INTERIOR LIGHTING DESIGN

A STUDENT'S GUIDE

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This guide on lighting design is intended for students who have no prior knowledge of lighting and also for those who are experienced but would like to bring themselves up to date with developments in lamp and luminaire design, modern design theory, European Standards and the CIBSE code for Interior Lighting 1994.

It develops the basic principles of lighting science but then goes on to provide a modern design perspective for both artificial lighting and daylighting which will be useful to experienced designers.

On completion, the student should be able to:

(i) Understand the physics of light.

(ii) Carry out illuminance calculations for various applications.

(iii) Know the characteristics and applications of the different types of modern lamps and luminaires.

(iv) Have a working knowledge of modern Control Systems for energy efficient lighting.

(v) Design lighting schemes taking both cost and quality considerations into account.

(vi) Design lighting schemes which are suitable for use with modern control systems.

(vii) Design combined daylight and supplementary lighting schemes for use in modern buildings.

(viii) Design Office Lighting to comply with the European Directive for Display Screen Lighting.

(ix) Design Emergency Lighting Systems.

Acknowledgements.

Reference has been made to the following:

The CIBSE Code for Interior Lighting 1994.
The CIBSE Lighting Guide LG 3 : 1996
The European Commission 1994 Directorate General for Energy 'Daylighting in Buildings', 'Energy Efficient Lighting in Offices', 'Energy Efficient Lighting in Buildings', 'Energy Efficient Lighting in Industrial Buildings', 'Energy Efficient Lighting in Schools'. 'Efficient use of Electricity in Industry',

The 2nd European Conference on Energy-Efficient Lighting 1993.

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ADAPTATION
The process of the eye adapting to brightness or colour.

APOSTILB (asb)
A unit of measurement of the amount of light leaving a surface (i.e. reflected light). The apostilb is not an SI unit and is equivalent to one lumen per square metre.

APPARENT COLOUR
The subjective hue of a source.

BLACK BODY
A “Perfect” emitter and absorber of radiation.

BRIGHTNESS
The subjective measurement of luminance.

CANDELA (cd)
Unit of luminous intensity approximately equal to one candle power.

CHROMA
An index of colour saturation. Ranges from 0 for neutral grey to 10 for strong colours.

CHROMATIC ADAPTATION
The eye adapting to changes in the colour of light sources.

COLOUR RENDERING (of a light source)
The ability of the source to render colours accurately. “Good colour rendering” suggests the source is rendering colours similar to the way daylight would.

COLOUR RENDERING INDEX (CRI) (of a lamp)
Is a measure of a lamp's colour rendering ability.

COLOUR TEMPERATURE (of a light source)
The temperature of a black body which emits radiation of the same chromaticity as the light source being considered.

CORRELATED COLOUR TEMPERATURE (CCT)(of a light source)
This is used to define the colour appearance of a light source. It is the temperature (K) of a black body which emits radiation nearest in chromaticity to the light source being considered.
e.g. the CCT of a white fluorescent lamp is 3500 K.

CYLINDRICAL ILLUMINANCE
The mean illuminance on the surface of a small cylinder located at a specific point in a room. The axis is taken to be vertical unless stated otherwise. (Unit Lux)

DAYLIGHT FACTOR
The illuminance at a point indoors, due to daylight, as a % of the horizontal illuminance outdoors, (direct sunlight is excluded from both values).

DIFFUSE REFLECTION
Reflected light from a matt surface.

DIFFUSE LIGHTING
"Soft" lighting in which the luminous flux comes from many directions, none of which predominates.

DIRECT LIGHTING
Lighting in which most of the luminous flux reaches the working plane directly without reflection from other surfaces.

DIRECTIONAL LIGHTING
Lighting on a task predominantly from one direction.

DISABILITY GLARE
Glare which impairs vision.

DISCOMFORT GLARE
Glare which causes discomfort.

