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LECTURE NOTES

UNIT III LIGHTING DESIGNS

Radiation quantities – spectral quantities – relationship between luminescence and radiant quantities – hemispherical reflectance and transmittance – photometry: cosines law, inverse square law. Vision – photopic, mesopic, scotopic visions. Colour – luminous efficiency function - Visual field glare, colour - day light calculations - day light design of windows, measurement of day-light and use of models and artificial skies, principles of artificial lighting, supplementary artificial lighting.

Optical measurement techniques can be divided into two types, they are

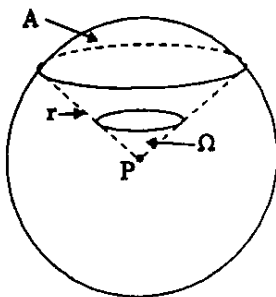
- i) Photometry – determination of optical quantities which is related to the sensitivity of the human eye.
- ii) Radiometry – it is measurement of energy per unit time emitted by light sources imping on a particular surface.

3.1 RADIATION QUANTITIES

1. Solid angle (Ω)

The geometric quantity of a solid angle Ω is a an observeds visual field.

If we imagine an observer located at a point P, his full visual field can be described by a sphere of arbitrary radius



Then, a certain part of this full visual field defines an area A on this spherical surface. The solid angle Ω is defined by

$$\Omega = A/r^2$$

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

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

The solid angle is measured in the unit of steradian (Sr).

The observe'ss total visual field is described by area of the whole surface of the sphere ($4\pi r^2$). Hence, the total solid is given by

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$$\Omega_{\text{total}} = \frac{4\pi r^2}{r^2}$$

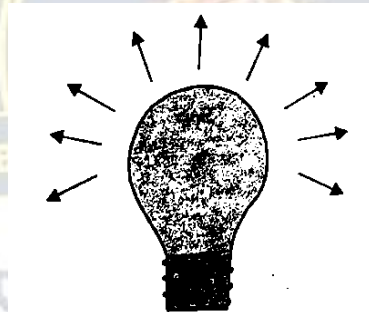
$\Omega_{\text{total}} = 4\pi \text{ sr}$

2. Radiant power or radiant flux (Φ_e)

It is defined as the total radiation emitted by a light source . it is measured in watts (W)

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

If a light source emits light uniformly in all directions, then it is called isotropic light source.



Radiant power does not imply on the spectral distribution or the directional distribution of the lamp output.

3. Radiant intensity (I_e)

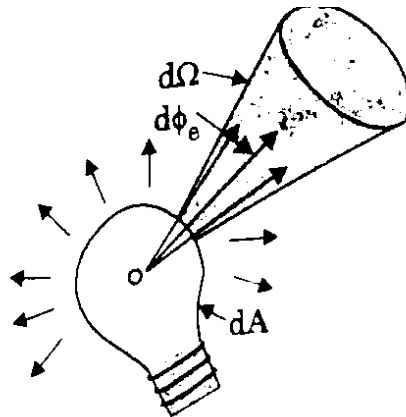
It is defined as the radiant flux ($d\Phi_e$) emitted by a light source per unit solid angle in a given direction.

It is given by

$$I_e = d\Phi_e / d\Omega$$

In general, radiant intensity depends on spatial direction. The unit of radiant intensity is W/sr

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4. Radiance (L_e)

It is defined as the radiant flux per unit solid angle per unit projected area perpendicular to the beam direction.

It is given by

$$(L_e) = d\phi_e / d\Omega dA \cos \Theta$$

In the above relation, Θ is the angle between the direction of the solid angle element $d\Omega$ and the normal of the emitting surface element dA .

It is also defined as the radiant intensity emitted per unit projected area perpendicular to the beam direction.

It is given by

$$L_e = dI_e / dA \cos \Theta$$

The unit of radiance is $W/m^2 \cdot sr$

5. Irradiance (E_e)

It is defined as the amount of radiant power incident on a surface per unit area.

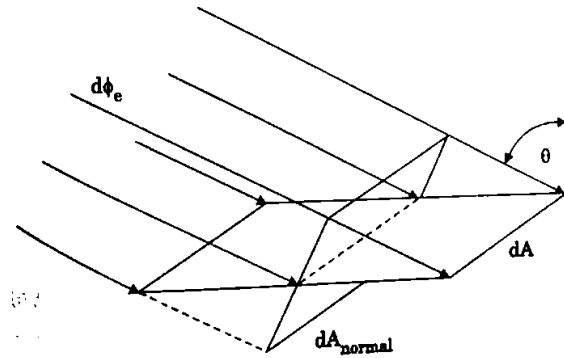
It is given by

$$E_e = d\phi_e / dA$$

Generally, the surface element can be oriented at any angle towards the direction of the beam. However, irradiance is maximum when the surface element is perpendicular to the beam.

