The higher value (H) of the range should be used at exceptional cases where low reflectance 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 and accuracy is not important and the task is executed only occasionally.

Recommended Illumination

The following Table 8.2 gives the recommended illuminance range for different tasks and activities for chemical sector. 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 (Source IS 3646 (Part I): 1992). For recommended illumination in other sectors, reader may refer *Illuminating Engineers Society Recommendations Handbook*.

Table 8.2 Recommended illuminance range for different tasks and activities for chemical sector

Petroleum, 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
Colour matching	750-100-1500

8.5 Methods of Calculating Illuminance - Lighting Design for Interiors

In order to design a luminaire layout that best meets the illuminance and uniformity requirements of the job, two types of information are generally needed: average illuminance level and illuminance level at a given point. Calculation of illuminance at specific points is often done to help the designer evaluate the lighting uniformity, especially when using luminaires where maximum spacing recommendations are not supplied, or where task lighting levels must be checked against ambient level.

If average levels are to be calculated, two methods can be applied:

1. For indoor lighting situations, the Zonal Cavity Method is used with data from a coefficient of utilization table.
2. For outdoor lighting applications, a coefficient of utilization curve is provided, the CU is read directly from the curve and the standard lumen formula is used.

Zonal Cavity Method for Indoor Lighting Calculations

The Zonal Cavity Method (sometimes called the Lumen Method) is the currently accepted method for calculating average illuminance levels for indoor areas, unless the light distribution is radically asymmetric. It is an accurate hand method for indoor applications because it takes into consideration the effect that inter-reflectance has on the level of illuminance.

Although it takes into account several variables, the basic premise that foot-candles are equal to luminous flux over an area is not violated.

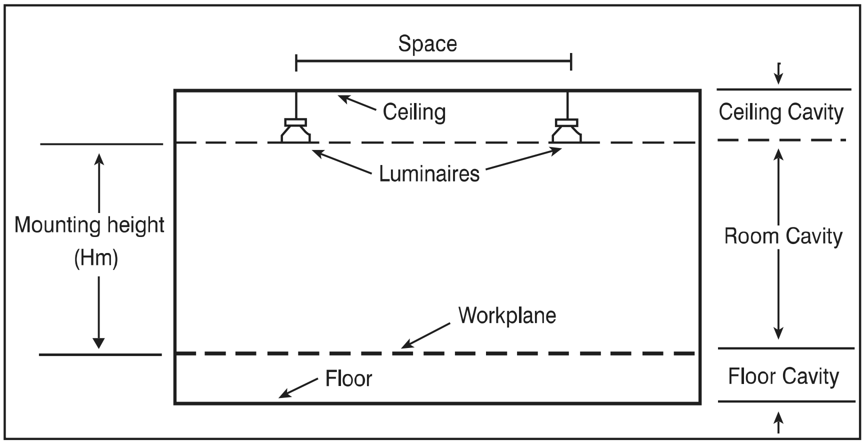


Figure 8.13 Typical Room Space

The basis of the Zonal Cavity Method is that a room is made up of three spaces or cavities. The space between the ceiling and the fixtures, if they are suspended, is defined as the "ceiling cavity"; the space between the work plane and the floor, the "floor cavity"; and the space between the fixtures and the work plane, the "room cavity."

Example:

The step by step process of lighting design is illustrated below with the help of an example. The Figure 8.13 shows the parameters of a typical space.

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-enameled 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

$$\textbf{Room Index} = \frac{\textbf{Length} \times \textbf{Width}}{\textbf{Mounting Height} \times (\textbf{Length} + \textbf{Width})}$$

$$= \frac{L1 \times L2}{(L9 - L8) \times (L1 + L2)} = \frac{10 \times 10}{2 \times (10 + 10)}$$

$$= 2.5$$

Step 4: Calculate the utilisation factor

Utilisation factor is defined as the percent 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 utilisation 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, utilisation factor is 0.66, corresponding to room index of 2.5.

Step-5: To calculate the number of fittings required, the following formula is used

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

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.

Light output = 3050 Lumens (Single Lamp)

LLF = Lamp lumen MF x Luminaire MF x Room surface MF

Where, MF = Maintenance Factor

Typical LLF values

Air conditioned office	0.8
Clean industrial	0.7
Dirty industrial	0.6

$$\mathbf{N = \frac{200 \times 100}{2 \times 3050 \times 0.66 \times 0.8} = 6.2}$$

So, 6 Numbers of Twin Tube Fixtures are required. Total number of 36 W lamp 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.

