3.6 COLOUR – LUMINOUS EFFICIENCY FUNCTION

Colour is the characteristic of human visual perception described through colour categories such as red, blue, yellow, green, orange and purple.

This perception of colour derives from the stimulation of cone cells by electromagnetic radiation spectrum of light.

Colour categories are associated with objects through the wavelength of the light reflected from them. This reflection is governed by the object's physical properties such as light absorption, emission spectra etc.

The science of colour is called chromatics, calorimetry or simply colour science. It includes the perception of colour by the human eye and brain, the origin of colour in materials, color theory in art and the physics of electromagnetic radiation in the visible range.

A color space is a specific organization of colours. By defining a colour space, colours can be identified numerically by coordinates.

An RGB (Red, Green, Blue) colour space is any additive colour space based on the RGB colour medal. A particular RGB colour space is defined by the three characteristics of the red, green and blue additive primaries. It can produce any chromaticity that is the triangle defined by those primary colours.

The RGB colour space for instance is a colour space corresponding to human trichromacy and to the three cone cell types. These cone cells respond to three bands of light; long wavelengths peak near (564 - 580 nm) red, medium wavelengths peaking near (534 - 545 nm) green and short wavelength light near (420 - 440 nm) blue.

Luminosity function or Luminous efficiency function

The luminous efficiency function describes the average spectral sensitivity of human visual perception of brightness.

It is based on subjective judgements of which of a pair of different coloured lights is brighter to describe relative sensitivity to light of different wavelengths. (Fig 3.6.1)

There are two luminosity functions in common use. For everyday the photopic luminosity function best approximates the response of the human eye. For low light levels, the response of the human eye changes and the scotopic curve applies.

The luminous flux, ϕ_{lum} is obtained from the radiometric light power using the equation

$$\Phi_{lum} = 683\frac{lm}{w}\int_{\lambda} v(\lambda)p(\lambda)d\lambda$$

where $P(\lambda)$ is the power spectral density (ie.,) the light emitted per unit wavelength and the prefactor 683 mW is a normalization factor. $V(lambda)$ is eye sensitivity function.

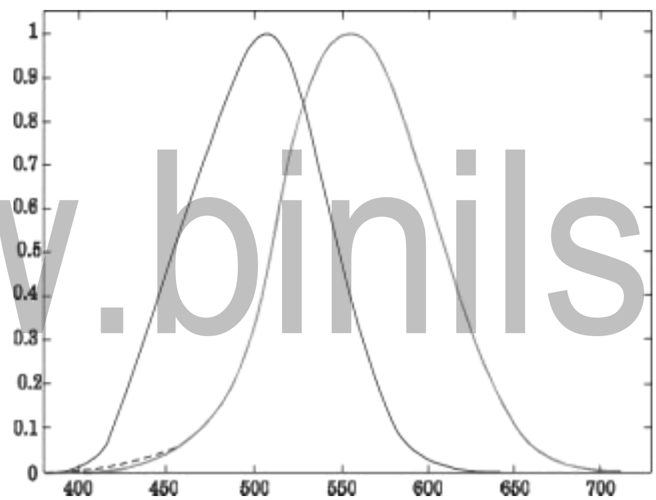


Fig. 3.6.1 Photopic, scotopic luminosity functions

The optical power emitted by a light source is given by

$$\boxed{\boldsymbol{P} = \int_{\lambda} \boldsymbol{P}(\lambda) \cdot \boldsymbol{d}\lambda}$$

The luminous efficiency of optical radiation is measured in units of lumens per watt of optical power. It is the conversion efficiency from optical power to luminous flux. The luminous efficiency is defined as

$$\text{Efficiency} = \frac{\phi_{lum}}{P}$$

Luminous efficiency = $\frac{\phi_{lum}}{IV}$

where the product (IV) is the electrical input power of the device.

For light sources with a perfect electrical power to optical power conversion, the luminous source efficiency is equal to the luminous efficiency of radiation.

3.9 DAYLIGHT DESIGN OF WINDOWS

Daylighting is the practice of placing windows or other openings and reflective surfaces so that during the day natural light provides effective internal lighting.

The particular attention is given to daylighting while designing a building. The aim is to maximize visual comfort or to reduce energy use.

Energy savings can be achieved from the reduced use of artificial (electric) lighting or from passive solar heating.

The amount of daylight received in an internal space can be analyzed by undertaking a daylight factor calculations.

Windows

Windows is used for allowing light, heat and sound. Majority heat gain and heat loss occurs. Double layered window is used to reduce noise and even heat, cold and other environmental factors.

If window height is increased from floor, light entering the building will be reduced. And ceiling from the floor should be the height of 2.5 m - 3 m is important for better lighting.

Windows on multiple orientations must usually be combined to produce the right mix of light for the building depending on climate and latitude.

Daylight window

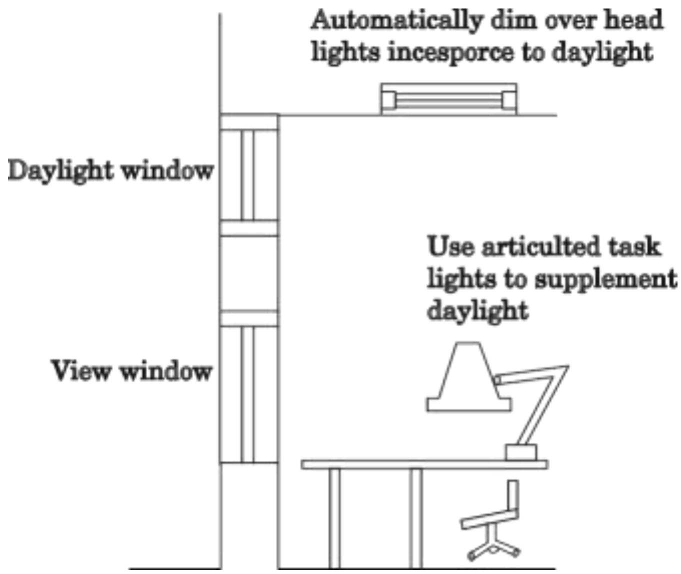


Fig. 3.9.1 Daylight window

Preferred Window-Wall Ratios (WWR)

For view and a positive connection out of doors, a minimum 20 percent to 30 percent ratio of window area in wall area is prefered.

Glazing the wall areas below desk height (0-30 inch above the floor) on befits for day light.

High windows

High continuous windows are more effective than individual or vertical windows, to distribute light deeper into the space.

Try to locate the top of windows close to ceiling line (for day lighting) but locate the bottom of windows no higher than 48 inches (for view).

Consider separating windows into two horizontal strips, one at eye level for view, and one above to maximize daylight penetration.

Light shelves

Consider using interior or exterior light shelves between the daylight window and the view window. These are effective for achieving greater uniforming of day lighting, and for extending ambient levels of light onto the ceiling and deeper into the space.

Some expertise and analysis will be required to design an effective light shelf.

Window and office placement

Daylighting is more cost effective if open plan workstations are located on the north and south side of the building. The open plan areas are more continuously occupied and achieve lower savings.

The open configuration also absorbs less light, and inter- reflections provide a more uniform distribution of light deep into the space.

The control of heat and glare on the east and west facades is difficult. The daylight and views are blocked in an effort to properly control the low sun angles.

By placing private offices on the east and west, occupants can individually control their blinds, and thereby control thermal discomfort and glare.

Interior sun control

Similar to exterior sun control, horizontal blinds on the south windows and vertical blinds on the east and west are most effective.

In northern latitudes, low angles of sun can enter the north windows on summer movings and afternoons.

