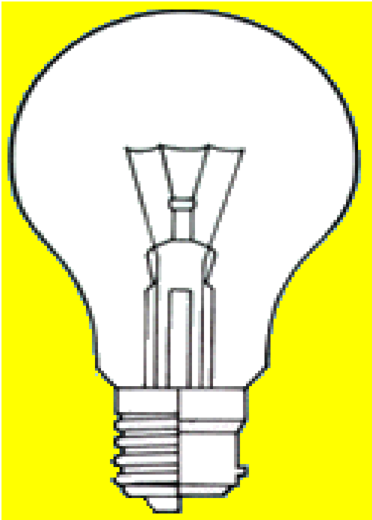
BEST PRACTICE MANUAL



LIGHTING

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1. INTRODUCTION

"Light is the first element of design; without it there is no color, form, or texture."

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 even in the 21st century to produce some light and more heat through incandescent lamps. Only in the past few decades have lighting products become much more sophisticated and varied. For example, considerable chemistry and physics are required to create an electric arc within a fluorescent lamp, and then to convert the energy from that arc into useful light.

Lighting energy consumption contribute to 20 to 45% in commercial buildings and about 3 to 10% in industrial plants. Most industrial and commercial energy users are aware of energy savings in lighting systems. Manufacturers are aggressively marketing their products these days and help the users to take a decision. Often times 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.

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

1. Selection of the most efficient light source possible in order to minimize power costs and energy consumption.
2. Matching the proper lamp type to the intended work task or aesthetic application, consistent with color, brightness control and other requirements.
3. Establishing adequate light levels to maintain productivity improve security and increase safety.

2 LIGHTING FUNDAMENTALS

2.1 Basic Theory

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 a body due to any of the following phenomenon.

Incandescence Solids and liquids emit visible radiation when they are heated to temperatures about 1000K. The intensity increases and the appearance become 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, as given in fig 2.1, 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.

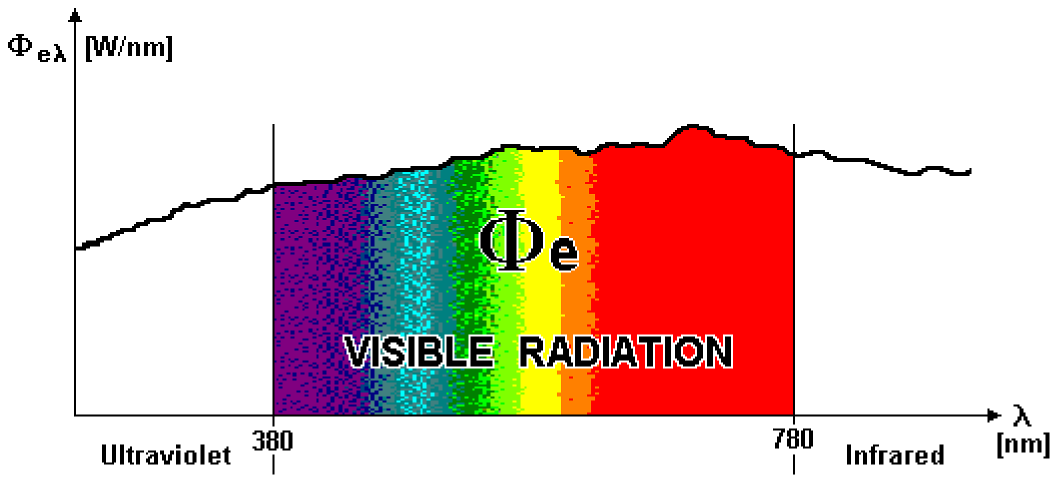


Figure 2-1: Visible radiation

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 human eye can detect a minimum flux of about 10 photons per second at a wavelength of 555 nm. Similarly, the eye can detect a minimum flux of 214 and 126 photons per second at 450 and 650 nm, respectively. This is due to the ‘relative eye sensitivity’ on different wavelengths. This non-linear response is not normally a problem as the eye is not a precise optical instrument able to accurately measure light levels. In fact, it is a very flexible and forgiving instrument able to adapt to an extremely wide range of conditions. The best sensitivity, as seen from figure 2.2 is at 555 nm wavelength having greenish yellow colour with a luminous efficacy of 683 lumens/Watt.

From figure 2.2, note that a light source, which is bluish in colour having wavelength 480 nm, has relative eye sensitivity of 0.1 and the theoretical luminous efficacy is likely to be 60 to 70 lm/W.

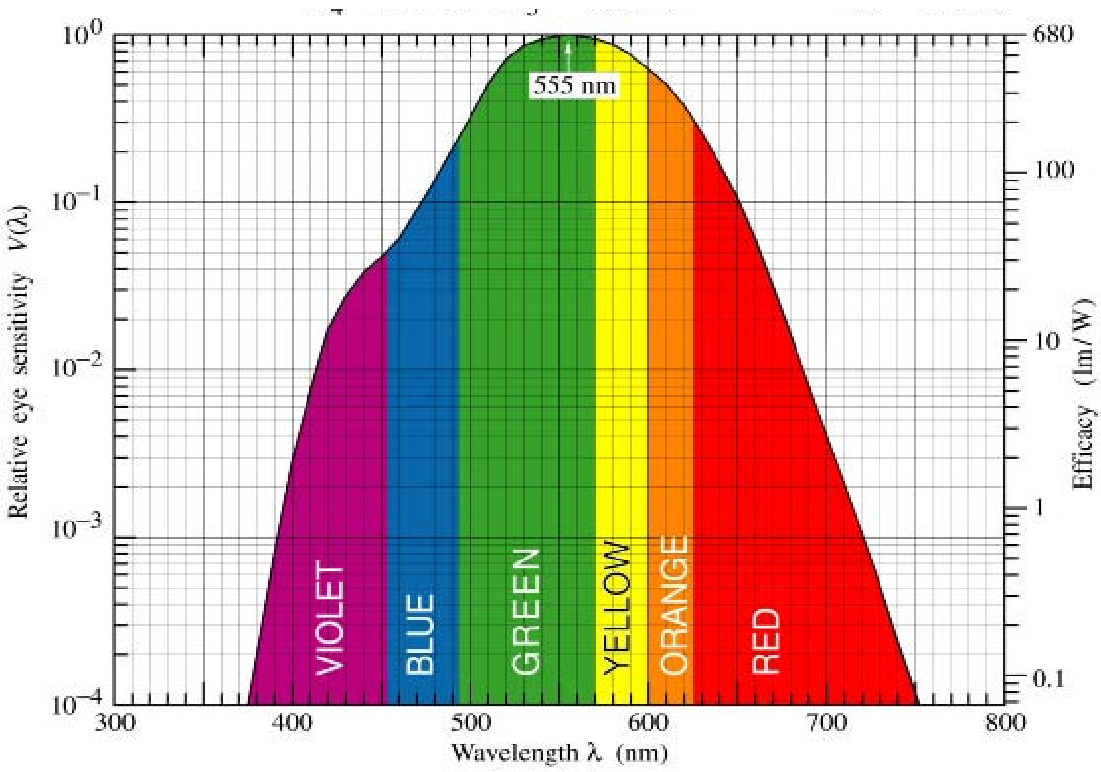


Figure 2-2: Relative eye sensitivity and luminous efficacy

2.2 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 (m^2) 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)

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. Figure 2.3 explains the difference.