DIVERSITY
The ratio of minimum to maximum illuminance (or luminance) over a specified area. (See also uniformity)

DOWNLIGHTER
Direct lighting luminaire which emits light only within a relatively small angle to the downward vertical.

DOWNWARD LIGHT OUTPUT RATIO (DLOR)
The ratio of downward light of a luminaire to its total light output.

EFFICACY
The ratio of lamp luminous flux divided by the power consumed by the lamp. The unit used is lumens per watt (lm/W). Where control gear is taken into account the unit becomes lumens per circuit watt.

ENERGY MANAGEMENT SYSTEM (EMS)
A computerised system for controlling energy use.

FLICKER
The visible modulation in light output due to the cyclic variation of a.c.

FLUX FRACTION RATIO (FFR)
The ratio of upward luminous flux to downward luminous flux.

GENERAL LIGHTING
Lighting illuminating a whole area.

GLARE
Discomfort or disability glare occurring when parts of the visual field are excessively bright.

GLARE INDEX
A quantification of discomfort glare in an installation.

GROUP LAMP REPLACEMENT
The replacement of all lamps usually after a specified period (usually 2 years) in an installation.

HUE
The attribute of colour that enables an observer to classify it as red, blue, etc., and excludes white, black and grey. (the shade of a colour).

ILLUMINANCE (E)
The level of illumination - normally taken on the working plane. Unit: Lux

ILLUMINANCE VECTOR
This is a vector representing the directional flow of light. It has both magnitude and direction.

ILLUMINATION
The process of lighting.

INCANDESCENT LAMP
A lamp which produces light due to its filament being heated to incandescence by current flowing through it.

INDIRECT LIGHTING
Lighting in which most of the luminous flux reaches the working plane after reflection from room surfaces.

INITIAL ILLUMINANCE
Average illuminance in a brand new installation

$$E_{avi} = \frac{E_m \text{ (Maintained illuminance)}}{\text{MF (Maintenance factor)}}$$

INITIAL LIGHT OUTPUT
The luminous flux from a new lamp. With discharge lamps this is usually taken after 100 hours of operation.

INSTALLED POWER DENSITY
The power needed, per square metre of floor area, to achieve 100 lux on a horizontal plane with general lighting.

ISOLUX DIAGRAM
A diagram which shows equal illuminance contours in an installation.

LAMP LUMEN MAINTENANCE FACTOR (LLMF)
The proportion of light output of a lamp, after a specified number of hours operation, to the initial light output of the lamp. (See maintenance factor)

LAMP SURVIVAL FACTOR (LSF)
The % of lamps still operating in an installation after a specified number of hours operation. (See maintenance factor)

LIGHT LOSS FACTOR (LLF)
This term has been replaced by maintenance factor in the 1994 CIBSE Guide. Previously LLF and MF differed in that the latter took no account of the lamp lumen maintenance factor (LLMF). In the 1994 Guide, maintenance factor takes LLMF into account.

LIGHT OUTPUT RATIO (LOR)
The ratio of the light output of a luminaire to the light output of the lamps without a luminaire.

LIGHTING DESIGN LUMENS
This term is now obsolete. It was given as the lumen output of a lamp after 2000 hours use. It was used to represent the average light output of a lamp throughout its life.

LOAD FACTOR
The ratio of energy consumed by a controlled lighting installation to the energy which would have been consumed without controls, over a period of time.

LOCAL LIGHTING - Lighting illuminating a small area.

LOCALISED LIGHTING
Lighting providing a higher illuminance over a particular area of an interior.

LUMEN
An SI unit of luminous flux. (A source of 1 candela, uniform intensity, emits 4π lumens)

LUMINAIRE
This term supersedes the term light fitting. It is the whole unit enclosing lamps, control gear, reflectors, diffusers etc.