Vertical blinds that retract fully for the middle of the day are recommended for these conditions. Perforated blinds and translucents shades may cause glare when hit by direct sunlight.

3.0 Introduction

The whole discipline of optical measurement techniques can be subdivided into two areas of **photometry** and **radiometry**.

The central problem of photometry is the determination of optical quantities closely related to the sensitivity of the human eye.

The radiometry deals with the measurement of energy per unit time (= power, given in watts) emitted by light sources imping on a particular surface. Thus, the units of all radiometric
quantities are based on **watts** (***W***).

The symbols for radiometric quantities are denoted with the subscript '*e*' for energy. Similarly, radiometric quantities given as a function of wavelength are labeled with the prefix "spectral" and the subscript "λ" for example spectral radiant power ϕ_λ.

The definitions of radiometric quantities cannot be understood without a basic comprehension of differential quantities.

The differential quantities $d\,\lambda$, dA and $d\,\Omega$ can be regarded as tiny intervals or elements $\Delta\,\lambda$, $\Delta\,A$ and $\Delta\,\Omega$ of the respective quantity.

As a consequence of the fact that these intervals or elements are very small, radiometric quantities can be considered constant over the range defined by $d\,\lambda$, dA and/or $d\,\Omega$.

Similarly, $d\,\phi_e$, dI_e, dL_e and dE_e can be regarded as small portions which add up to the total value of the respective quantities.

3.11 Models of artificial skies

a) Model studies can be used to predict daylight penetration into any building. This is the only reliable prediction method in the case of unusual situations, complex geometries or heavily obstructed windows.

b) The artificial sky simulates the standard overcast sky conditions by giving uniform luminance.

c) There are two basic forms of artificial sky: the hemispherical and the rectangular.

d) Hemispherical artificial sky is mostly constructed as a diffusely reflective opaque dome surface, illuminated from below, or a translucent dome with lighting mounted behind

e) The rectangular sky has a luminous ceiling and four strictly vertical walls lined with mirrors. The multiple reflections between accurately parallel opposing mirrors give an infinite horizon effect. The mirror glass absorption through multiple reflections ensures a luminance distribution.

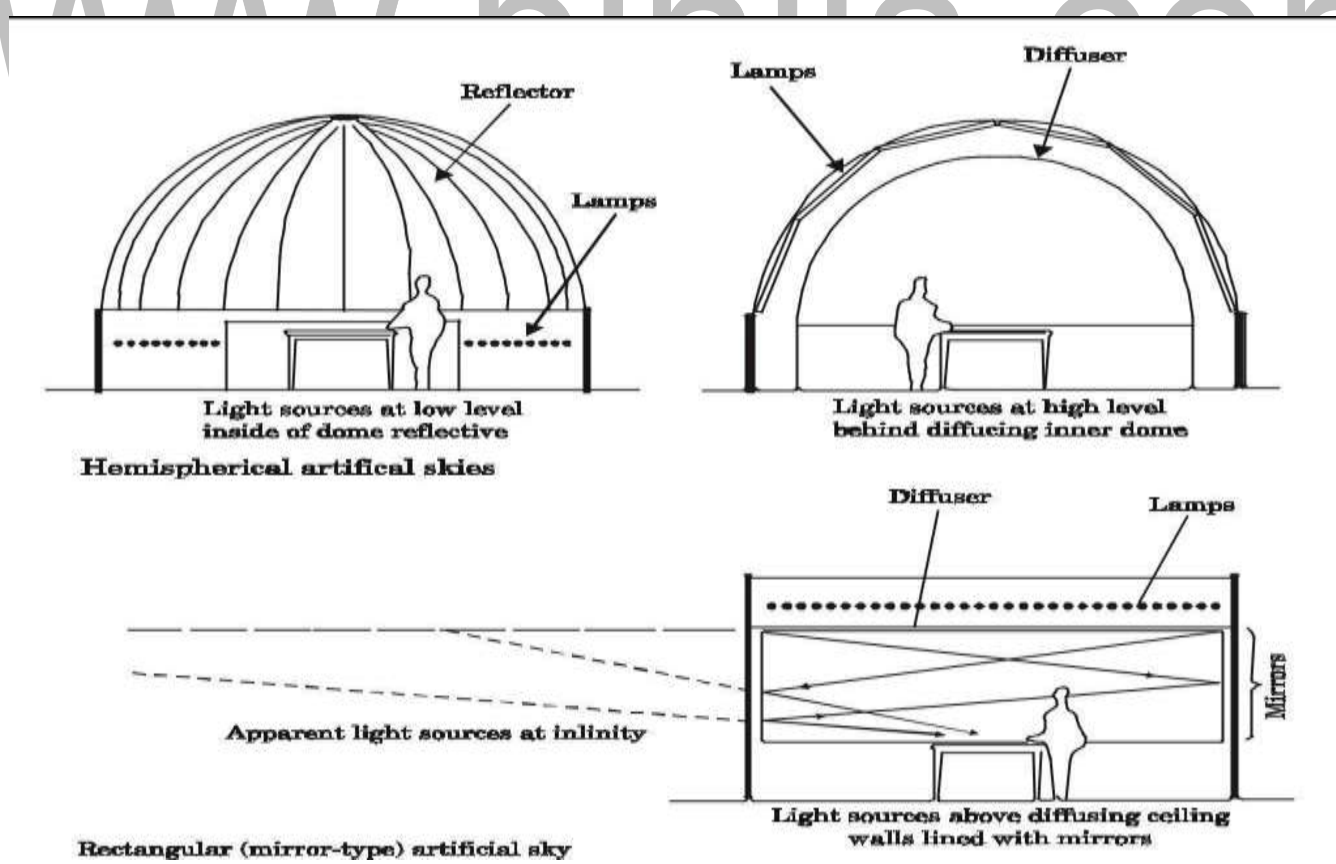


Fig:3.11.1- Models of artificial skies

Principles of artificial lighting

- Artificial lighting is the lighting which is man-made such as fluorescent, tungsten, sodium and mercury vapor lamp etc.
- Artificial lights are the other sources of light which is developed to compensate for or assist the natural light. It will have different frequencies and wavelengths that determine the light color.
- Artificial lighting can be done in three ways: Direct, Semi-direct (or) Reflected and Indirect.

a) **Direct light** is the undiffused & unfiltered light traveling directly from the light source to the subject. Direct light is like full sun on a clear day.

b) **Semi-direct light** is the light proceeding from a light source and bouncing off a remote surface and reflecting onto an object. Light reflected into an umbrella with a black backing is an example of semi-direct light. It is visible but brightness will be less.

c) **Indirect light** is invisible but it falls on working area. The combination of all these 3 types of lighting can be used on any systems.

- The most common artificial light sources are as follows:

Incandescent lamp –Light is produced by passing current through a filament (Tungsten). This method is considered wasteful as most of the energy entering the lamp leaves it as heat instead of visible light.

Compact fluorescent lamp (CFL) - It was designed as a more efficient replacement for incandescent lamp. It is supplied with the fixing system (screw or bayonet).

Fluorescent tubes - It is the main form of lighting for offices and commercial buildings. They are a form of gas discharge lamp. They are covered in a thin glass cylinder.

Discharge lamps - They work by striking an electrical arc between two electrodes, causing a filter gas to give off light.

Light Emitting Diode (LED) - LEDs use semi-conductors to convert electrical energy directly into light. They are only recently becoming available as a light source for lighting purposes. LED torches are becoming very popular, as they provide a far longer battery life than other types of light.