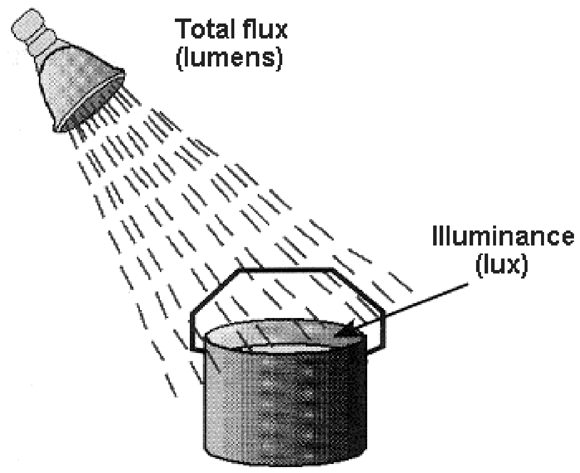


Figure 2-3: Illuminance and lumens

2.3 The 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).

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

Where E = Illuminance, I = Luminous intensity and d = distance

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.

You measure 10.0 lm/m^2 from a light bulb at 1.0 meter. What will the flux density be at half the distance?

Solution:

$E_{1m} = (d_2 / d_1)^2 * E_2$

$= (1.0 / 0.5)^2 * 10.0$

$= 40\ lm/m^2$

2.4 Colour 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.

2.5 Colour Rendering

The ability of a light source to render colour of surfaces accurately can be conveniently quantified by the colour-rendering index. This index is based on the accuracy with which a set of test colours 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 colour rendering properties of light sources.

Table 2-1: Colour Rendering Index

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

Color temperature is how cool or warm the light source appears. Incandescent lamps have a warmer appearance than mercury vapor yard lights, for example.

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.

3 LIGHTING SYSTEM COMPONENTS

3.1 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.

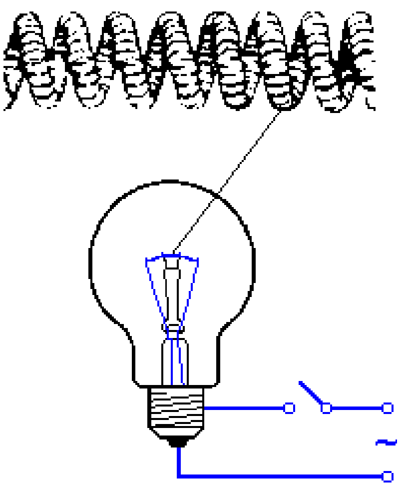


Figure 3-1: Incandescent lamp

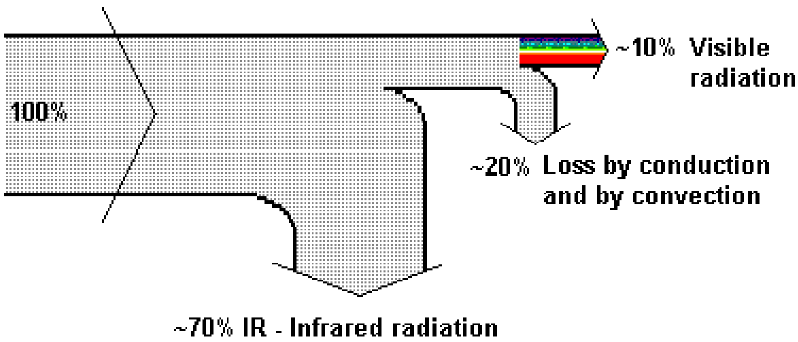


Figure 3-2: Energy flow diagram of incandescent lamp

Features

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

3.2 Tungsten-Halogen Lamps

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.

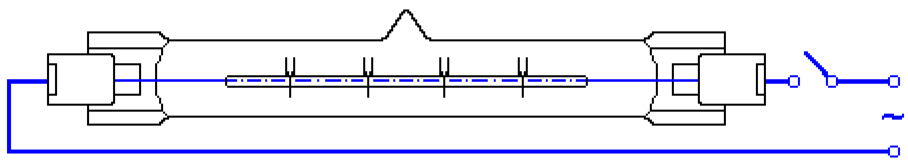


Figure 3-3: Tungsten Halogen Lamps

Features

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

Advantages
- More compact
- Longer life
- More light
- Whiter light (higher colour temp.)

Disadvantages
- Cost more
- Increased IR
- Increased UV
- Handling problem

3.3 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.

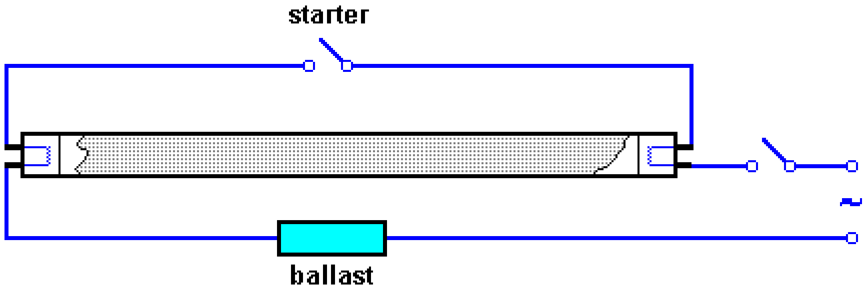


Figure 3-4: Fluorescent lamp

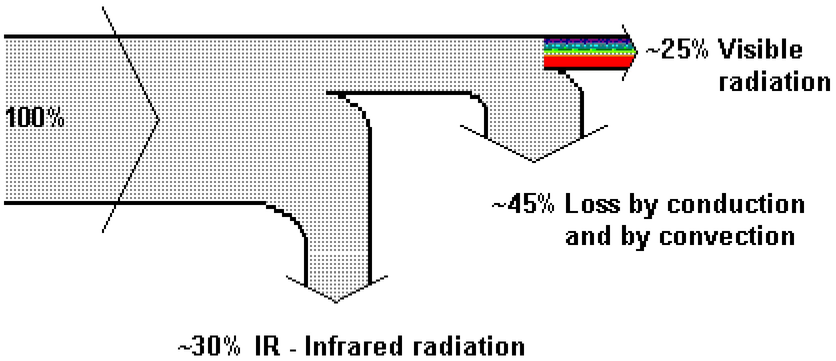


Figure 3-5: Energy flow diagram of fluorescent lamp

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.