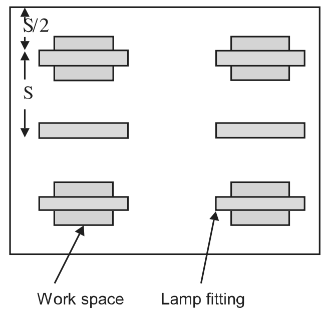


Figure 8.14 Arrangement of Fittings

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 Figure 8.14. The luminaire closer to a wall should be one half of spacing or less.

Luminaire Spacing

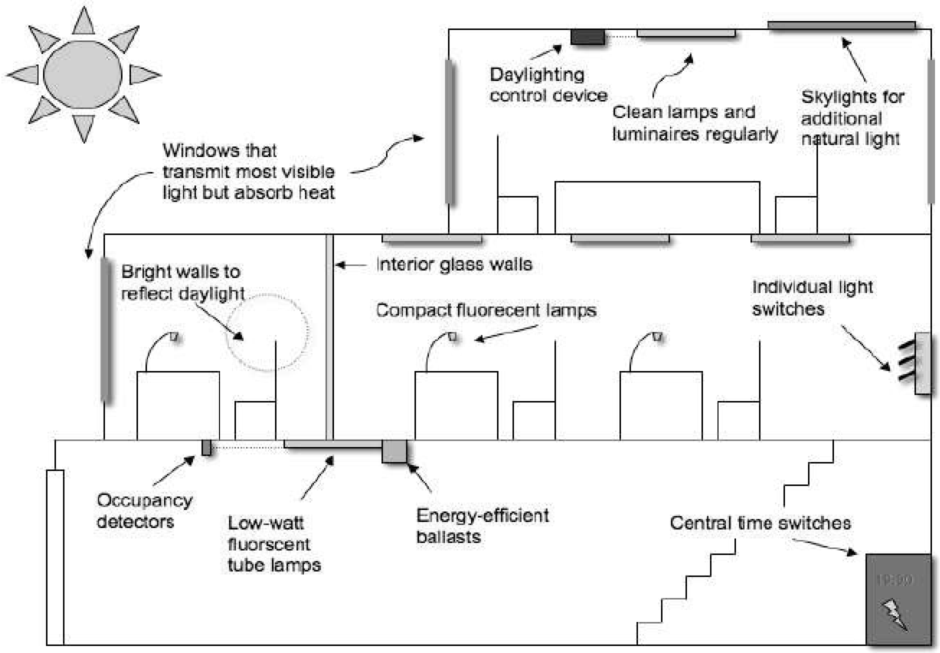
Spacing between luminaires	= 10/3	= 3.33 m
Mounting height (L9-L8)		= 2.0 m
Space to height ratio (SHR)	= 3.33/2.0	= 1.66

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.

8.6 General Energy Saving Opportunities

Changing the light bulbs is not the only way to improve the use of lighting. Below are some examples of many other options available:



a) 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.

Some of the methods to incorporate day lighting are:

i. 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.

ii. 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.

iii. 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.

iv. Use of atrium with FRP dome in the basic architecture can eliminate the use of electric lights in passages of tall buildings.

v. 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.

vi. Mounting Solar tube on the roof, with the help of advanced optics and special duct work to direct sunlight deep into the buildings and spreading out over large internal spaces providing heat and glare free daylighting for 8-10 hrs in a day

b) 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.

c) 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 no of general lighting fixtures, reduce the wattage of lamps, save considerable energy and provide better illuminance and also provide aesthetically pleasing ambience.

d) Selection of high efficiency lamps and luminaries

The details of common types of lamps are summarised in Table 8.1 above. It is possible to identify energy saving potential for lamps by replacing with more efficient types. The following examples of lamp replacements are common. There may be some limitations if colour 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.

e) Reduction of lighting feeder voltage

Figure 8.15 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 8.3 summarises 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.