Supplementary artificial lighting

There are two forms of artificial lighting as follows: Indoor lighting & Outdoor lighting

Indoor lighting

Indoor lighting is usually accomplished using light fixtures (also called Luminaire) and it is a key part of interior design. Luminaire is a lighting unit consisting of one or more electric lamps with all of the necessary parts and wiring. Light fixtures are classified according to the light function, lamp type and installation method.

Let's discuss light fixtures based on light function which are further classified according to the function of aim of using it.

a)Ambient lighting (general lighting) –This lighting provides an area with overall illumination. It radiates a comfortable level of brightness without glare, and allows us to see and walk safely. It is often provided by traditional pendant type fixtures, down lights, ceiling mounted fixtures. Having a central source of ambient light in all rooms is fundamental to a good lighting plan.

b)Task lighting –It is aimed at a specific task. It is a way to provide more light on a specific area to perform a task that requires more light than the ambient fixtures can give.

It can be provided by recessed and tack lighting, pendant lighting and under cabinet lighting, as well as portable floor and desk lamps.

c)Accent lighting –It is also a sort of a directional lighting that adds drama to a place by creating visual interest. It is used to draw the eye to houseplants, paintings, sculptures and other prized possessions. It is usually provided by recessed and track lighting or wall-mounted picture lights.

d)Guidance lighting –It is designed to help us see our way safely. The light in your closet,light near door bell, night lights, path lighting and motion lights are good examples of informational lighting.

e)Decorative lighting –It is used to decorate the interior of a room or auditorium. Light strips, pendants, chandeliers are examples of light fixtures that draw attention and add beauty to the place.

3.4 Photometry

It deals with the measurements of the intensity of light emitted by a source, its illuminating power or intensity of illumination of a surface is called photometry.

Luminous flux ((ϕ)

Light energy emitted per second from a light source. Unit is lumen (lm).

If ϕ is the luminous flux radiated by a source within a solid angle Ω in any particular direction
then luminous intensity is given by

$$I = \frac{\phi}{\Omega}$$

If ϕ is measured in lumens and Ω in steradian.

Then
$I = \frac{\text{lumen}}{\text{steradia}}$ **or** candela

Unit: Hence, **unit of luminous intensity is Candela(Cd).**

Lumen

It is the luminous flux emitted from a standard candle.

Luminous intensity or illuminating power (I)

Illuminating power of a source in any direction is defined as the luminous flux emitted per unit solid angle in that direction.

Candela

A light has a luminous intensity of 1 candela if it emits 1 lumen (1 lm per steradian.)

Illumination or intensity of illumination (E)

The luminous flux incident normally per unit area of the surface is called illumination or intensity of illumination.

If ϕ is the total flux falling over an area *A*, then

llumination, $\boldsymbol{E} = \frac{\phi}{\square}$

If ϕ is measured in lumen and *A* is in metre^2.

$$E = \frac{lumen}{metre^2}$$

i.e., lumen per metre^2 or lux.

COSINES LAW

In optics, Lambert's cosine law states **that the radiant intensity or luminous intensity observed from an ideal diffusely reflecting surface is directly proportional to the cosine of the angle between the direction of the incident light and the surface normal.** The law is also known as cosine emission law or Lambert's emission law.

- The law is also known as cosine emission law or Lambert's emission law.
- A surface which obeys Lambert's law is said to be Lambertian and exhibits Lambertian reflectance. Such a surface has the same radiance when viewed from any angle.

Illuminanation: It is amount of light flux that is incident upon unit area of the given surface. Illuminance is also called as illumination

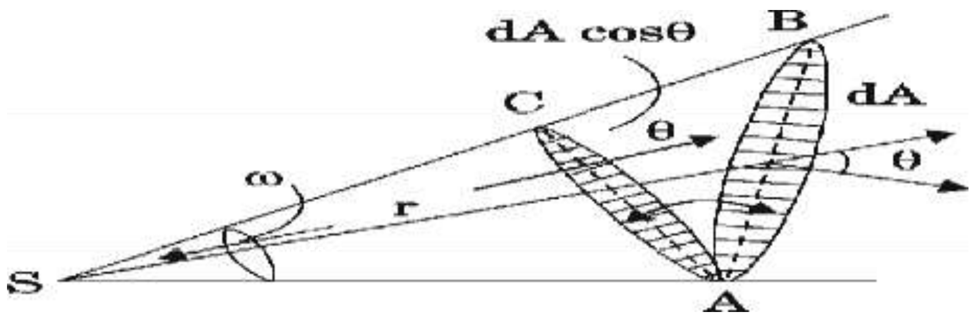


Fig:3.4.1- Light flux upon some area

If *dF* is the elemental light flux incident on an elementary area *dA* then illuminance *E* is defined as

$$\boldsymbol{E} = \frac{df}{dA}$$

Its units are lumen per sqmetre.

Consider an elementary surface *AB* of area *dA* illuminated by the source *S* [fig 3.4.1] which subtends solid angle 'Ω' at the point source *S*.

It light flux '*F*' lumens falls on the area *AB* then Intensity of illumination

$$E = \frac{F}{dA} \quad \text{................(1)}$$

If *L* is the illuminating power or luminous intensity of the source, it is defined as luminous flux per unit solid angle.

$$L = \frac{F}{\Omega}$$

$$\text{(or)} \quad F = L\Omega$$

Substituting for *F* in equation (1) we have

Intensity of Illumination $E = \frac{L\Omega}{dA}$

If 'r' is the distance of the surface from ''dA'' from the source then

$$\Omega = \frac{dA\cos\theta}{r^2}$$

Substituting for ω in equation (2), we obtain

$$\text{Intensity of illumination E} = \frac{LdACos\theta}{r^2 dA}$$

$$E = \frac{LCos\theta}{r^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Equation (3) is known as Lambert's Cosine Law.

It states that intensity of illuminance is

i) directly proportional to cosine of the angle of incidence of light radiation on the surface and

ii) inversely proportional to the square of distance between the surface and source.

Special case:

If θ = 0 degrees

E = $\frac{L}{r^2}$

INVERSE SQUARE LAW

The inverse square law defines the relationship between the irradiance from a point source and distance. It states that the intensity per unit area is inversely proportional to the square of the distance.

Consider a point source '*S*' of light. It is radiating equally in all directions. Draw two concentric spheres (fig. 3.4.2) of radii r_1 and r_2 around of source. Let the energy radiating from the source per sec be *Q*.

This energy will fall normally on the surface of sphere(1). Energy incident per sec on unit area of sphere having radius

r_1 is $I = \frac{\square}{4\pi r^2}$ .... (1)

Since light is falling normally,here θ = 0 degrees, cosθ = 1

Similarly for sphere of radius r_2 and incident energy on unit area

$I_2 = \frac{Q}{4\pi r_2^2}$ ....(2)

From (1) & (2)

$\frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}$....................(3)

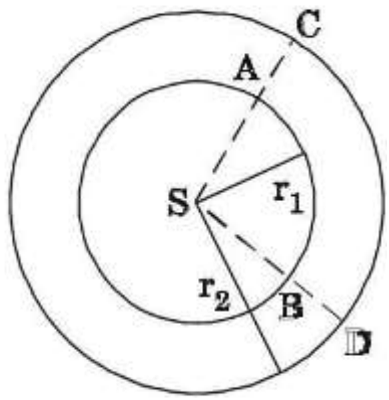


Fig:3.4.1-Concentric Spheres of radius r_1 and r_2

It states that amount of light energy falling on a given surface is inversely proportional to the square of the distance of the Surface from Source.