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

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It is noted that the corresponding area $dA_{(normal)}$ which is oriented perpendicular to the incident beam is given by

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

$$\therefore E_{e, normal} = \frac{d\phi_e}{\cos \theta \, dA}$$

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

$$\left(\because E_e = \frac{d\phi_e}{dA} \right)$$

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

The unit of irradiance is W/m^2 .

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3.2 Spectral quantities:

Spectral radiant power ($\phi_\lambda (\lambda)$)

It is defined as a source's radiant power per unit wavelength interval as a function of wavelength.

The spectral radiant power in terms of differential radiant power and wavelength interval between λ and $\lambda + d\lambda$ is given by

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

The unit of spectral radiant power is W/nm

Rearranging above equation,

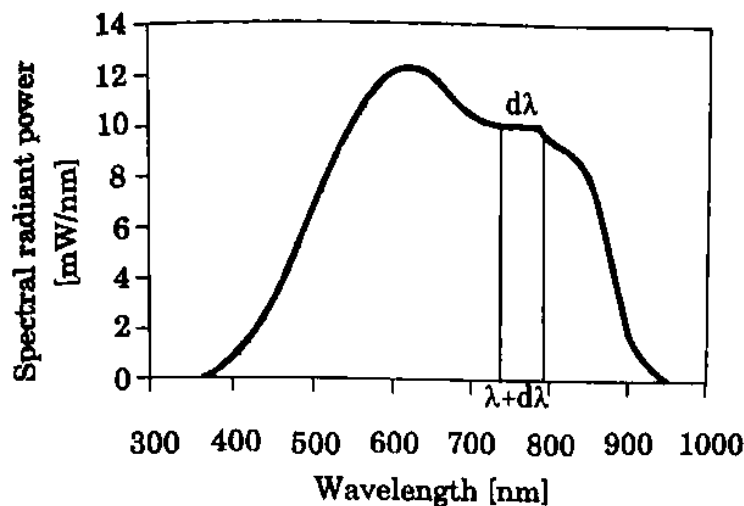
$$d\phi_e = \phi_\lambda (\lambda) d\lambda$$

This equation can be visualized geometrically. 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 to the area under the graph of $\phi_\lambda (\lambda)$ in the interval between λ and $\lambda + d\lambda$

Thus, area describes the contribution of this wavelength interval to the total value of radiant power

It is graphically represented by the total area under the graph of spectral radiant power $\phi_\lambda (\lambda)$



Mathematically, it is expressed by the integral

Generally, a radiant quantity is calculated from the respective spectral quantity by integration over wavelength range from $\lambda = 0$ to $\lambda = \infty$

However, this integration is often restricted to a certain wavelength range, which is indicated by

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the respective prefix. For instance, UV irradiance is defined as

$$\phi_e = \int_0^{\infty} \phi_{\lambda}(\lambda) d\lambda$$

UV range is defined from $\lambda = 315\text{nm}$ to $\lambda = 400\text{nm}$.

3.3 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.

1. Luminous flux (ϕ)

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

2. Lumen

It is the luminous flux emitted from a standard candle

3. 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.

4 Candela

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

5. Illumination or intensity of illumination (E)

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

3.4 Cosines Law

Statement

It states that the intensity of illumination is directly proportional to cosine of the angle of incidence of the light radiations on the given surface.

This law is also known as cosine emission law or Lambert's cosine law.

Illumination is amount of light flux incident on unit area of the given surface.

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

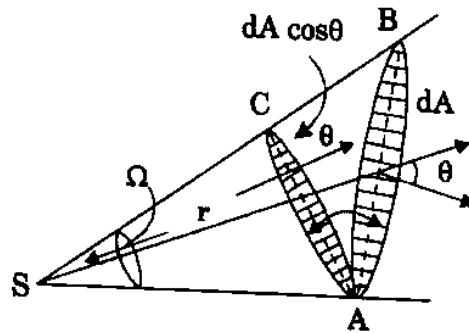
$$E = dF/dA$$

Its unit is lumen per sq meter.

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Explanation

Let us consider an elementary surface AB of area dA illuminated by the source by the source S this surface area subtends solid angle Ω at the point source S.