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

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.

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

Halo phosphate

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

Tri-phosphor

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

3.4 Compact Fluorescent Lamps

The recent compact fluorescent lamps open up a whole new market for fluorescent sources. These lamps permit design of much smaller luminaires, 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).

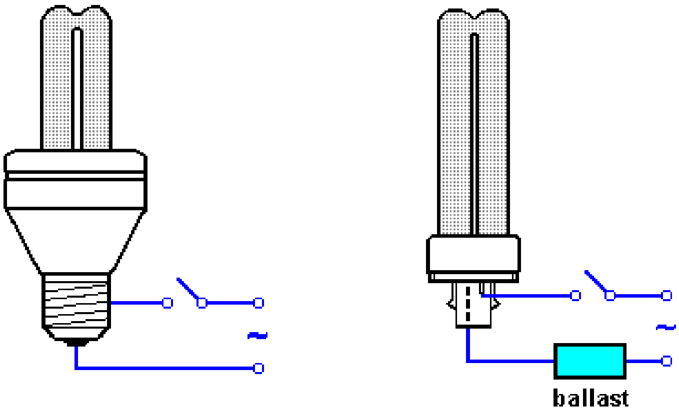


Figure 3-6: CFL

Features

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

3.5 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.

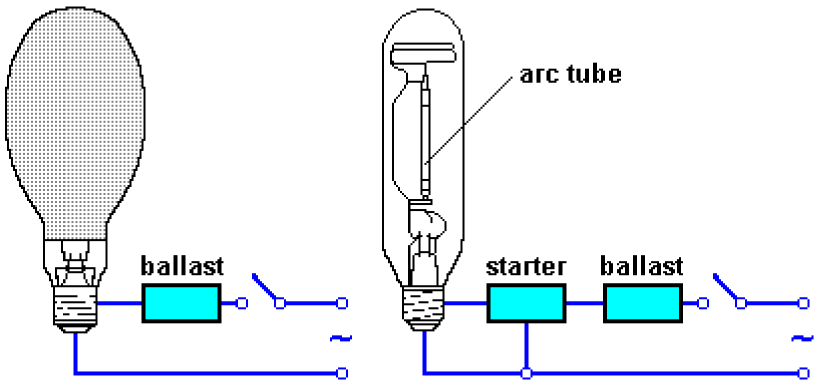


Figure 3-7: Sodium Vapor Lamp

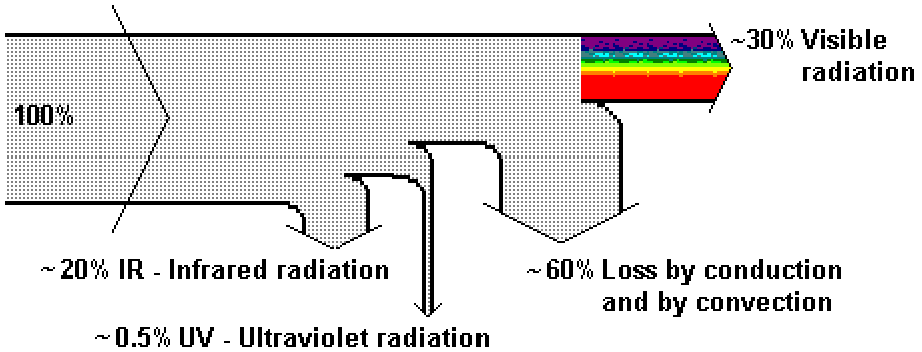


Figure 3-8: Energy Flow diagram of high pressure sodium lamp

Features

Efficacy – 50 - 90 lumens/Watt (better CRI, lower Efficacy)
Colour Rendering Index – 1 – 2
Colour Temperature – Warm
Lamp Life – upto 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.

3.6 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 efficacious 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
Colour Rendering Index – 3
Colour Temperature – Yellow (2,200K)
Lamp Life – upto 16,000 hours
Warm up – 10 minutes, hot re-strike – up to 3 minutes

3.7 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.

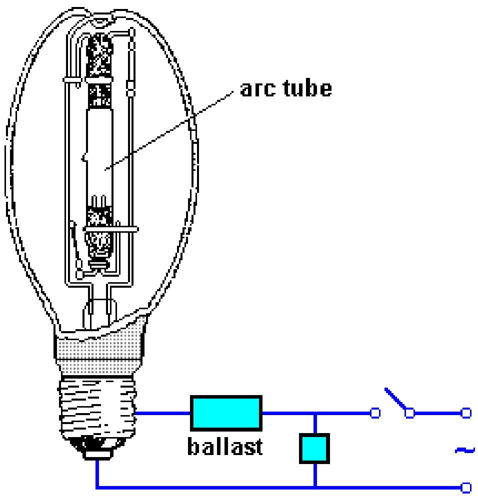


Figure 3-9: Mercury vapour lamp

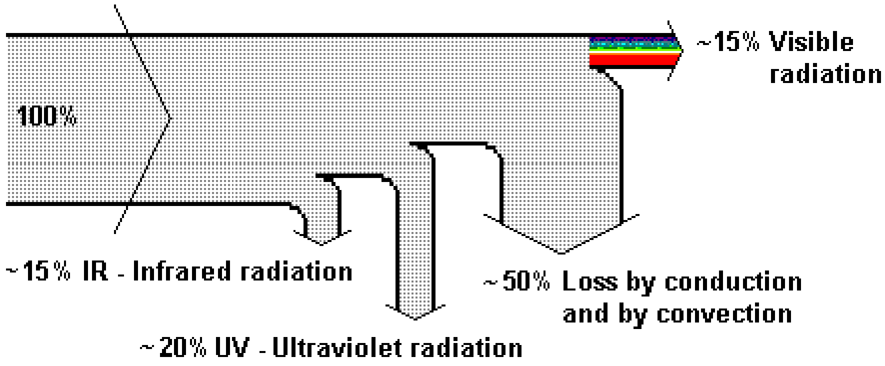


Figure 3-10: Energy flow diagram of mercury vapor lamp

Features

- Efficacy – 50 - 60 lumens/Watt (excluded from part L)
- Colour Rendering Index – 3
- Colour Temperature –Intermediate
- Lamp Life – upto 16,000 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

3.8 Blended Lamps

Blended lamps are often described as two-in-one lamps. This combines two source 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.