If we consider two surfaces $AB\ dA_1$ and $CD dA_2$ on the two spheres then energy incident, per sec over them is

$$E_1 = \frac{QdA_1}{4\pi r_1^2}$$

$$E_1 = \frac{QdA_2}{4\pi r_2^2}$$

$$\frac{QdA_1}{4\pi r_1^2} = \frac{QdA_2}{4\pi r_2^2}$$

Hence $E_1 = E_2$

$$\frac{QdA_1}{4\pi r_1^2} = \frac{QdA_2}{4\pi r_2^2}$$

$$\frac{dA_1}{dA_2} = \frac{r_1^2}{r_2^2}$$

or from eqn (2) & (3)

$$\frac{I_1}{I_2} = \frac{dA_1}{dA_2}$$

According to the inverse square law, illuminance on a surface decreases inversely proportional to the square of the distance between the light source and illuminated surface.

Inverse square law is applied to obtain luminous intensity.

3.10 PRINCIPLES OF ARTIFICIAL LIGHT

Light can be produced by nature or by humans. "Artificial" light is typically produced by lighting systems that transform electrical energy into light.

Nearly all lighting systems do so either by passing an electrical current or through gases until they excited to and produce light energy.

Incandescent light sources are an example of the first method, called incandescence. Current is passed through a filament, which heats until it glows. This method is considered wasteful (most of the energy entering the lamp leaves it as heat instead of visible light. Other light sources were pioneered that relay on the gaseous discharge method, including fluorescent, high-intensity discharge (HID) and low-pressure sodium light sources.

A typical lighting system is comprised of one or more of these light sources, called the lamps. Fluorescent, HID and low-pressure sodium lamps operate with a ballast, a device that starts the lamp and regulates its operation. Lamps and ballasts in turn are part of the luminaire, or light fixture, which houses the system and includes other components that distribute the light in a controlled pattern.

Artificial lighting is the lighting which is man-made such as flourescent, tungsten, sodium and mercury vapour lamp etc., It may be used as a supplement to natural light as natural light is not available.

CATEGORIES OF LIGHT

DIRECT

Direct light is light travelling unimpeded from the light source to the subject, not filtered, diffused, reflected or altered. Direct light is like full sun on a clear day.

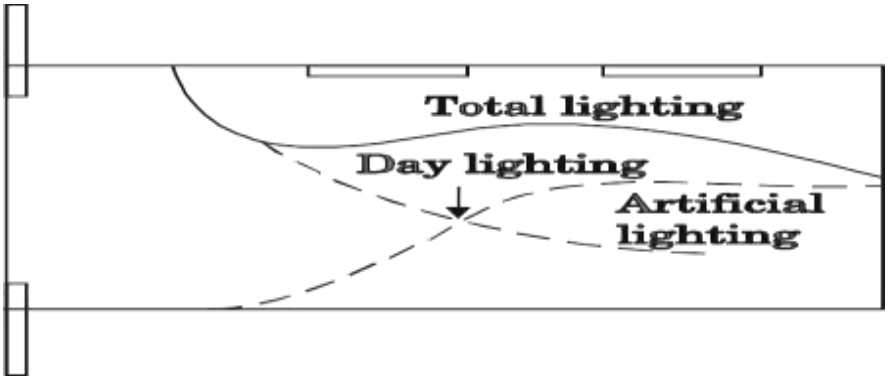


Fig. 3.10.1- CATEGORIES OF LIGHT

The effect of extensive use of lighting is direct, impressive and active both ambient light and artificial light. (as in the use of flash fill illumination; or in a studio environment where two or more light sources are used).

REFLECTED

Second type is **Semidirect (or) Reflected lighting**. It is visible but brightness will be less.

Reflected light is light proceeding from a light source and bouncing off a remote surface and reflecting onto an object. Light reflected into an umbrella with a black backing is an example of reflected light.

Light can also be reflected off a white wall or a silver or white card and directed toward a subject. Reflected light is less directional than an unimpeded source light.

The third type is **Indirect lighting**. It is invisible but it falls on working area.

The combination of 3 types of lighting can be used on any lighting systems. All the methods gives pain to the eyes, if proper lighting is not set in. Table lamp is useful but it is harmful to the eyes.

First: Artificial light sources

Artificial light sources are categorized by the technology used to produce the light. The five most common light sources are as follows:

1. Incandescent lamp

2. Compact fluorescent lamp
3. Fluorescent tube
4. Discharge lamps
5. Light Emitting Diode (LED)

1-Incandescent lamp

Until recently the most common electric light source is the incandescent lamp. This is still widely used, although it has relatively low energy efficiency. It leads to replacement by other more efficient lamps such as the CFL. (fig. 3.10.2).

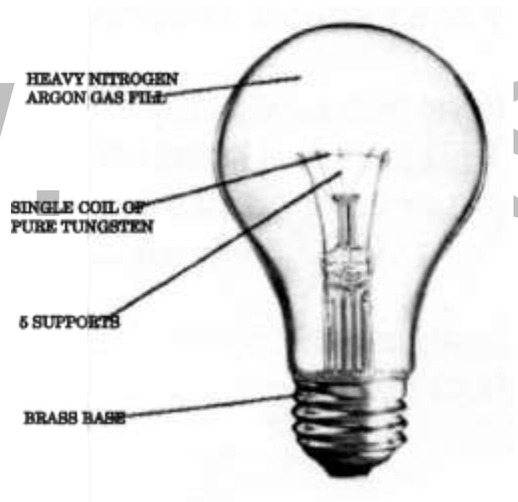


Fig. 3.10.2- Incandescent lamp

A larger variety of shapes, sizes and power is available, as well as different colour ranges. Typical lamps for household use range from about 40 to 100 W.

2. Compact fluorescent lamp

The Compact Fluorescent Lamp (CFL) is designed as a more efficient replacement for incandescent lamp. It can be used in many light fittings designed for incandescent lamps. (Fig. 3.10.3)

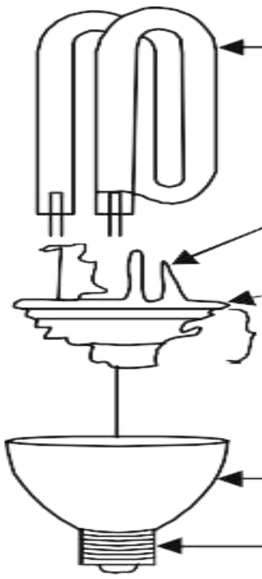


Fig. 3.10.3 Compact fluorescent lamp

3. Fluorescent tube

Fluorescent tubes are the main form of lighting for offices and commercial buildings.

