# Module 4

# Lighting Application

# Lesson 20

# Conclusions on Illumination Engineering

This lesson is to conclude the first part of the course on Illumination Engg.

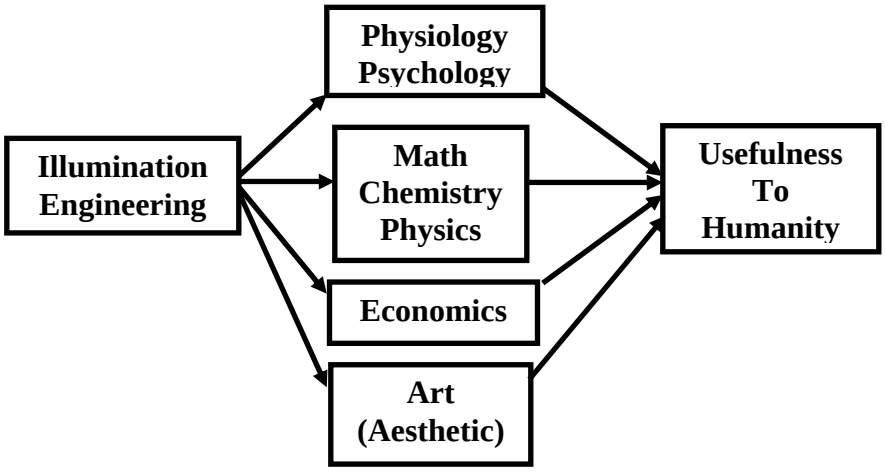


**Fig. 1 Inputs necessary for Illumination Engg**

It recaps the summary of material covered under Illumination Engineering. This forms the 50 % of the course. Nineteen lessons covered need for lighting, behavior of eye, Principles of artificial Lighting, Measurements, calculations & Applications. Figure 1 shows the typical inputs necessary to a person dealing with Illlumination Engg. to make it useful to the humanity.

First lesson stressed the need for lighting .Good lighting aims so that our eyes clearly and pleasantly perceive things. Invariably artificial lighting schemes use some form of physical phenomena. All lighting sources today employ electrical energy. Electrical Energy sources may be DC or AC single phase or three phases. Usual Sources of electrical energy are Hydro & Thermal. Usually load is unbalanced for a practical 3-phase system.

## Radiation

Second lesson deals with radiation. Light is the Radiant energy that provides visual sensation. Human eye can sense over the 380nm (violet) to 700nm (red) wavelength.. Maximal relative energy content of sunlight around 550 nm coincident with maximal luminosity of human eye. Artificial light sources employed may be broadly categorized as Incandescent Lamps and Gas Discharge Lamps. These are based on the following four Physical Processes:

- Incandescence
- Luminescence
- Fluorescence
- Phosphorescence

However, we learn as we go along that Good efficient lighting is obtained by combining luminescence & fluorescence. Having learnt about necessity of artificial Illumination and radiation characteristics, it is time to look at how the eye responds.

## Eyes & Vision

A human eye resembles a camera in structure and function. Important parts of a human eye are Iris / pupil, Lens and Retina. The vision is either Photopic (dealing with fine image details and color discrimination, due to cone cells) or Scotopic (functions in dim light and no image details, due to rod cells). It may be mentioned that Human eye is achromatic in nature. Dispersive power of human eye is little greater than water. Eye is subject to Purkinjee Effect essentially dealing with shift of luminosity and ability of eye to adjust. Best sensitivity of cone cells is around 550nm (i.e. yellowish green hue) and that for rod cells is around 507nm (i.e.bluish green). Good lighting scheme should aim at Prevention of defective vision, Optimization of resources and improving conditions of visibility. Visibility depends on the (Observer Issues) size / details of object, level / quality of illumination, contrast / color and available time. It also depends on efficacy of individual, one's eye defects, optical / physical fatigue and distraction. The Causes of fatigue could be rotating source, focusing on the source of glare, reading double impression. Usually after a days work pupil is dilated a nights rest offsets fatigue due to a days work.Visibility reduces due to eye defects and fatigues. Eye defects are caused due to aging, use or abuse. Hence, good illum0ination looks for producing clear and quick images. Illumination affects physiology as well as psychology, hence quality lighting is important. Factors governing illumination quality are glare, diffusion, direction / focus, composition and distribution. Minimum lighting required for good visibility is 100 ft-cd or more. For good visibility, brightness of surrounding should be greater than 0.01 ft-L & also should be less than that of the test object. Apart from illumination, visibility is talked in terms of visual acuity, visual efficacy, visual speed and visual health.