LUMINAIRE MAINTENANCE FACTOR (LMF)
The ratio of light output after a specified period of time to initial light output of the luminaire. This takes account of dirt and dust reducing the light output of the luminaire. (See maintenance factor)

LUMINANCE (L)
This is a measure of the objective brightness of a surface or a light source. Brightness is a subjective term dependent on the person as well as other factors. Luminance is an objective measurement performed photometrically. (UNIT: cd/m^2)

LUMINOUS FLUX (Ø)
The light emitted by a source or received by a surface (Unit: Lumen)

LUMINOUS INTENSITY (I)
Describes the light output of a source in a given direction. (Unit: Candela)

LUX - The SI unit of illuminance. 1 Lux = 1 lumen per square metre.

MAINTAINED ILLUMINANCE (E_m)
The average illuminance on the working plane at the end of the maintenance period.

MAINTENANCE FACTOR (MF)
The ratio of illuminance at the end of the maintenance period to the initial illuminance.

MF = LSF x LLMF x LMF x RSMF

MAXIMUM ILLUMINANCE (E Max)
The highest illuminance at any point of the working plane.

METAMERISM
The phenomenon where coloured objects match under one light source but do not match under another. This also refers to sources having the same apparent colour but do not have the same colour rendering properties.

MINIMUM ILLUMINANCE (E Min)
The lowest illuminance on the working plane.

MUNSELL SYSTEM
Colour classification of room surfaces taking account of hue, value and chroma.

OPERATING EFFICACY
The efficacy of a lighting installation in use taking account of energy saving techniques. Operating efficacy = installed efficacy x load factor.

REFLECTANCE
Ratio of light reflected from a surface to the light received on it.

ROOM INDEX
This takes account of room proportions and height of the luminaire above the working plane. It is used to determine the Utilisation factor.

$$R.I. = \frac{L \times W}{(L + W)\, H_m}$$

where

L = Length
W = Width
Hm = Height of luminaire above working plane.

ROOM SURFACE MAINTENANCE FACTOR (RSMF)
The proportion of illuminance at the end of the maintenance period to the initial illuminance taking account of the reduction in room reflectances because of dirt and dust. It is separate to LMF and LLMF. (See maintenance factor)

SCALAR (SPHERICAL) ILLUMINANCE (E_s)
The average illuminance on a very small sphere at a particular point in a room.

SCALLOPING
A regular pattern of light and shade on walls. This is an important factor when designing indirect lighting installations.

SKY COMPONENT DAYLIGHT FACTOR (D_C)
The illuminance directly received indoors at a specified point from a sky of assumed luminance; it is expressed as a % of the horizontal outdoor illuminance. Direct sunlight is excluded from both values of illuminance.

SPACE TO HEIGHT RATIO (SHR)
The ratio of: Distance between luminaire centres, in a regular square array of luminaires, divided by their height above the working plane.

SPECULAR REFLECTION
Reflection from a mirror or similar surface with no diffuse reflection.

SPOT LAMP REPLACEMENT
The replacement of lamps as they fail rather than group lamp replacement after a specified period.

STROBOSCOPIC EFFECT
An optical illusion where moving machinery may look stationary, or operating at a different speed to which it actually is. This is caused by the flicker (modulation of light flux) of discharge lamps operating on a 50 Hz ac cycle.

TASK AREA - The area where an activity takes place requiring illumination.

TRANSMITTANCE - The ratio of light transmitted through a substance to the incident light.

UNIFIED GLARE RATING (UGR) SYSTEM
An internationally agreed numerical rating for discomfort glare proposed by Commission Internationale de l'Eclairage (CIE) but not yet finalised.

UNIFORMITY
Ratio of minimum to average illuminance, normally taken on the working plane. (See also diversity)

UPLIGHTER
A luminaire used for indirect lighting which directs its light onto the ceiling or upper walls.

UPWARD LIGHT OUTPUT RATIO (ULOR)
Ratio of upward (above horizontal) light output to the total light output of lamps.

UTILANCE (U)
Ratio of light reaching working plane to light output of luminaires.