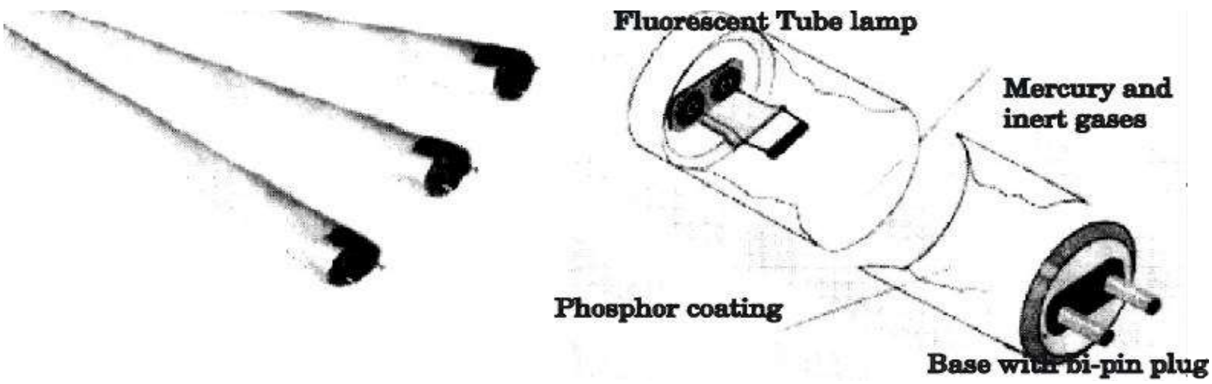


Fig. 3.10.4- Fluorescent tube

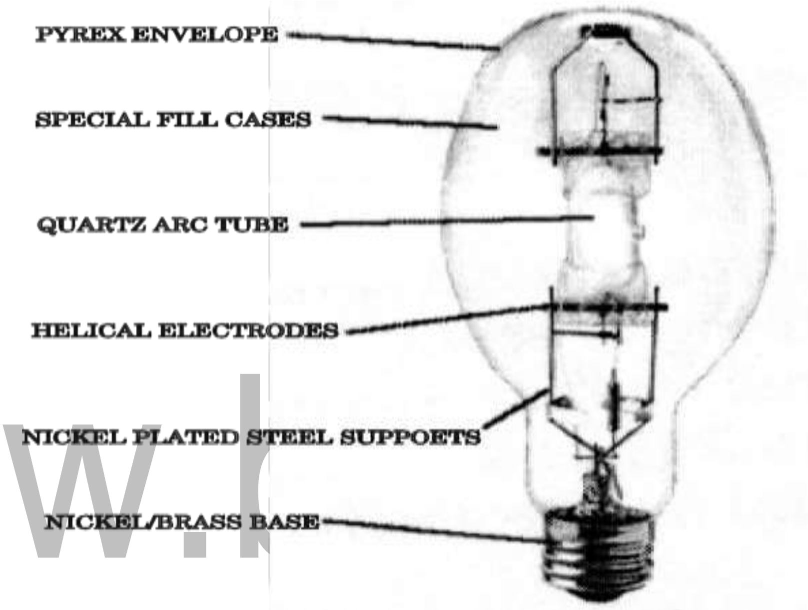
They are a form of gas discharge lamp. They are formed in a long thin glass cylinder. These lights have contacts at either end that secure them to the fitting (or luminaire) and provide the electrical connection.

The tube contains mercury vapour at low pressure. The inner wall of the glass is coated with a phosphor that reacts to ultra-violet radiation. When electricity is passed through the vapour it emits UV radiation that is converted by the phosphor to visible light. (Fig. 3.10.4).

4. Discharge lamps

Discharge lamps work by striking an electrical arc between two electrodes, arc between two electrodes, causing a filter gas to give off light.

Different metals and filler gasses can be used to provide a range of colour



and brightness. (Fig. 3.10.5)

Fig. 3.10.5 Discharge lamps

Discharge lamps provide high luminous efficacy combined with long life, resulting in the most economical light source available.

5. Light Emitting Diode (LED)

LEDs use semi-conductors to convert electrical energy directly into light. They are only recently becoming available as a light source for lighting purposes. They are highly efficient and long lasting. (Fig. 3.10.6)

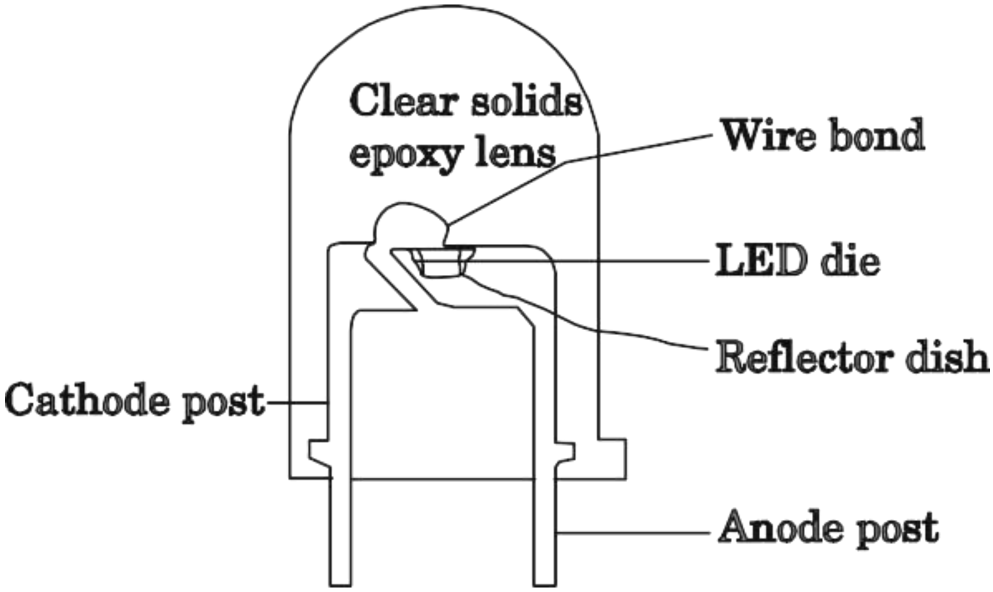


Fig. 3.10.6 Light Emitting Diode (LED)

LED torches are becoming very popular, as they provide a far longer battery life than other types of light source.

Second: Forms of Artificial lighting

There are two forms for Artificial lighting as follows:

1. **Indoor lighting**
2. **Outdoor lighting**

1. Indoor lighting

Indoor lighting is usually accomplished using light fixtures, and it is a key part of interior design.

Luminaire is a device that distributes filters or transforms the light emitted from one or more lamps. The luminaire includes all the parts necessary for fixing and protecting the lamps, except the lamps themselves.

In some cases, luminaries also include the necessary circuit auxiliaries, together with the means for connecting them to the electric supply. The basic physical principles used in optical luminaire are reflection, absorption, transmission and refraction.

Types of Indoor Light fixtures/luminaries

Light fixtures/Luminaries are classified according to the following:

1. The light function.
2. Lamp type.
3. Installation method.
4. The percentage of light output above and below the horizontal.

Types of Light fixtures according to light function

There are five basic types of light fixtures according to the function of aim of using it as follows:

- Ambient (general lighting).
- Task
- Accent
- Informational lighting/Guidance Lighting
- Decorative lighting

Ambient lighting provides an area with overall illumination. Also known as general lighting, it radiates a comfortable level of brightness without glare and allows you to see and walk about safely.

Ambient lighting is often provided by traditional pendant type fixtures, down lights, chandeliers, or ceiling mounted fixtures etc.

Task lighting should be free of distracting glare and shadows and should be bright enough to prevent eye strain.

Informational lighting (Guidance lighting)

It is designed to help us see our way safely. The light in your closet, the light by your door bell, and night lights, as well as path lighting and motion lights, are all good examples of informational lighting.