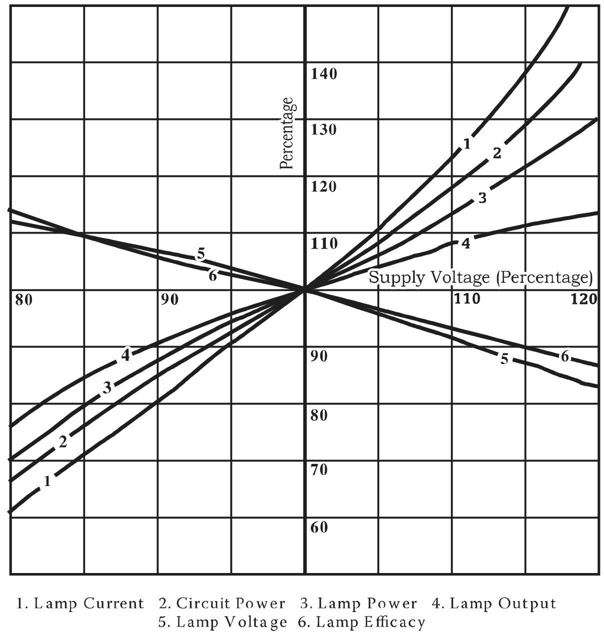


Figure 8.15 Effect of Voltage Variation on Fluorescent Tube light Parameters

Table 8.3 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		

f) Electronic 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. The basic functions of electronic ballast are:

- To ignite the lamp
- To stabilize the gas discharge
- To supply the power to the lamp

The losses in electronic ballasts for tube lights are only about 1 Watt, in place of 10 to 15 Watts in standard electromagnetic chokes.

The additional advantage is that the efficacy of tube lights improves at higher frequencies, resulting in additional savings if the ballast is optimised to provide the same light output as with the conventional choke. Hence a saving of about 15 to 20 Watts per tube light can be achieved by use of electronic ballasts. With electronic ballast, the starter is eliminated and the tube light lights up instantly without flickering.

g) Lighting controllers

Automatic control for switching off unnecessary lights can lead to good energy savings. This includes dimmers, motion & occupancy sensors, photosensors and timers.

h) 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 basic maintenance includes cleaning of lamps and fixtures, cleaning and repainting interiors, relamping etc

8.7 Energy Efficient Lighting Controls

Occupancy Sensors

Occupancy-linked control can be achieved using infra-red, acoustic, ultrasonic or microwave sensors, which detect either movement or noise in room spaces. These sensors switch lighting on when occupancy is detected, and off again after a set time period, when no occupancy movement detected. They are designed to override manual switches and to prevent a situation where lighting is left on in unoccupied spaces. With this type of system it is important to incorporate a built-in time delay, since occupants often remain still or quiet for short periods and do not appreciate being plunged into darkness if not constantly moving around.

Timed Based Control

Timed-turnoff switches are the least expensive type of automatic lighting control. In some cases, their low cost and ease of installation makes it desirable to use them where more efficient controls would be too expensive.

Types and features

The oldest and most common type of timed-turnoff switch is the “dial timer,” a spring-wound mechanical timer that is set by twisting the knob to the desired time. Typical units of this type are vulnerable to damage because the shaft is weak and the knob is not securely attached to the shaft. Some spring-wound units make an annoying ticking sound as they operate. Newer types of timed-turnoff switches are completely electronic and silent. Electronic switches can be made much more rugged than the spring-wound dial timer. These units typically have a spring-loaded toggle switch that turns on the circuit for a preset time interval. Some electronic models provide a choice of time intervals, which you select by adjusting a knob located behind the faceplate. Most models allow occupants to turn off the lights manually. Some models allow occupants to keep the lights on, overriding the timer. Timed-turnoff switches are available with a wide range of time spans. The choice of time span is a compromise. Shorter time spans waste less energy but increase the probability that the lights will turn off while someone is in the space. Dial timers allow the occupant to set the time span, but this is not likely to be done with a view toward optimising efficiency. For most applications, the best choice is an electronic unit that allows the engineering staff to set a fixed time interval behind the cover plate.

Daylight Linked Control

Photoelectric cells can be used either simply to switch lighting on and off, or for dimming. They may be mounted either externally or internally. It is however important to incorporate time delays into the control system to avoid repeated rapid switching caused, for example, by fast moving clouds. By using an internally mounted photoelectric dimming control system, it is possible to ensure that the sum of daylight and electric lighting always reaches the design level by sensing the total light in the controlled area and adjusting the output of the electric lighting accordingly. If daylight alone is able to meet the design requirements, then the electric lighting can be turned off. The energy saving potential of dimming control is greater than a simple photoelectric switching system. Dimming control is also more likely to be acceptable to room occupants.