UTILISATION FACTOR (UF)
Proportion of light reaching working plane to light output of lamps. It depends on room index, room reflectances and type of luminaire used.

VECTOR/SCALAR RATIO
The ratio of illuminance vector magnitude divided by scalar illuminance.

VISUAL ACUITY
The ability to discriminate between objects placed very closely together. An optician measures acuity as the ratio of the distance a person can read a line on a chart to the standard distance which a person of normal sight can read the line. (e.g. 6/12 means the person can read at 6m what the normal sighted person can read from 12 m)

VISUAL FIELD
The extent of what can be seen when looking in a certain direction.

VISUAL TASK
The visual work being performed.

WORKING PLANE
The plane in which the visual task lies. It is normally taken as 0.8m above floor level.

SECTION 1

LIGHTING SCIENCE, THEORY AND CALCULATIONS

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SECTION 1 - LIGHTING SCIENCE

1.1 INTRODUCTION

Light is the visible part of the electromagnetic spectrum. Light radiates and can travel unlimited distances through space. Light rays can however, be reflected, transmitted or absorbed when they strike an object. The visible spectrum is only a small part of the full electromagnetic spectrum (see figure 1.1a). The main source of our natural light is the sun, which has a core temperature of approximately 10,000,000 K but a surface temperature which is a relatively cool 6,000 K. It is this surface temperature which determines the energy levels at the different frequencies of the electromagnetic spectrum.

Figure 1.1a shows a graph of electromagnetic energy transmitted by a black body at 6000 K across the frequency spectrum. The visible spectrum is the frequency span between 380 nm and 720nm.

ELECTROMAGNETIC SPECTRUM

Cosmic Rays	Gamma Rays + X Rays	Ultra Violet	Visible Spectrum	Infra Red	Radar	T.V. + Radio