Decorative lighting

Light strips, pendants, chandeliers, and sconces are all examples of light fixtures that draw attention to themselves and add character to the place being lighted. Many are also used for general lighting. (Fig. 3.10.7)

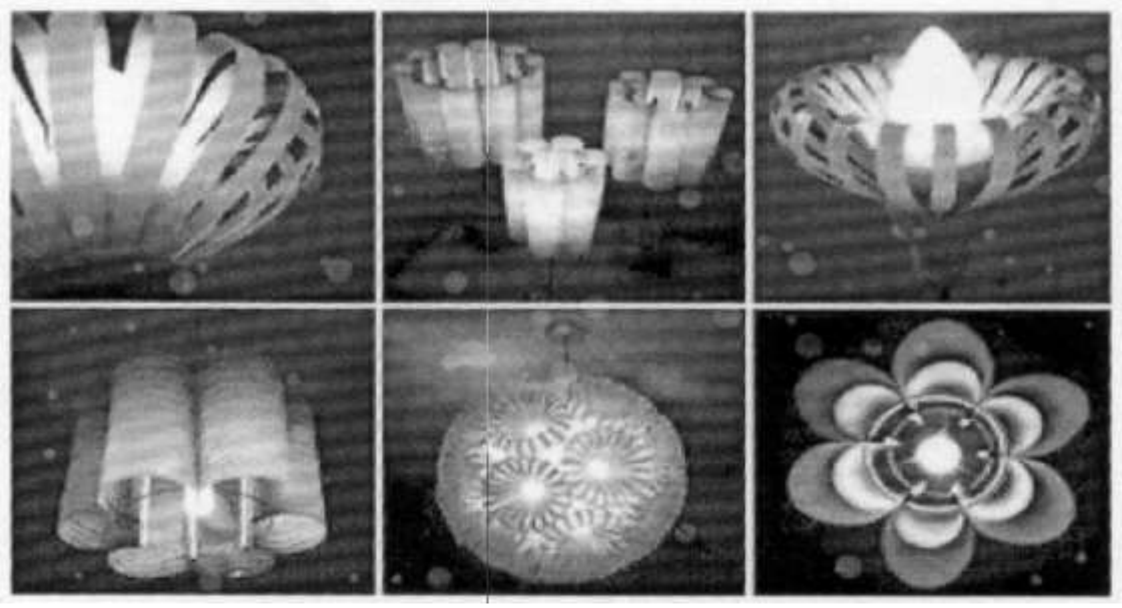


Fig. 3.10.7 Decorative lighting

3.1 RADIATION QUANTITIES

Solid angle

The geometric quantity of a **solid angle** Ω quantifies a part of an observer's visual field.

If we imagine an observer located at point *P*, his full visual field can be described by a sphere of arbitrary radius *r* (Fig. 3.1.1).

Then, a certain part of this full visual field defines an area *A* on the sphere's surface and the solid angle Ω is defined by

$$\Omega = \frac{A}{r^2}$$

As the area *A* is proportional to r^2, this fraction is independent of *r*.

If we want to calculate the solid angle determined by a cone, as shown in fig. 3.1.1 area *A* is the area of a spherical calotte.

However, as the solid angle is not only defined for conical parts of the full visual field, area *A* can be any arbitrary shape on the sphere's surface.

Although Ω is dimensionless, it is common to use the unit **steradian (sr)** . The observer's total visual field is described by the whole surface of the sphere, which is given by $4\pi r^2$, and thus covers the solid angle (Fig 3.1.1).

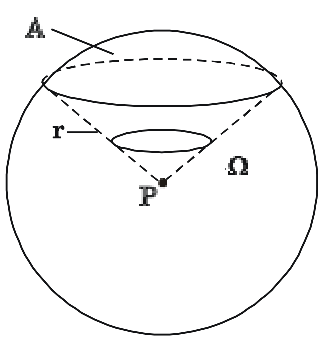


Fig. 3.1.1 Solid angle Ω quantifies a certain part of the visual field, seen by an observer located at P.

$$\Omega_{total_r} = 4\pi \text{ sr} = 12.57 \text{ sr}$$

Radiant power or radiant flux ϕ_e

It is defined by the total power or radiation emitted by a source (lamp, light emitting diode, etc.), transmitted through a surface or impinging upon a surface. Radiant power is measured in watts (W).

The definitions of all other radiometric quantities are based on radiant power.

If a light source emits uniformly in all directions, it is called an **isotropic light surface**. (Fig 3.1.2).

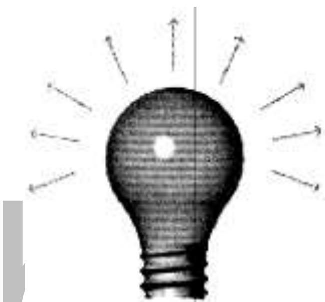


Fig. 3.1.2 The radiant power of ϕ_e of a light source is given by its total emitted radiation.

Radiant power characterizes the output of a source of electromagnetic radiation only by a single number and does not contain any information on the spectral distribution or the directional distribution of the lamp output.

Radiant intensity I_e

Radiant intensity I_e describes the radiant power of a source emitted in a certain direction. The source's (differential) radiant power $d\phi_e$ emitted in the direction of the (differential) solid angle element $d\,\Omega$ is given by (Fig. 3.3)

$$\boxed{d\phi_e = I_e\, d\,\Omega}$$

and thus

$$\Phi_e = \int I_e \, d\Omega$$

In general, radiant intensity depends on spatial direction.

The unit of radiant intensity is **W/sr**.

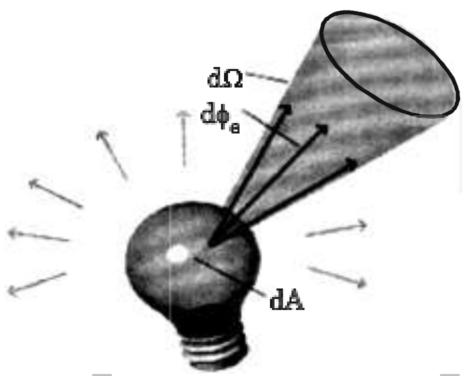


Fig. 3.1.3 Directional distribution of radiant intensity for an incandescent bulb

Radiance L_e

Radiance L_e describes the intensity of optical radiation emitted or reflected from a certain location on an emitting or reflecting surface in a particular direction. The radiant power $d\phi_e$ emitted by a surface element dA in the direction of the solid angle element $d\,\Omega$ is given by

$$d\phi_e = L_e \cos\theta \, dA \, d\Omega$$

In this relation, θ is the angle between the direction of the solid angle element $d\Omega$ and the normal of the emitting or reflecting surface element dA.

From the definition of radiant intensity I_e, it follows that the radiant intensity emitted by the area element dA in a certain direction is given by

$$dI_e = L_e \cos\theta \, dA$$

Thus,

$$I_e = \int_{\text{emitting}} L_e \cos\theta \, dA$$

The unit of radiance is $\mathbf{W/(m^2 \cdot sr)}$

Irradiance E_e

Irradiance E_e describes the amount of radiant power impinging upon a surface per unit area. In detail, the radiant power $d\phi_e$ upon the surface element dA is given by

$$d\phi_e = E_e \, dA$$

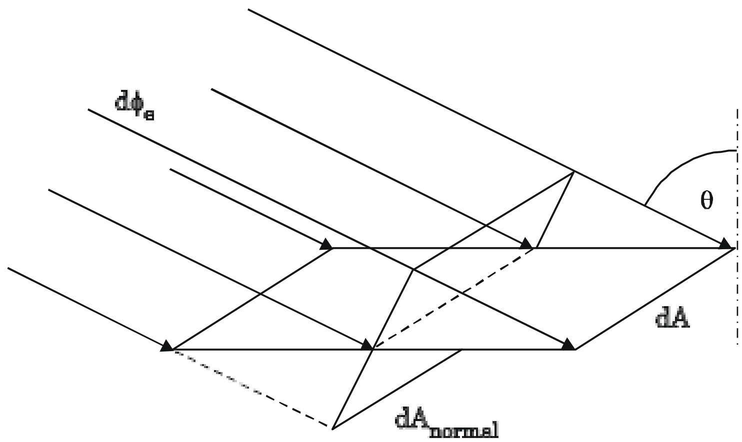


Fig. 3.1.4 Irradiance is defined as incident radiant power $d\phi_e$ per surface area element dA .