Acuity is the ability to distinguish details depending upon: brightness of the object, characteristics of light entering the eye, contrast maintained. With age there is a reduction of visual activity, decrease in size & elasticity of pupil, decrease in flexibility of optic lens there by leading to higher levels of illumination requirement. Monochromatic light has good acuity producing distinct images on retina and details are distinguished well. Combination of different colors reduces acuity which is known as Chromatic Aberration. Color sensation by eye has a lag which depends on presentation & cessation of stimulus, rate of rise / fall of sensation (different for various colors) and nature of simultaneous colors & combination of colors

## Laws of Illumination

Next lesson deals with quantification Illumination. Unit of luminous intensity is Candela (Cd), it is the luminous intensity of a surface which is1/600,000 of a blackbody, at the solidification temperature of Platinum (1773 °C) under standard atmospheric pressure. Luminous intensity over 1 steradian solid angle by a source of 1 Cd is called as 1 lumen of light flux (lm). For a point source one talks of MSLI or average intensity x solid angle (mean spherical Luminous intensity). Hence, Luminous Flux = luminous intensity × solid angle. Illuminance is luminous flux per unit area.
Frechner's Law states that the same percentage change in stimulus calculated from the least amount perceptible gives the same change in sensation. Inverse Square Law states that the intensity of illumination produced by a point source varies inversely as square of the distance from the source.

- Lambert's Cosine Law of Incidence –

$$E = \frac{I \times \cos\alpha}{D^2}$$

- Lambert's Cosine law of Emission –

$$I_m = I \times \cos\alpha$$

## Photometry

The next lesson deals with Measurement issues. This is necessary before using any lamp source. This involves comparing it with a primary standard (standard lamp) using a photometric bench. This comparison may be carried out by varying position of standard lamp, by varying position of test lamp or by varying position of the screen on the photometric bench. The lesson also addresses issues pertaining to direction of light. Luminnaires are used for directing the light from a source of light in the desired direction. Types of luminaires employed may be broadly categorized as directed reflectors or diffusing.

## Incandescent Lamps

Having covered generics, we take now each type of lamp in the subsequent lessons. As the name suggests Incandescence employs radiation at high temperature. Incandescent Lamps called Type-B employ tungsten / osmium / tantalum filament, in vacuum, where as those called Type-C: tungsten filament, in inert gas (generally a mixture of Ar & $N_2$). Tungsten being ductile in nature, having high melting point & high radiation efficiency has been widely in use as filament material. However, at higher wattages the filament tends to evaporate and darken the bulb known as lamp darkening. Use of inert gas in incandescent lamps helps in decreasing the rate of evaporation of tungsten & improves efficiency. Further it is observed that higher efficiency is obtained when incandescent lamps are operated at low voltages. Filament characteristics depend on filament length, filament diameter, coil spacing, lead wires, method of mounting, no. of supports, properties of gas employed , gas pressure, bulb size and shape of bulb.

Usually Bulbs are designed for uniform radiation, accurate consumption of power, good efficiency and reasonable rating of life. The most common lamps employed fall under the category of Discharge Lamps, this is covered in the next three lessons.

## Discharge Lamps I

This lesson introduces discharge lamps. They either use Luminescence which produces light radiation by chemical / electrical action on gas / vapor or Fluorescence where in radiation is absorbed at one wavelength & radiated at another wavelength with in visible spectrum. It is to be noted that in lighting arrangements a combination of luminescence & fluorescence increase efficiency far beyond incandescence. Efficiency is measured in terms of lumens per watt of power consumed. Thus discharge lamps consist of discharge of electricity through a tube containing a conducting medium. Conduction is by way of electrons. Types of electron emission may be Electric Field Emission, Thermionic Emission or Photoelectric Emission. So in a discharge lamp gas / vapor is made luminous by an electric discharge whose color / intensity are dependent on gas / vapor used and intensity to some extent proportional to current. Broadly discharge lamps are of two categories 1) Mercury Vapor Lamps, 2) Sodium Vapor Lamps. Mercury vapor lamps tend to give a light bluish green color (deficient in red color). They have a starting electrode provided to initiate the arc. After a run-up time of typically 2 min., mercury vapor discharge starts. Gas at high pressure improves the CRI (color rendering index) of mercury

vapor discharge lamp. With Sodium vapor lamps a pre-heating heater is provided. The lamp glows initially with red color (Neon -vapor discharge which is used as initiating gas) & then turns to orange yellow arc (Sodium vapor discharge)

## Discharge Lamps II

Low pressure Sodium vapor Lamp has outer envelope of inner surface is coated with Indium Oxide & that acts as an IR reflector. While high pressure mercury vapor Lamp gives rise to bluish white line spectrum, together with some phosphors improves color. If some luminescent powder is put in the tubular lamps it enhances brilliancy of light Radiation from Low Pressure Hg-vapor lamp (which is in the UV-region) is impinged on luminescent materials, they reradiate at longer wavelength of visible spectrum. This is the principle of Fluorescent Lamps. Various types of Fluorescent Lamps Day Light Lamp, Standard White Lamp and Soft White Lamp**.** Factors deciding the dimension of fluorescent lamps are luminous efficiency, brightness, lumen output, lumen maintenance and reliable starting. The voltage rating of the lamp is decided by arc length, bulb diameter and lamp current.