If light flux F lumens falls on the area AB then, intensity of illumination

$$E = F/dA \dots\dots(1)$$

The illuminating power or luminous of the source, L is defined as luminous flux per unit solid angle

$$L = F/\Omega$$

Sub for F in eqn (1), we have

Intensity of illumination

$$E = L\Omega/dA \dots\dots(2)$$

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

$$\Omega = dA \cos\theta / r^2$$

Sub for Ω I eqn (2), we obtain the intensity of illumination

$$\begin{aligned} E &= L dA \cos\theta / dA r^2 \\ &= L \cos\theta / r^2 \\ E &= L \cos\theta / r^2 \dots\dots(3) \end{aligned}$$

This equations (3) is known as Lamberts cosine law.

For a given light source and surface area L/r^2 is constant. Hence, intensity of illumination is directly proportional to cosine of angle of incidence.

3.5 Inverse square law

Statement

This law states that the intensity of light incident on the surface is inversely proportional to the square of the distance between the source and the surface.

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Explanation:

Let us consider a point source S of light. It is radiating light equally in all directions. Two concentric spheres of radii r_1 and r_2 around the source per second be Q.

Thus light energy falls normally on the surface of sphere. The light energy incident per second on unit area of sphere of radius r_1 given by

$$I_1 = Q/4\pi r_1^2$$

Similarly for sphere of radius r_2 the incident light energy per unit area is given by

$$I_2 = Q/4\pi r_2^2$$

From (1) and (2)

$$I_1 / I_2 = r_2^2 / r_1^2$$

Thus, the amount of light energy falling on a given surface is inversely proportional to the square of the distance of the surface energy.

3.6 Relationship between luminance and radiant quantities:

The same emissive power in different wavelength regions may cause different visual perceptions on brightness of the source.

If the wavelength lie beyond the visible part of the spectrum, the source remains invisible irrespective of its intensity.

For a given power, the source is the brightest at a wavelength of 555nm.

The ratio of spectral density $\phi_{v\lambda}$ of the luminous flux and the spectral emissive power P_λ for identical visual perceptions at different wavelengths is to be estimated.

Quantitatively, this relation is characterized by the ratio

$$V_\lambda = \phi_{v\lambda} / P_\lambda$$

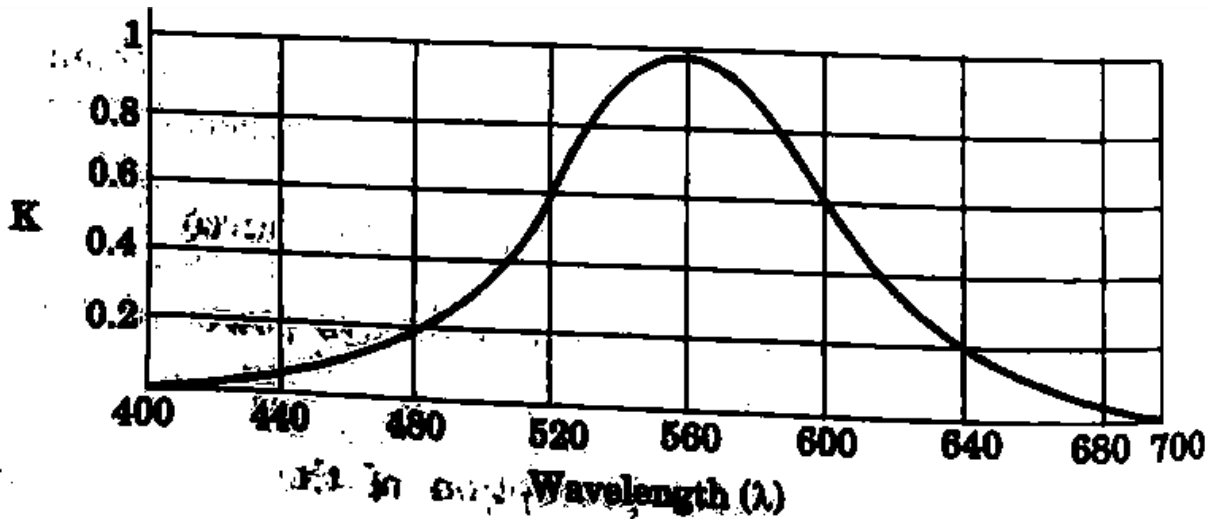
V_λ is called the spectral luminous efficiency

The luminous flux is estimated from the visual perception of the emissive power in lumen, and P is expressed in watt.