Generally, the surface element can be oriented at any angle towards the direction of the beam. However, irradiance is maximised when the surface element is perpendicular to the beam: (Fig. 3.1.4)

$$d\phi_e = E_{e,\,normal}\, dA_{normal}$$

Note that the corresponding area element dA_{normal}, which is oriented perpendicular to the incident beam, is given by

$$dA_{normal} = \cos\theta\, dA$$

with θ denoting the angle between the beam and the normal of dA, we get

$$E_e = E_{e,\,normal} \cos\theta$$

The unit of irradiance is **W/m^2**.

Radiant exitance M_e

Radiant exitance M_e quantifies the radiant power per unit area, emitted or reflected from a certain location on a surface.

In detail, the (differential) radiant power $d\phi_e$ emitted or reflected by the surface element dA is given by

$$d\phi_e = M_e \, dA$$

From the definition of radiance follows that the (differential) amount radiant exitance dM_e emitted or reflected by a certain location on a surface in the direction of the (differential) solid angle element $d\,\Omega$ is given by

$$dM_e = L_e \cos\theta \, d\,\Omega$$

and consequently

$$M_e = \int L_e \cos\theta \, d\,\Omega$$

The integration is performed over the solid angle of 2π steradian corresponding to the directions on one side of the surface and θ denotes the angle between the respective direction and the surface's normal.

The unit of radiant exitance is **W/m²**. In some particular cases, $M_e = E_e$.

3.2 SPECTRAL QUANTITIES

Spectral radiant power is defined as a source's radiant power per wavelength interval as a function of wavelength. In detail, the source's (differential) radiant power $d\phi_e$ emitted in the (differential) wavelength interval between λ and $\lambda + d\lambda$ is given by

$$d\phi_e = \phi_\lambda(\lambda)\, d\lambda$$

This equation can be visualised geometrically (see Fig. 3.2.1). As $d\lambda$ is infinitesimally small, spectral radiant power $\phi_\lambda(\lambda)$ is approximately constant in the interval between λ and $\lambda + d\lambda$.

Thus, the product $\phi_\lambda(\lambda)\, d\lambda$ equals the area under the graph of $\phi_\lambda(\lambda)$ in the interval between $\lambda + d\lambda$.

Thus area describes the contribution of this wavelength interval to the total value of radiant power ϕ_e. It is graphically represented by the total area under the graph of spectral radiant power $\phi_\lambda(\lambda)$.

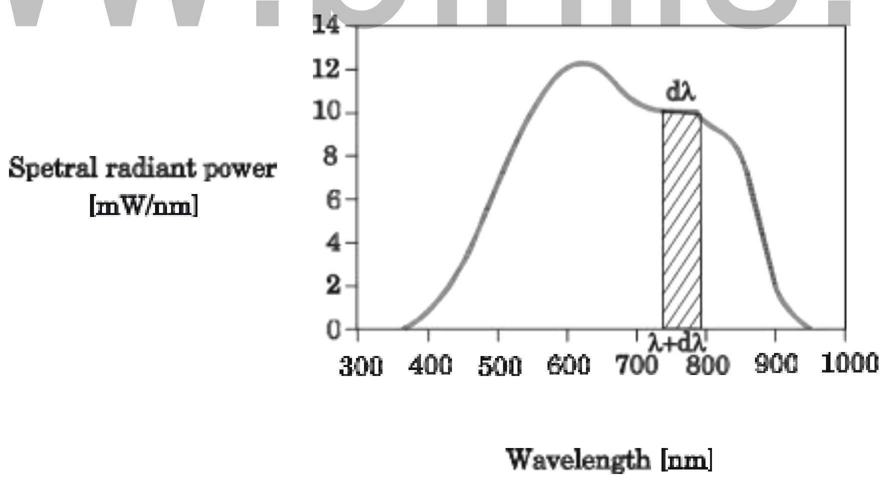


Fig. 3.2.1- Spectral radiant power $\phi_\lambda(\lambda)$ wavelength

Mathematically, this is expressed by the integral

$$\Phi_e = \int_0^\infty \phi_\lambda(\lambda)\,(d\lambda)$$

The unit of spectral radiant power is **W/nm** or **W/Å**.

The other spectral quantities are defined correspondingly and their units are given by the unit of the respective quantity, divided by nm or Å.

Generally, a radiant quantity is calculated from the respective spectral quantity by integration over wavelength from

$\lambda = 0$ to $\lambda = \infty$.

However, this integration is often restricted to a certain wavelength range, which is indicated by the respective prefix. For instance, UVA irradiance is defined as

$$E_{e,\,UVA} = \int_{315\,nm}^{400\,nm} E_{\lambda}(\lambda)\, d\lambda$$

as the UVA range is defined from $\lambda = 315$ nm to $\lambda = 400$ nm.

3.12 SUPPLEMENTARY ARTIFICIAL LIGHTING

An artificial sky allows us to test the daylighting performance of a scale model under overcast sky conditions. There are newer multiple-lamp artificial skies which are computer controlled and capable of creating any desired sky distribution. However, those skies are very expensive in both, purchase and maintenance, and are not widely used. (fig. 3.12.1)

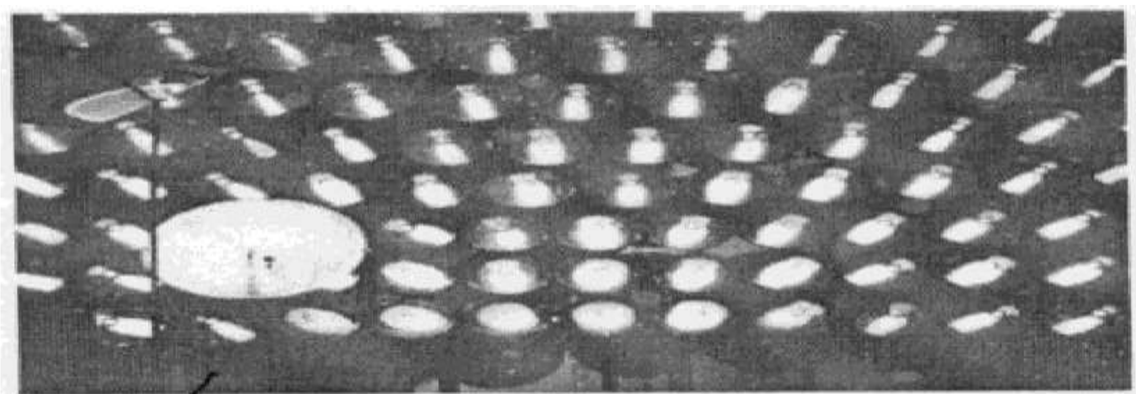


Fig. 3.12.1- Multi-lamp artificial sky with sun simulator

The most economic artificial skies are simple boxes with mirrors inside and diffuse lighting in the top. Traditionally, mirrored artificial skies are used for daylight factor analysis of scale models.

There are newer, more sophisticated (and more expensive), designs that have several hundred lamps which are individually controlled by a computer. Those skies can be programmed to model any sky distribution. Pre-programmed settings allow for a dynamic simulation of an entire day or for several seasons. Sometimes sun simulators are incorporated into the sky allowing for sun penetration studies which are otherwise done in a **heliodon**.

For the measurement of daylight factors, dual or multi-cell illuminance meters are very useful

to model the reflectance values inside the model as accurately as possible. It is often best to get samples of the actual materials that are going to be used such as paint or pieces of carpet.