## Discharge Lamps III

As already discussed fluorescent lamps are Low Pressure Mercury vapor lamps. For a given current & tube diameter of fluorescent lamp we have voltage directly proportional to length, inversely proportional to diameter and inversely proportional to current through discharge tube. By a $T_{12}$ fluorescent tube we mean that a tube with diameter of 12 × (1/8)" i.e. 1.5". Radiation output from a fluorescent tube is directly proportional to the current density in the tube**.** Fluorescent lamps emit a considerable amount of UV & IR radiation along with visible radiation. UV radiation is converted to visible light using phosphors. There are beneficial applications. UV radiation is beneficial in small quantities. Applications of UV radiation are water purification, detoxifying bacteria, curing of diseases, dye & food processing and employed in producing Vitamin-D in food sources.

Compact Fluorescent Lamps (CFL) are compact, efficient, energy saving, having higher lifetime with reasonably good CRI & near daylight illumination characteristics. Moreover they have all the accessories inbuilt. Hence they are better than traditional fluorescent lamps in terms of economy and efficiency.

## Illumination Systems I

Now using the lamps discussed so far lighting system needs to be developed. These are termed Illumination Systems. This lesson discusses the issue. Illumination system comprises of a lamp (the artificial source of light), luminnaires & the control gear. Commercial luminnaires can be categorized into general or industrial**.** Luminnaires are also characterized by the way they control & direct light i.e. luminous intensity, luminous distribution and number of lamps. Although use of mirrors in luminnaires are avoided as they cause glare modern luminairres do have properly positioned mirrors to act as reflectors. Efficiency of a luminnaire is talked in terms of light output ratio (LOR). This includes both downward as well as upward light. Practically DLOR (downward LOR) is of importance. Luminnaires for hazardous areas should maintain temperature and are hence encapsulated to resist pressure. Gasketted luminnaires which are

completely sealed takes care of handling moisture & dust. Emergency lighting should have self supporting power system to provide lighting when normal lighting fails.

## Illumination Systems II

The II part on Illumination systems addresses control gears. Control gears are the accessories that help in controlling the requisite amount of light flux on the work plane. Gas discharge lamps are constant current devices. Constant current is achieved by use of ballasts. Requirements for good ballasts very less undue power loss, should offer high impedance to audio frequency, should suppress EMI / RFI / TVI, should provide proper starting conditions and should have as high power factor as possible. To improve power factor capacitors are used in series. Excepting high pressure mercury vapor lamps, all lamps have starting voltage more than spark over voltage, hence require starters & igniters to be used as starting devices. Igniters are small three electrode devices which are fired by controlled pulses from small electronic circuits. Apart from local & general lighting dimmers / timers are used in lighting systems to have good control and direction of light.

## Glare

This lesson discusses all important issue of glare, which affects the performance of lighting system. By definition Glare is the brightness within the field of vision. Effects of glare injures the eye, disturbs the nervous system, causes annoyance, discomfort & fatigue, reduces efficiency of work, interferes with clear vision and risk of accident increases. Glare could be direct bright luminaire in the field of vision or Reflected Glare due to reflection from a glossy surface. Reflected glare causes more annoyance than direct glare. Direct glare can be minimized by mounting luminaires well above the line of vision. When glare level impairs the vision, it is said to be Disability Glare. If eye is subjected to glare for a long time results in Discomfort Glare.
Glare Evaluation Systems in vogue are American system (VCP), British system (Glare Index) and European system (Luminance Curves). Luminance angle limit for luminaires is between $45° < \gamma < 85°$. Other source of glare being windows. It is of two types i.e. veiling it can be prevented by using curtains, blinds or louvers. Reflections and reflected glare. The Techniques employed for minimization of glare from luminaires are not locating luminaires in the forbidden zone, increasing light from sideways or using luminaires having large surface area.

In addition CRF (Contrast Rendition Factor) – influence of lighting on task contrast & task visibility. By definition Task Visibility is the ratio of Given Emission and Sphere Illuminance. Where Sphere Illuminance is the Illuminance by the source providing equal luminous intensity in all directions. Also known as ESI (Equal Spherical Illuminance).