The spectral luminous efficiency depends on the wavelength. It is equal zero for wavelength lying beyond the visible range.

$$K = V_\lambda / V(555 \text{ nm})$$

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If the spectral emissive power P_λ is known, then the total emissive power is given by

$$P = \int_0^\infty P_\lambda d\lambda$$

From eqn, the spectral density of the luminous flux is defined by

$$\phi_{V\lambda} = V(555 \text{ nm}) K(\lambda) P_\lambda$$

The luminous flux is expressed in the form

$$\phi_V = \int_{\lambda_1}^{\lambda_2} \phi_{V\lambda} d\lambda$$

$$\phi_V = \int_{\lambda_1}^{\lambda_2} V(555 \text{ nm}) K(\lambda) P(\lambda) d\lambda$$

3.7 Hemispherical reflectance and Transmittance

Hemispherical reflectance

It is defined as the ratio of the radiant flux reflected from a surface to radiant flux incident to it.

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Hemispherical Transmittance

It is defined as the ratio of the radiant flux transmitted through a surface to the radiant flux incident to it.

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

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 colour space is any additive colour space based on the RGB colour model. A particular RGB colour space is defined by the three characteristics of the red, green and blue additive primaries and 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 that 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.

3.9 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.

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3.10 VISION-PHOTOPIC, MESOPIC, SCOTOPIC

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 ganglion 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.

The central fovea consists of very compact cones, thinner and more rod like appearance than comes. These comes are densely packed. There are three kinds of cones, designated the long-wavelength, medium-wavelength and short-wavelength cones. Formerly they are 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 for us to discern fine details and colours.

3.11 Daylight

Daylight is the combination of direct and indirect sunlight during the day time. This includes direct sunlight, diffuse sky radiation and both of these reflected by the earth and terrestrial objects.

Daylight factor (DF)

It is the ratio between the measured internal and external light levels. It represents the amount of daylight received into an indoor space or room. DF is given by

The daylight factor is defined as: $DF = E_i/E_o * 100$

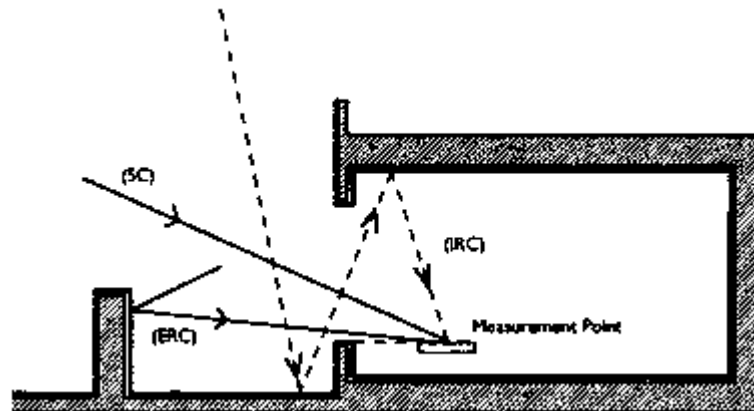
where,

E_i - illuminance due to daylight at a point on the indoors &

E_o - is illuminance at a point on the outdoors.

- a) Daylight can be handled quantitatively by using relative values (daylight factor) which compare indoor to outdoor illuminance.
- b) Illuminance level (LUX) at a point is given by

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Daylight design of windows

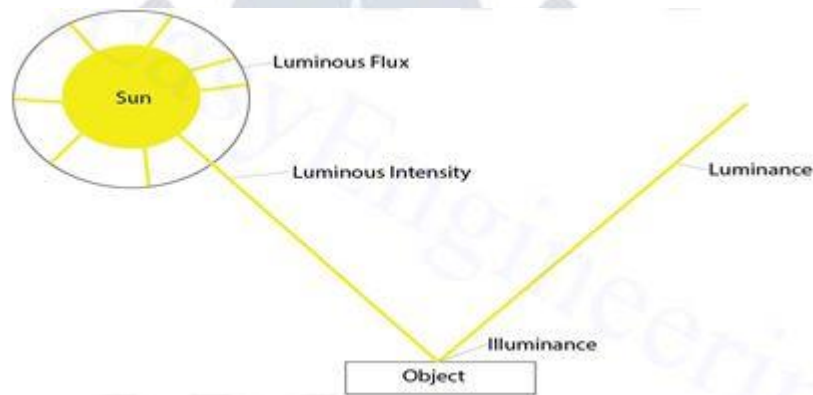
Daylighting refers to the practice of placing windows or other openings & reflective surfaces to achieve effective internal lighting through natural daylight. The particular attention is given to daylighting while designing a building. The aim is to maximize visual comfort or to reduce energy use.