3.5 VISION-PHOTOPIC, MESOPIC, SCOTOPIC

The terms photopic, mesopic and scotopic refer to three ranges of human vision adaptation level. These three differ in anatomical response, spectrum and their effect on visual acuteness.

The terms photopic, mesopic and scotopic refer to the primary use of the cones, rods and other light-sensitive cells on the retina of the human eye.

Fovea is responsible for sharp central vision. It is necessary in human for activities where visual detail is of primary importance such as reading and driving.

Fovea consists parafovea belt and perifovea outer region. Parafovea is the intermediate belt. In this, the garglian cell layer is composed of more than five rows of cells as well as highest density of cones.

Cones cover most of the retina and their greatest concentration (50 cones per 100 micron) is at the fovea at the centre back of the eye. (Fig. 3.10)

The perifovea contains low density of cones (12 per 100 micron).

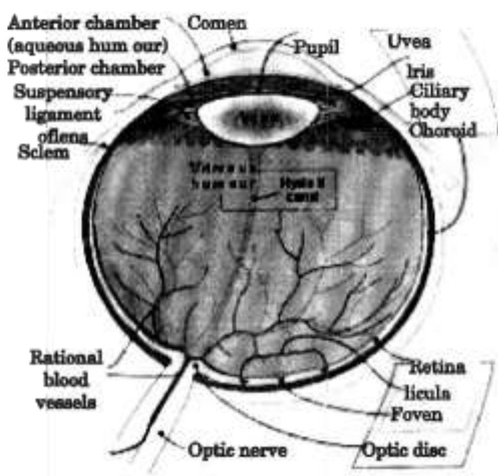


Fig. 3.5.1 Schematic diagram of the human eye

The center of the fovea has cone photoreceptors. The central fovea consists of very compact cones, thinner and more rod like appearance than cones. These cones are densely packed.

There are three kinds of cones, designated the long-wavelength, medium-wavelength and short-wavelength cones. Formerly they are added red, green and blue cones.

In combination, these cones are responsible for giving us color vision.

Cones are the most active in medium and high light levels. As the general environmental brightness drops, the cones becomes less effective and it becomes difficult to discern fine details and colours.

Photopic vision

This term refers to cone vision and covers adaptation levels of 3 candela per square metre and higher. Adaptation level is the overall brightness of environment that eyes are adjusted to.

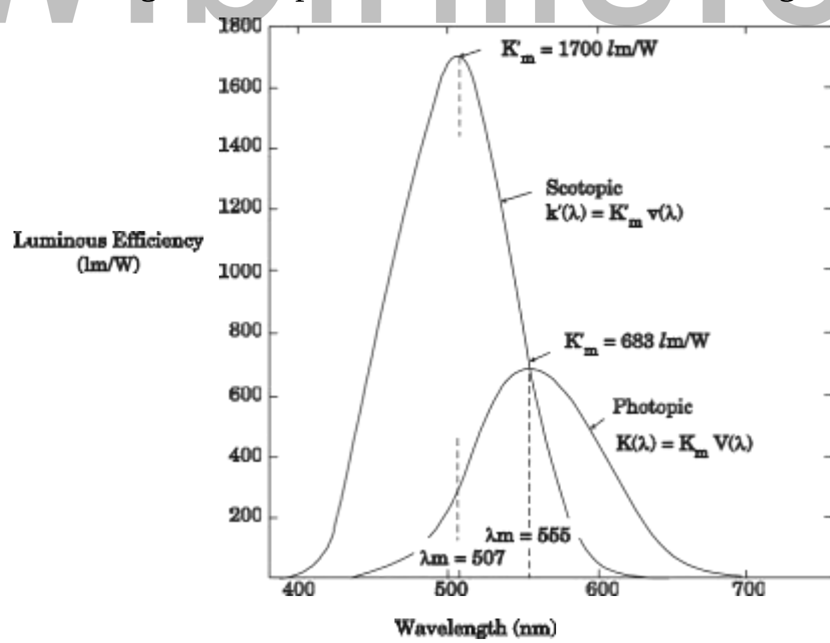


Fig. 3.5.2 (Photopic, mesophic scotopic vision curve)

www.binils.com for Anna University | Polytechnic and Schools

If the average reflectance of our environment is 30%, an adaptation level of 3 cd / m^2 would result from illuminance of approximately 30 lux (3 foot candles).

The combined peak sensitivity of the cones is at $\lambda = 555$ nm in the yellow green part of the visible spectrum. The lumen, basic metric of visible light is defined by the combined cone response (Fig 3.5.1).

Mesopic vision

This term refers to the range of human vision with both rods and cones active.

Scotopic vision

At this point, the ability to discern colors is gone. There are no rods at the fovea and the cones are not receiving enough light to be stimulated.

Because of this difference in spectral sensitivity the lumen defined according to the cone response is not a very good measure of visibility at low light levels.

As the light level drops our peak visual sensitivity shifts towards the blue end of the visible spectrum.

For most night time applications, it is in mesophic range, with the peak being somewhere between yellow-gree and blue-green. The lower the light level, the greater shift away from the photopic sensitivity curve.

3.7 VISUAL FIELD GLARE

Glare is difficulty seeing in the presence of bright light such as sunlight or artificial light (car head lamps at night). Because of this, some cars include mirrors with automatic anti-glare functions.

Glare is caused by a significant ratio of luminance between the task and the glare source. Factors such as the angle between the task and glare source and eye adaptation have significant impacts on the experience of glare.

Types of Glare

Glare is generally divided into two types;

(i) **discomfort glare and**

(ii) **disability glare.**

Discomfort glare results in an instinctive desire to look away from a bright light source or difficulty in seeing a task.

Disability glare impairs the vision of objects without necessarily causing discomfort. This will arise when driving westward at sunset.

Disability glare is often caused by inter-reflection of light within the eyeball. This reduces the contrast between task and glare source such that the task cannot be distinguished. When glare is so intense that vision is completely impaired, it is called dazzle.

Reducing factors of visibility

Glare can reduce visibility by

1. Reduction of brightness of the rest of the scence by constriction of the pupils.
2. Reduction in contrast of the rest of the scence by scattering of the bright light within the eye.
3. Reduction in contrast by scattering light in particles in the air.

4. Bloom surrounding objects infront of glare.

5. Reduction in contrast by reflection of bright areas on the surface of a transparent medium or glass, plastic or water.

When the sky is reflected in a lake, so that the bottom below or objects in the water cannot be seen. This is known as veiling glare.

Methods to reduce glare

1. Sunglasses are often wore to reduce glare. The polarized sunglasses are designed to reduce glare caused by light reflected from non-metallic surfaces such as water, glossy printed matter or painted surfaces.
2. An anti-reflective treatment of an eyeglasses reduces the glare at night and glare from inside lights and computer screens.
3. Some types of eyeglasses can reduce glare that occurs because of the imperfections on the surface of the eye.

Measurement of glare

Glare is typically measured with luminance meters or luminance cameras. Both are able to determine the luminance of objects within small solid angles. The glare of a scene (ie.,) visual field of view, is then calculated from the luminance data of that scene.

Unifed Glare Rating

The unifed glare rating (UGR) is a measure of the glare in a given environment.

It is basically the logarithm of the glare of all visible lamps divided by the background illumination (L_b).

$$\text{UGR} = 8 \log \left[\frac{0.25}{L_b} \sum_n L^2 \frac{w_n}{P_n^2} \right]$$

where log is the common logarithm (base 10).

L_n - luminance of each light source numbered,

ω_n - solid angle of the light source seen from then

and