All this means three categories of lighting are required they are general lighting local lighting and a combination of local & general lighting. Combination of general & local lighting are preferred to avoid glare

## Color

Next lesson deals with issues pertaining to color. Three Components of Color Perception are Source of Illumination, Object Illuminated and detector. Source color tells us about spectral

power distribution of the light source. Object Color denotes appearance of the object due to selective appearance of incident light. Perceived Color is a result of object characteristics together with viewing conditions. Color characteristics are assessed by Color Rendering Index (CRI). CRI is appearance of an object under test source in comparison to appearance under standard light conditions, like those under natural day light conditions. Color standards follow Munsell system or CIE system.

## Interior Lighting

Next lesson discusses recommendations pertaining to interior lighting. Good interior lighting is governed by intensity (ample to see clearly & distinctly), distribution ( maintained nearly uniform), using soft & well diffused light, color (depending on taste / purpose) with source located well above plane of vision (to avoid glare). Although shadows are required for actuating depth of the object. It shouldn't be too apparent abruptly or dense. Also it shouldn't be harsh & needs to be toned down. General lighting controlled to suit psychological moods. Natural / daylight illumination constantly varies with weather, time of day & season. We design the window opening such that the minimum daylight illuminance is twice the artificial illuminance that is sufficient for the required task Location of lamps depends on candle power, maximum allowable spacing, height at which located, position of obstructions ( if any) and required distribution of light. Color reflectance from the interior finishing affects utilization. With all this like any other system interior lighting needs to be periodically checked & maintained. It is advisable that lamps are replaced when they reach 70% of its life or when illumination level falls below standard level. Moreover it is preferred to change lamps in groups rather than individually. Next important issue pertains external lighting. This consists of Sports lighting and Road Lighting.

## Sports Lighting

This lesson details sport lighting recommendation. Sports Lighting has four user groups in mind Players, officials, Spectators and Media. Category of sport is made as A, B or C depending on the size of the ball/object and place of the game. "C" denotes fast paced game with small sized object. Horizontal Illuminance, vertical illuminance and illuminance uniformity are crucial for this category of lighting. Color appearance is very important for media coverage. Considering all user groups a CRI of 65 and color temperature of at least 4000 K is recommended.

## Road Lighting

This lesson looks into Road Lighting recommendations. The aim of the Road lighting is for safe, quick and comfortable movement of traffic. From this view point, there are five categories of Roads, A, B, C, D and E depending on the type and density of traffic. Mostly sodium vapor lamps are preferred on the roads. At junctions mercury vapor lamps may be provided to highlight the junction.. Tunnel lighting also needs to be carried out in such a way as to gradually change the light level. Tunnels are lit during the day as well as night. Residential areas usually employ post top lanterns

## Lighting Calculations

This lesson discusses lighting calculation methods. No doubt, today there are many software packages are available, but one needs to have a physical basis of assessing the results. Therefore, it is necessary to know how manual calculations are done. Illuminance level depends on the nature of working environment & is specified in terms of horizontal, vertical & inclined illuminance. These are obtained graphically from numerical tables. Isolux diagrams are used for calculation of illumnance & luminance levels. A room may be divided into four zones for purposes of calculation of illumination level as work plane, wall area below luminaire, on the frieze (wall area above luminaire) and ceiling

Horizontal illuminance is given by:

$$E_{avg} = \frac{\phi_{tot}}{A} \times UF \times M$$

Utilization Factor (UF) depends on light distribution of luminaire and reflectance of ceiling / walls

Vertical Illumination is given by: $E_{avg} = \frac{\phi_{tot}}{A} \times UF \times M$

Luminaire Luminance is given by: $L_{\gamma} = \frac{I_{\gamma}}{A_{\gamma}}$

where Aγ is the apparent area in the specified direction & is given by

$$A_{\gamma} = A_h \times \cos\gamma + A_v \times \sin\gamma$$

## Lighting Application

Having had a look at all aspects of lighting this lesson looks at lighting applications. Industrial lighting is dictated by nature of work, shape of space and ceiling structures. Industrial lighting is classified as single storey without skylight, multi storey, single storey with skylight or high bay light. Additional lighting is used if general lighting doesn't meet requirements viz. illuminated magnifying glass, stroboscopic lighting, monochromatic light etc. Fluorescent lamps with louvres & diffusers are preferred for office lighting. Vertical illumination becomes necessary for blackboards in educational institutions. In shops, restaurants & other commercial places, local & color lighting is employed to highlight a particular place / product. In hospitals lighting is done according to convenience of patients, technicians & doctors. Operation theatres need shadow free lighting. ICU & X-ray rooms have low luminance levels. Some of the Indian Standards for lighting application are also covered in this lesson. Details can be had from hand book of BIS. Mostly adopted from CIE