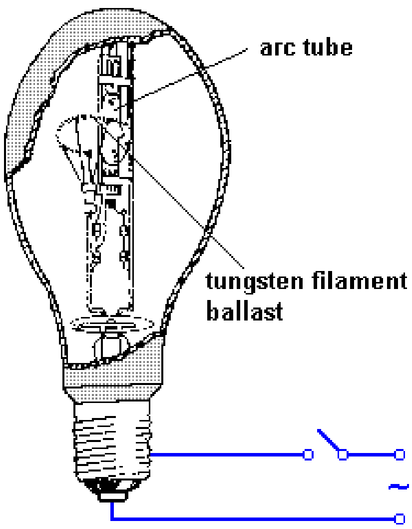


Figure 3-11: Blended lamp

The tungsten filament coiled in construction encircles the discharge tube and is connected in series with it. The fluorescent powder coating is given on 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

3.9 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
Colour Rendering Index – 1A –2 depends on halide mix
Colour 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 colour, 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

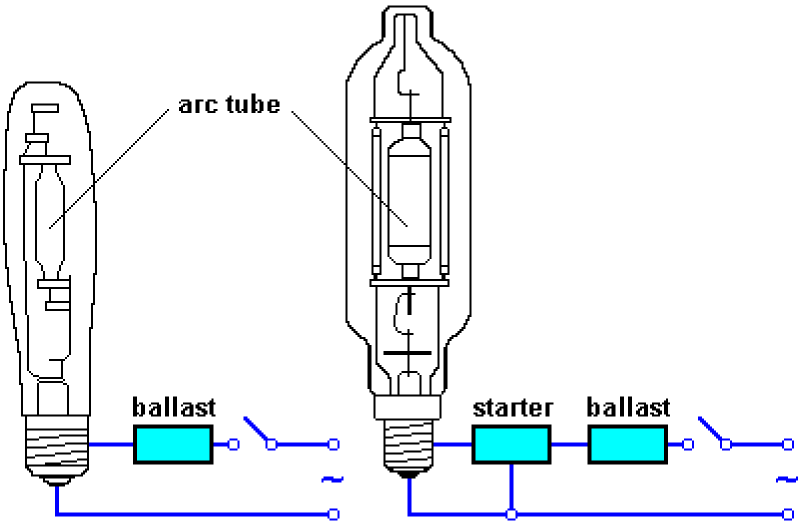


Figure 3-12: Metal halide lamp

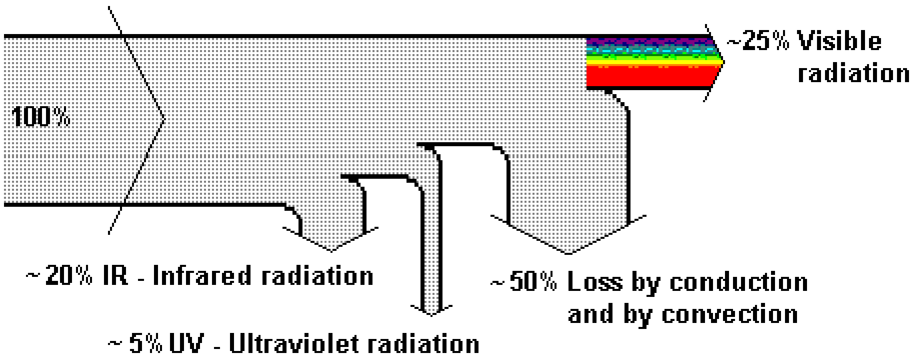


Figure 3-13: Energy flow diagram of metal halide lamp

3.10 LED Lamps

LED technology has improved significantly over the past 5 to 10 years. Light output has reached a point where LEDs are viable for many applications, especially colored light applications. More importantly, LED manufacturers see improvements in light output continuing for years to come such that LEDs could make sense for virtually any lighting application.

Basic components are:

- LEDs
- Driver (power conversion device)
- Control devices (dimming controls, color mixing controls)
- Optics
- Fixture (housing, including heat sink devices, to contain all components)

An LED driver converts a system voltage (e.g., 120vac) into power required by the LED system. Delivering proper power to an LED system is crucial to maintaining correct light levels and life expectancy of the LEDs. The driver also regulates power delivered to the LEDs to counter any fluctuations in system conditions. Drivers also isolate the LED system from the high voltage system to reduce shock hazards and make a lighting system safer.

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 phosphor-coated blue LED lamp. LED lamps last 40,000 to 100,000 hours depending on 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.

The luminous efficacy of LEDs in comparison with other lamps is given below.

Table 3-1: LED lamps

Source	Efficacy (Lu/W)
LED	10-45
Incandescent	10-30
Fluorescent	60-90
Neon	5-20
HID	70-110

This does not tell the whole story. Efficiency of the complete system must be considered while making comparison. Colored LEDs used in applications such as traffic signals and channel letters can be up to 90% more efficient than neon and incandescent. This is true because these applications have historically filtered white light to get a specific color of light . So most of the light is wasted in the filtering process. Plus, the point source nature of LEDs offers the opportunity to engineer optically superior fixtures (i.e., less light losses for more usable light).

Increases in LED efficacy is a major area of research in the industry, and significant improvements are anticipated for years to come.

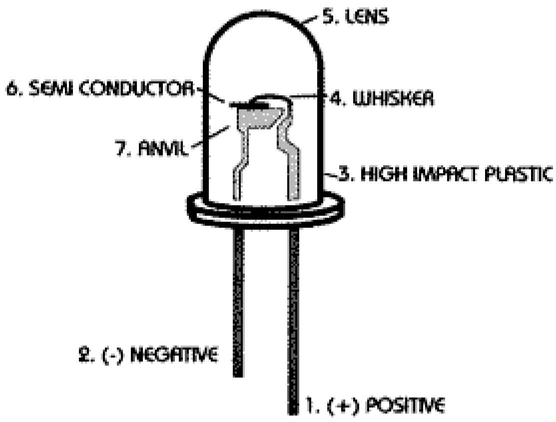


Figure 3-14: LED lamp

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.

3.11 Luminaires/Reflectors

The most important element in a light fitting, apart from the lamp(s), is the reflector. They 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 reflectance 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)

Figure 3-15: Mirror optics luminaire

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.

4 DESIGNING WITH LIGHT

4.1 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. However, just saying 'good lighting' does not specify how much is good.

Taj Mahal can be viewed in moonlight of 0.2 lux; measuring length using a micrometer requires 500 to 1000 lux. 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.

Table 4-1: Recommended lighting levels

	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, colour 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 localised lighting for visually exacting tasks	3000	Minutely detailed and precise work, e.g. Very small parts of instruments, watch making, engraving.

Indian standards IS 3646 & SP-32 describes the illuminance requirements at various work environments in detail.

The second question is about the quality of light. In most contexts, quality is read as colour rendering. Depending on the type of task, various light sources can be selected based on their colour rendering index.

4.2 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.