Localized Switching

Localized switching should be used in applications which contain large spaces. Local switches give individual occupants control over their visual environment and also facilitate energy savings. By using localized switching it is possible to turn off artificial lighting in specific areas, while still operating it in other areas where it is required, a situation which is impossible if the lighting for an entire space is controlled from a single switch.

Street Lighting Systems and Controls

Street lighting /Public lighting is one of the major electrical loads in municipal areas. Number of street lights used in a Municipal area varies from 20000 – 50000 in numbers depending on the kilometers of road illuminated within the municipal limits. Typical electrical load of municipal lighting system varies 2MW to 7 MW. The type of lamps used in Municipal area includes Fluorescent Tube light/ Mercury Vapor Lamps/ Sodium Vapor Lamps and Metal Halide Lamps. High Mast towers are also used at strategic junctions in the Municipal area. LEDs are also used for traffic signaling purpose in municipal areas.

Following controls are adopted to reduce energy consumption in street lighting system:

1. Timer control (Switch ON/OFF as per set timing)
2. Day light control(Based on illumination level)
3. Selective switching/Alternate switching of street lights low traffic density areas (after midnight).

4. Switching control based on lux levels. (after midnight)
5. Installations of Voltage controllers to be operated after midnight.
6. Installation of PLC controlled Lighting panels for effective control and monitoring.

8.8 Standards and Labeling Programs for FTL Lamps

Considering the large number of fluorescent lamps (FTL) in usage, BEE has included FTL under Standard and Labeling Programme (S&L). The S&L Programme covers 4 feet tubular fluorescent lamps (101mm) for wattages up to 40W. The S&L programme includes 6500K colour temperature for halo-phosphates and 6500K, 4000K & 2700K for tri-phosphate category. The star rating scheme for FTL is given in Table 8.4.

Table 8.4 Star Rating scheme for FTL (101 mm)

	1 Star	2 Star	3 Star	4 Star	5 Star
Lumens per Watt at 0100 hrs of use	<61	>=61 & <67	>=67 & <86	>=86 & <92	>=92
Lumens per Watt at 2000 hrs of use	<52	>=52 & <57	>=57 & <77	>=77 & <83	>=83
Lumens per Watt at 3500 hrs of use	<49	>=49 & <54	>=54 & <73	>=73 & <78	>=78

8.9 Lighting Case Study

Replacement of existing T12 Fluorescent lamps in street lighting system with LED lamps

Existing: Fluorescent lamp (T12) fixture of 40 numbers is connected to the entire campus for security purpose. All the lights remain in operation for around 12 hours at night (6 p.m. to 6 am) every day throughout the year. All the light fixtures are equipped with electromagnetic ballast which consumes around 12 to 14 watt of additional power while in operation. Hence the power consumption of a single fluorescent light fixture considering minimum ballast loss is 40+12=52 watts. The total light output of all the fluorescent light fixtures is around 2400 lumen.

Proposed: It was proposed to replace existing lamps with high efficient LED lamps of 18 W with a luminous efficacy of around 120-140 lm/w. The total luminous output of these lamps is around 2340 lumen.

Calculation

Existing Fittings			
No of FTL-T12 lamps installed	=	40	No's
Wattage Consumed			
40 No's of (40W+12W (Ballast)=52 W)	=	2.1	kW
Average operating hours per day	=	12	hrs/day

Total energy consumed by operating the lights	=	25	kWh/day
Annual energy consumption by operating the lights (365 days/year)	=	9125	kWh/annum
Proposed option			
Replacement of all 40 no's of 40 Watts T12-FTL with 18 Watts LED lamps			
Total energy consumed by operating with LED	=	0.72	kW
Average operating hours per day	=	12	hrs/day
Total kWh/day consumed by operating the lights	=	9	kWh/day
Annual energy consumption by operating the lights (365 days/year)	=	3285	kWh/annum
Savings			
Total energy reduction per annum	=	5840	kWh/annum
Annual monetary savings (@Rs. 5/unit)	**=**	***29,200***	***Rs./annum***
Investment @ **Rs.2500/ Lamp**	=	1.0	Lakhs
Simple payback period	=	3.4	Years