- a) **Windows** is used for allowing light, heat and sound. Windows on multiple orientations must usually be combined to produce the right mix of light for the building depending on climate and latitude.
- b) **Window-Wall ratio (WWR)** - Minimum 20 percent to 30 percent of window area should be provided in total wall area to achieve better daylighting.
- c) **High windows** are more effective than individual or vertical windows, to distribute light deeper into the space.
- d) Consider separating windows into two horizontal stripes, one at eye level for view and one above to maximum daylight penetration
- e) **High ceilings** - More daylight savings will be realized if ceiling heights are 10 feet or higher.
- f) **Light shelves** - Using interior and exterior light shelves between the daylight window and the view window.
- g) Daylighting is more effective if open plan workstations are located on the north and south side of the building. Open configuration absorbs less light and inter-reflections provide a more uniform distribution of light deep into the space.
- h) **Interior sun control** - Horizontal blinds on the sound windows and vertical blinds on the east and west windows are most effective.

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Measure of Daylight

- Luminous flux** – The amount of light given off by a particular source in all directions is called luminous flux (or luminous power). It is measured in lumens.
- Radiant flux** – It is a measure of total power of the electromagnetic radiation from a source and not just visible light but also infrared and ultraviolet light, and is measured in watts.
- Illuminance** – It is the total luminous flux incident on a surface per unit area. It is a measure of how much amount of incident light illuminates the surface. It is used by most common performance indicators to determine daylight availability in the interior. It is measured in lux.



- Luminance** – It is a measure of the luminous intensity per unit area of light travelling in a given direction. It describes the amount of light that get reflected from a particular area. The unit of luminance is candela per square metre.
- Luminance levels can be measured with a luminance meter or through the use of high dynamic range imaging technique coupled with a digital camera and luminance mapping software.

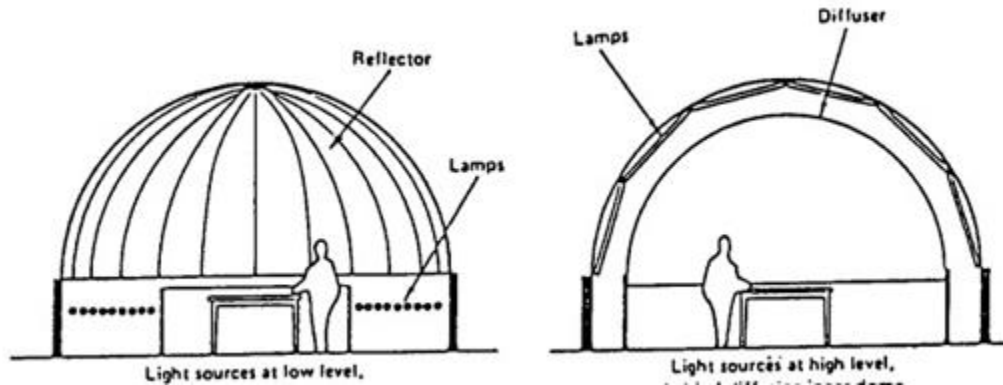
3.12 Models of artificial skies

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

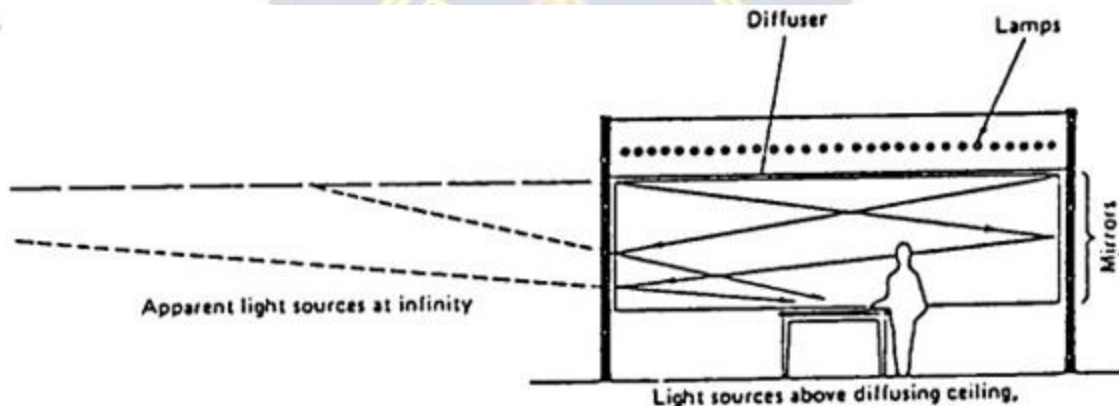
There are two basic forms of artificial sky

- hemispherical and the rectangular.
- Hemispherical artificial sky is mostly constructed as a diffusely reflective opaque dome surface, illuminated from below.

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- (iii) 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.



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

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.

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.

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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.

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.

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

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

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.

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.

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