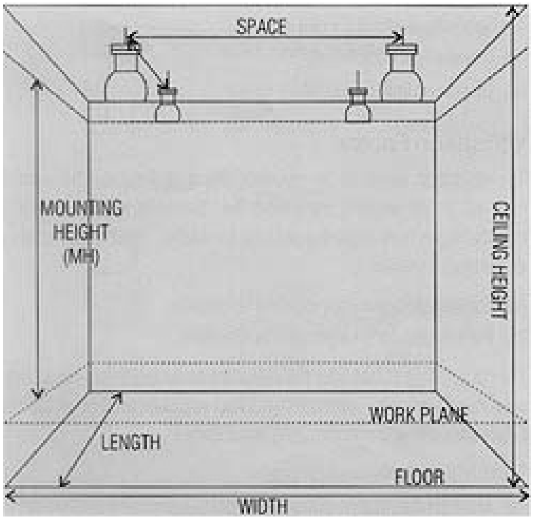


Figure 4-1: Room dimensions

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-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:

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

$$= \frac{L1 \times L2}{(L9 - L8) \times (L1 + L2)} = \frac{10 \times 10}{2 \times (10 + 10)}$$
$$= 2.5$$

Step 4: Calculating the Utilisation factor

Utilisation factor is defined as the percent of rated bare-lamp lumens that exit the luminaire and reach the workplane. 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 use 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 4.2. The luminaire closer to a wall should be one half of a spacing or less.

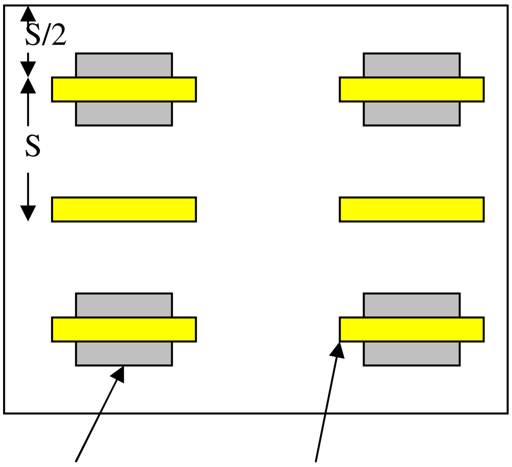


Figure 4-2: Luminaire spacing

Spacing between luminaires = 10/3 = 3.33 metres
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.

4.3 Energy efficiency in design

The above method of design is oriented towards providing required illumination at work plane with a uniformity of at least 0.8. Energy efficiency by providing task lighting can be accommodated in the above design method by specifying a lower value of general illuminance and providing separate lighting above the task. The following options can be considered in the above lighting design problem.

- Suppose the above 10 m X 10m office space is to be designed for an illuminance of 100 lux. Using the above design method, we will finally arrive at a configuration of using 3 nos twin tube (2X36 W fluorescent lamps). It is then possible to give additional task lighting on the work space to provide 200 lux on the plane.

- If in the original design, providing twin tube fixtures can be provided above the work places and single tube fixtures at empty spaces, the total number of lamps required can be reduced to 10 instead of 12.

- It is also possible to do away with the luminaires placed in the middle row, reducing the number of luminaires from 6 to 4. In this case, the space to height ratio will be 1.8. This design philosophy would ensure that light is available where it is required and that sufficient general illumination is available in all areas.

- The mounting height is 2.9 meter from the floor and 2.0 meter from the workplace. If the mounting height can be reduced to 2.4 meter from the floor by properly bringing down the lamps with suitable extensions, the illuminance at the work plane will be vastly improved. For example, in the above system, the distance between the lamp and the work plane is 2.0 meter in the original design. If it can be brought down to 1.5 meters, the illuminance will be 50% more on the work plane. Use of 6 nos single tube fixtures in the above layout may then be sufficient to give an average illuminance of 150 lux.

- Use of specular (Mirror optics) reflectors in place of porcelain enameled reflectors can also improve the illuminance.

5 ENERGY SAVING OPPORTUNITIES

5.1 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:

1. 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.

2. 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.

Figure 5-1: Day lighting using polycarbonate sheets

3. 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.

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

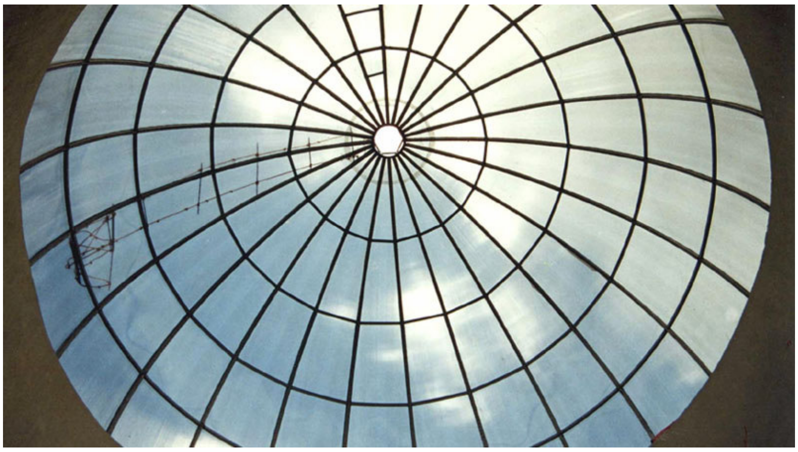
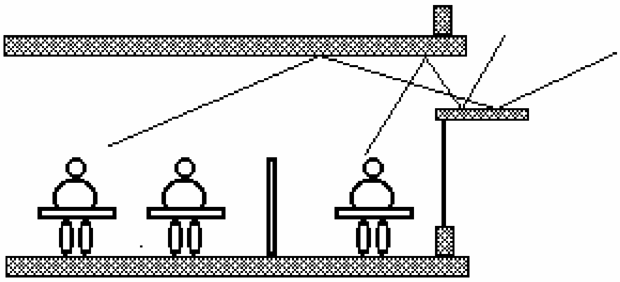


Figure 5-2: Atrium with FRP dome

5. 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.



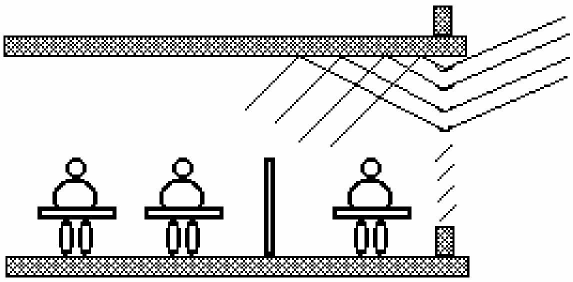


Figure 5-3: Concept of Light Shelf to provide Natural Lighting without Glare

Light pipe: This is a reflective tube that brings clean light from the sky into a room, no need for lighting or incandescent bulbs. These are Aluminium tubes having sliver lining inside. One 13" light pipe can illuminate about 250 sq.ft of floor area with an illuminance of 200 lux. A 9" dia pipe can give the same iilluminance over a 100 sq.ft area.

A 4 ft length of light pipe of the above size provides a daytime average of 750 watts worth of light in June, 250 watts in December. If the pipe length increases to 20 ft, 50% of the light reaches the surface. These are expensive, costing between 150 to 250 dollars and is one of the emerging technologies in day lighting.

Figure 5-4: Light pipes

5.2 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.

5.3 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 no 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 realised. 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.

5.4 Selection of High Efficiency Lamps and Luminaires

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

Table 5-1:Information on Commonly Used Lamps

Lamp Type	Lamp Rating in Watts (Total Power including ballast losses in Watts)	Efficacy (including ballast losses, where applicable) Lumens/Watt	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
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	>12000
Low Pressure Sodium Vapour Lamps (LPSV)	35,55,135 (48,68,159)	90 to 133	--	>12000

The following examples of lamp replacements are common.

- Installation of metal halide lamps in place of mercury / sodium vapour lamps

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

- Installation of High Pressure Sodium Vapour (HPSV) lamps for applications where colour rendering is not critical

  High pressure sodium vapour (HPSV) lamps offer more efficacy. But the colour 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 the 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, colour rendering may also be a guiding factor. Table 5.2 summarises the replacement possibilities with the potential savings.

Table 5-2: 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 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.

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.

5.5 Reduction of Lighting Feeder Voltage

Fig. 5.5 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 5.3 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.

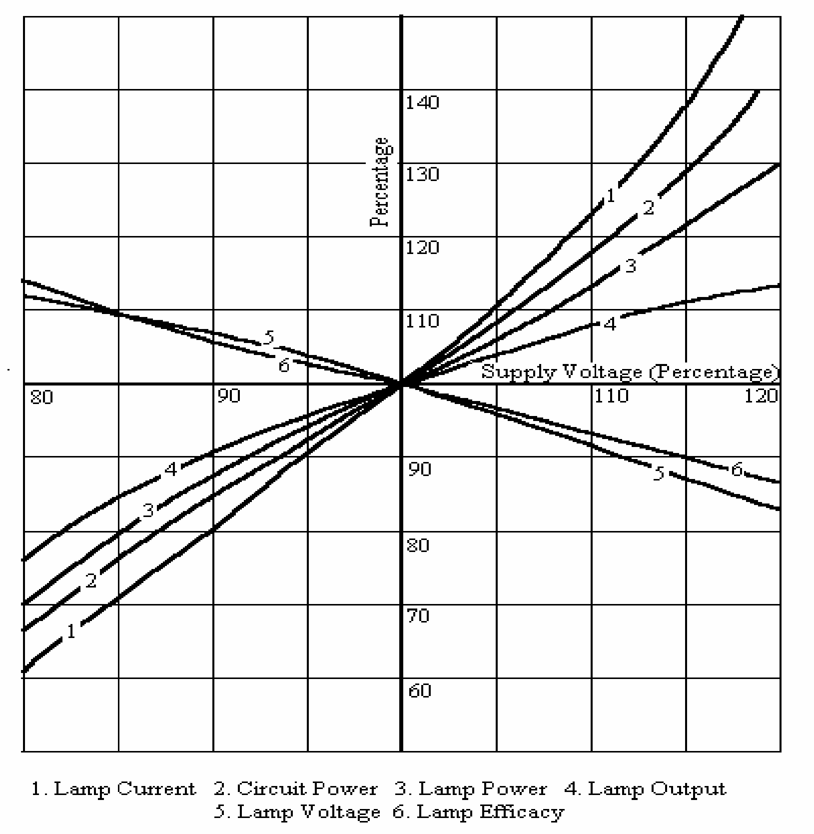


Figure 5-5: Effect of Voltage Variation on Fluorescent Tube light Parameters

Table 5-3: 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		

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 %	Decreases by 2 %
Power input	Decreases by 8 %	Increases by 3 %

5.6 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 losses in electronic ballasts for tube lights are only about 1 Watt, in place of 10 to 15 Watts in standard electromagnetic chokes. Table 5.4 shows the approximate savings by use of electronic ballasts.

Table 5-4: 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

The additional advantage is that the efficacy of tube lights improves at higher frequencies (refer fig.5.6), 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.

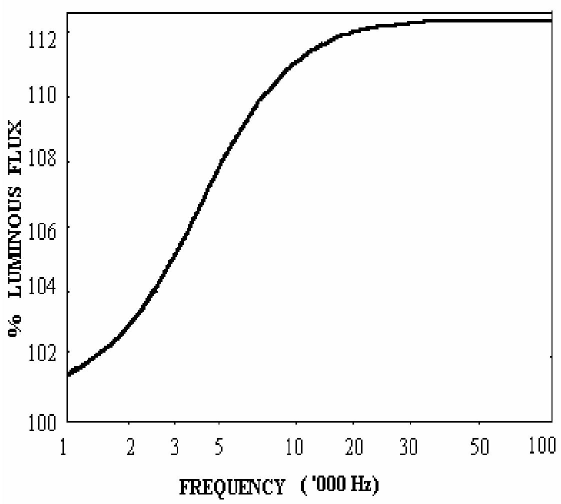


Figure 5-6:Increase in Light Output from Tube lights at Higher Operating Frequencies

A good number of 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 also been developed for 20W and 65W fluorescent tube lights, 9W & 11W CFLs, 35W LPSV lamps and 70W HPSV lamps. These are now commercially available.

5.7 Low Loss Electromagnetic Chokes for Tube Lights

The loss in standard electromagnetic choke 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.

5.8 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 motorised 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 optimise performance. The microprocessor is programmed to memorise 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 personal occupancy sensor beneath binder bin or desk and position so that it cannot detect motion outside 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.

5.9 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. The advantage of the T5 lamps is that due to its small diameter, luminaire efficiencies can be improved by about 5%. 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. 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 aluminium 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.

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 U.S.A. has been slow in accepting this technology, as the 4 foot, T8 lamps consume only about 35 Watts. Secondly, the focus in the U.S.A. has generally been on better optic control, rather than on lamp efficiency.

5.10 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 percent to 30 percent 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.

6 CASE STUDIES

6.1 Use of Translucent Roof Sheets to Utilize Natural Light

High bay fixtures of 250 W HPSV lamps were used for illumination in shop floor. It was decided to replace some of the existing asbestos roof sheets with translucent polycarbonate sheets. Total of 6 nos transparent sheets of 3.0 m X 0.5 m area were used. The following table summarises energy saving.

Table 6-1: Natural lighting

Description	Unit	Qty.
Power consumption of lamp+ ballast	Watts	285
Total strips installed	nos	2
Total number of lamps switched off	nos	8
Daily operating hours	hours	8
Energy saved per day	kWh	18.2
Annual energy savings (@ 300 days/annum)	kWh	5472
Annual energy cost saving (@ Rs 5.0/kWh)	Rs	27,300
Investment	Rs	14,000
Payback period	months	6

Additional benefits include better lamp life, lower replacement cost etc.

6.2 Reduction of Lamp Mounting Height & De-lamping at FMCG Plant

After a survey of the illuminance level in the plants and offices, trials were taken by reducing the mounting height of selected tube lights by 1 metre and removing one tube light and choke from the twin fixture. Reflective film (Aluminium foil) was applied on the inside of the fixture to improve reflection.

In fixtures with acrylic diffusers, holes were drilled in a symmetrical fashion and one tube light was removed. It was found that the illuminance on the working plane was almost similar to the original levels with the twin tube lights.

Over a period of two years, about 1400 tube lights were removed. Total investment for lowering the fixtures, reflective films etc was Rs 1.0 lakhs. Annual energy saving was found to be 3,70,000 kWh.

6.3 Daylight-Dimming Lighting System

The coffee shop of a commercial building was lighted by 25.60 cm x 120 cm, recessed luminaires, each with two magnetic ballasts and four 40 W cool white, T12 lamps. Lighting is used only from Monday to Friday beginning at approximately 7AM and continuing through approximately 6PM. The building's east and west facades are more than 70% glazing which provides abundant natural daylight to the buildings interior During the afternoon one or more of the three lighting circuits is usually switched off for a short period (30 to 60 minutes).

The new controllable lighting system replaced the inefficient magnetic ballasts and poor color rendering 40W T12 cool white lamps with a single electronic dimming ballast and two high color rendering (85CRI) 32W T8 lamps in each luminaire. The building was divided into five linear north-south zones, with each zone of five luminaires controlled by a single ceiling mounted photo sensor. The photo sensor regulates the light level (to a minimum of 20%) for the ballasts in each zone based on the available light measured in its conical field of view. The target illuminance was 300 lux. The overall lighting power savings (nearly 76%) is a result of converting to a more efficient electronic ballast/lamps system, adding ballast dimming capabilities, and tuning light levels through de-lamping. The old system of magnetic ballasts and 40W T12 lamps consumed a maximum of 4.65 kW (186 watts/luminaire). The new system at full output was measured to consume a maximum of 1.5 kW (60 watts/luminaire). The graphical representation of energy profile is given below in fig 6.1.

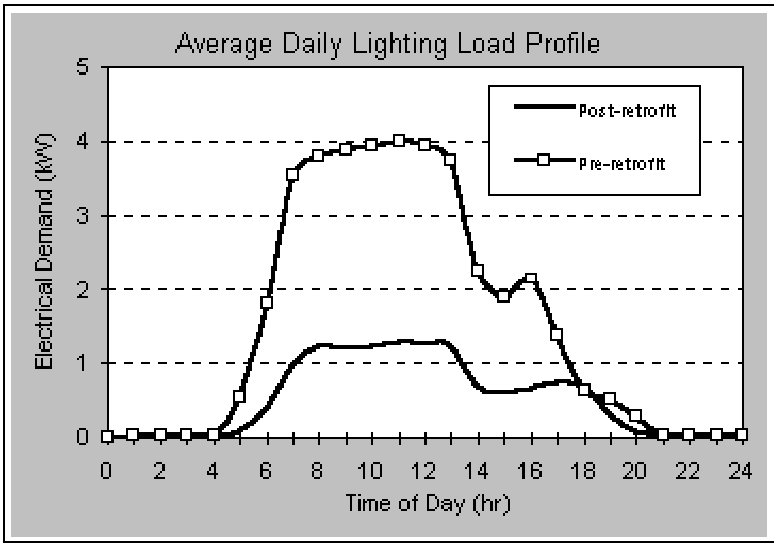


Figure 6-1: Lighting load profile

6.4 Use of lighting voltage controller to reduce lighting energy consumption

A paper manufacturing plant has a connected lighting load of nearly 370 kW. This consists of fluorescent fittings, HPSV,HPMV & CFL lamps for plant, office and area lighting. The lighting load is fed from 3.3 kV bus by 4 nos. of LT transformers. These transformers have lighting loads apart from other loads. Each transformer is connected to a Lighting circuit Distribution box. The total actual load varies between 300 to 350 kW during night. Meters are fitted at each DB to measure power consumption.

The voltage levels at lighting DBs vary between 225 & 240 V. Lighting loads consume less power at lower voltages. The plant lighting voltages were at a level, which could be brought down further. The installation of lighting voltage controllers, of different kVA, on each DB brought down the lighting consumption by 20%. The output voltages were set at 210 V.

Particulars Actual energy savings
No. of DB lighting circuits = **4**
Total Power consumption = **338 kW**

After installation
Total Power consumption= **275 kW**
Annual Total energy savings, lakh kWh = **2.45**
Annual Cost savings, Rs. lakh = **4.89**
Cost of Implementation, Rs. lakh = **12.37**
Simple payback period, Year = **2 year 6 months**

6.5 Use of occupancy control

This project outlines the use of passive infrared control systems for occupancy-based control in an office building. The room area was 55 sq.m and the power consumption measured was 0.67 kW.

There are 4 nos twin tube fixtures having 2 X 36 W tube lights. Two circuits were used; each one controls two nos fixtures. Lights were switched on in the morning and switched off only in the evening.

After implementing the PIR scheme, the ON time of lights reduced from average 50 hours/week to 32.7 hours/week. Cost of implementing the scheme was 130 dollars. Annual saving was found to be 70 dollars. Simple payback period was 2 years.

6.6 Savings in Lighting at Engineering Plant

- Use of Twilight (dawn/dusk) switches to avoid early switching on and delayed switching off of lights resulted in energy savings are 6000 kWh/annum i.e. Rs. 16,000/- per annum, against an investment of Rs.7,700/-.
- Replacement of 12 nos. 125 Watt HPMV lamps by 70 Watt HPSV lamps for streetlights resulted in a saving of 1,900 kWh/annum i.e Rs. 4,456 per annum, against an investment of Rs. 11, 280/-.
- Replacement of 2 nos. 1000 Watt halogen lamps by 250 Watt HPSV lamps resulted in a saving of 4,348 kWh i.e. Rs.9,953/- per annum, against an investment of Rs.8,900/-.
- 22 nos. 250 Watt HPMV lamps (which had been purchased before the energy audit, but yet not installed) were returned and replaced by 15 nos. 150 Watt HPSV lamps. Thus the additional energy consumption of of 9,660 kWh/annum i.e. Rs.23,184/- per annum was avoided, against an investment of Rs. 20,700/-.

6.7 Use of Electronic Ballasts at Electrical Switchgear Manufacturing Plant

24000 conventional electromagnetic ballasts, on 4 feet tube light fittings, have been replaced by electronic ballasts. For 2400 hours/annum operation, the energy saving in tube lights is about 8,83,200 kWh/annum. The additional savings due to reduced heat load on the air-conditioning system is 1,39,090 kWh/annum. The total energy saving is about 19,05,490 kWh/annum i.e. Rs.62.9 lakhs/annum.

6.8 Use of T5 fluorescent lamps in Pharmaceutical industry

Prior to the installation of T5 lamps, the administration, Clean room and R&D areas of the plant were using T8 (36W) lamps. There were about 1500 lamps altogether. The laps were having electromagnetic ballasts which consume about 12 watts/lamp.

After consultations with the manufacturer of T5 tube lights, a deferred payment scheme was evolved where in the cost of the lamp will be repaid in 12 months. Warranty was also given for 12 months, during which if a lamp fails, free replacement is ensured. The price of one T5 lamp was Rs 875/-.

Total power consumption of a 36 W lamp and choke was 48 watts. The new T5 lamp power consumption was 29 Watts including the built in electronic ballast. The same mirror optic fixtures were used.

Energy saving per lamp was found to be 19 watts. Lamps in administration and R&D area used to ON for 10 hours/day. In clean room area, about 600 lamps are kept ON continuously. Assuming 25 days/month, the annual energy saving was about 1.33 lakh kWh/annum. I.e Rs 6.0 lakhs. Total Investment was Rs 13.1 lakhs and payback period of 2.1 years.

6.9 Street lighting modifications at Municipal Corporation

Conventionally, streetlight planning in Vadodara Municipal Corporation was not systematic – it was normally quantity based and not lighting design based. Photometric & Installation terms were totally ignored and the Selection criteria for Lamps & Luminaires ignored.

Conventional Installation Of Street Light

Pole height	8.5 to 10 Meters
Mounting height	7 to 8 meters
Span between Poles	30 Meters
Over hang	1.5 to 3 Meters
Angle of Tilt	15 Degrees
Wattage of Luminaries	250 W MV/SV
Illumination	Very poor, Less than 10 lux

VMC realized the need for uniform & required level of illumination with increased energy efficiency. As a part of this innovation, VMC decided to develop street lighting on new roads in a scientific and systematic manner by implementing "*Code of practice for lighting of Public thoroughfares IS 1944 (Part I & II), 1970".*

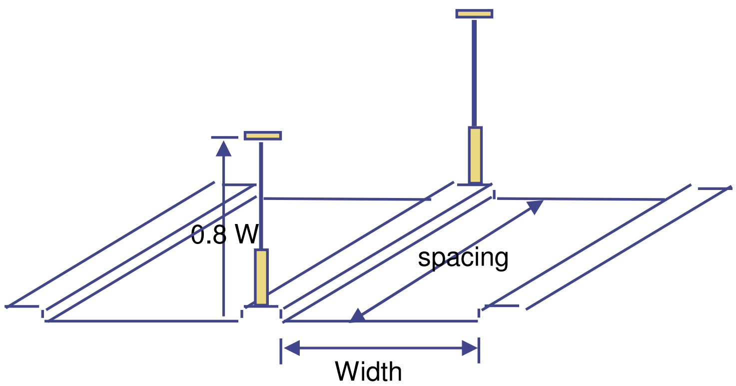
Modifications

Mounting Height	10 Mtrs (7 to 8)
Span between Poles	42 to 44 Mtrs (30)
Over hang	0.9 to 1.25 Mtrs
Angle of Tilt	5 to 10 Degree (depending upon width of road)

Use of better luminaires to focus lighting down.

Comparison of old and new designs per km road length.

		Old design	New Design	
Nos of Poles		33	22	(33% reduction)
Nos of Luminaries	(250W HPSV)	66	44	(33% reduction)
Cost of Installations		Rs 7,57,100	Rs 5,90,000	(22% saving)
Annual Electrical Consumption		74,500 Kwh	50,100 Kwh	(32.75% saving)
Average Illumination		Less than10 Lux	30 Lux with 40% Uniformity	



During different seasons street light ON / OFF timings are changed.

- The ON time varies from 6:00 pm during winters to 7:45 pm during summers.
- The OFF time varies from 7:15 am during winters to 5:30 am during summers.
- It is necessary to fix ON / OFF timings for the entire year according to sunset and sunrise timings.
- For this purpose annual programmable time switches are preferable rather than the conventional manual ones to switch ON & OFF exactly at the required timings throughout the year.
- Almost 5 to 10% savings are achieved by using annual programmable time switch.

The entire capital cost of Rs. 24.1 Million spent to install street lighting on 21 major roads is recoverable in terms of electrical saving within 54 months.

6.10 LED Lamps for signage lighting

Advance Transformer Company, Rosemont, Illinois, manufactures lighting products and a leader in LED drivers. When it came to renovate its corporate identity sign displayed on its headquarters building, the company decided to take a new approach by using light emitting diode (LED) technology.

Advance's 15+ year-old channel-letter sign originally employed neon as its light source, with letter-shaped neon tubes illuminating a number of blue plastic "letter lenses" mounted on the outside of the building.

But after renovating the sign with LumiLeds LEDs powered by its own Advance signPRO™ LED drivers, the resulting improvements in sign brightness and efficiency were literally astounding to every one familiar with the pre-LED and post-LED signs. In the prototype phase, by configuring the LED equivalent of the original neon system and found that it burned 5-6 times brighter than the neon. They subsequently brought the LED wattage down to an optimal lumen output level for the application, but have still been amazed at how much brighter and more evenly lit the new sign is relative to its predecessor. Working with local sign company Quantum Graphics of Alsip, Illinois, LEDs were mounted on the metal inserts and the assemblies were installed with the blue plastic "letter lenses" on the outside of the building, replacing the old neon tubes. The compact, lightweight Advance signPRO LED drivers were mounted inside the building, about 6 to 8 feet remote from the sign itself, in the junction boxes spaced along the length of the sign and formerly occupied by the large, heavy and unwieldy neon power supplies. At a later stage of the project, new blue plastic "letter lenses" were installed as well, replacing the older, faded lenses. Reflecting its ownership by parent company Philips Electronics, the new "Philips-Advance" sign ultimately required about 750 LEDs driven by roughly 25 40-watt and 25-watt Xitanium drivers.

A typically non-traditional application for LEDs based on the large (3 foot 6 inch) height of the sign's letters, the benefits of the conversion have been substantial—e.g., greatly improved energy-efficiency, reduced maintenance requirements, and tremendously enhanced sign brightness and impact. The use of LEDs reduced the sign's input watts from 3,500 to 1,000. In other words, with LEDs, they are enjoying 3-4 times more lumen output than the old neon sign offered at only 1/3 of the input power, which has translated to over $1,500 a year in combined energy savings and reduced maintenance costs.

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