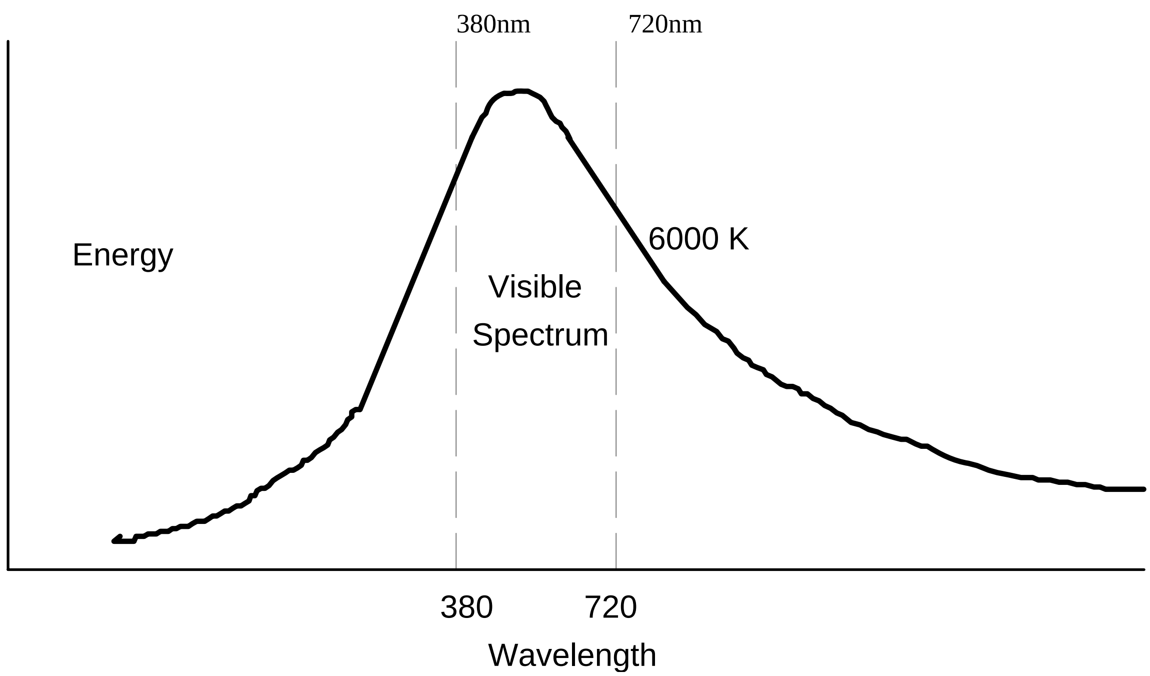


Fig 1.1a

1.2 THE VISIBLE SPECTRUM

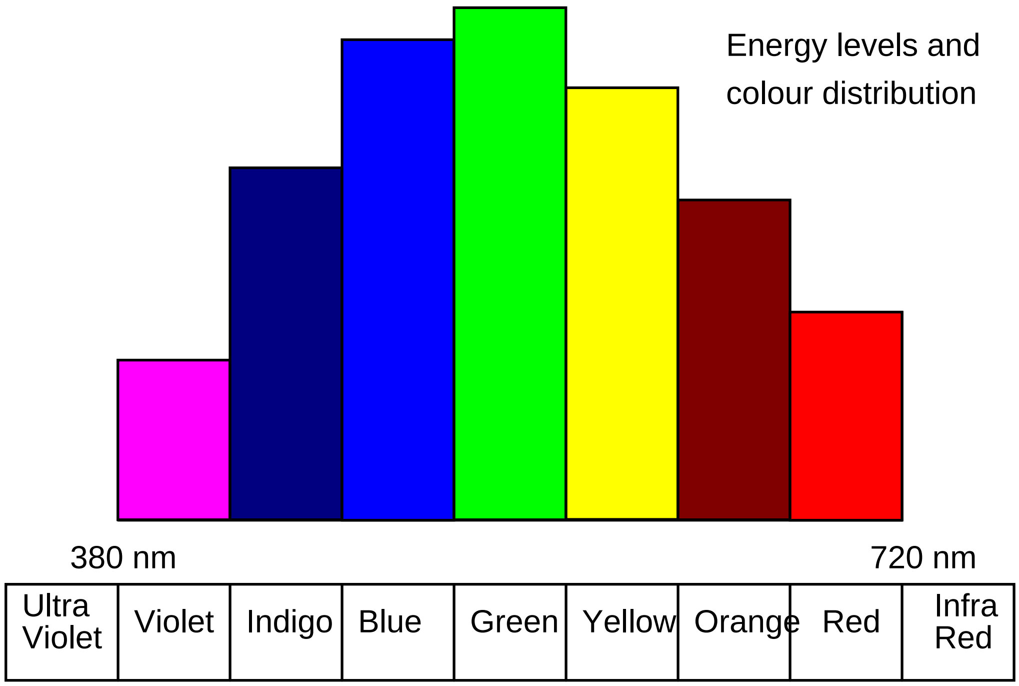


Fig. 1.1b

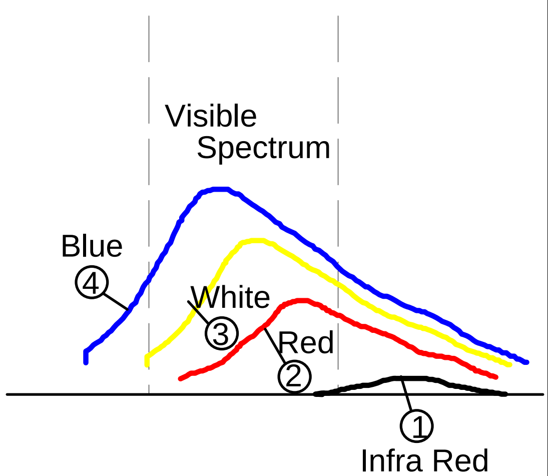


Fig. 1.2

Consider the effect of heating a piece of soft iron in a fire. If the iron is heated for a short time, it will radiate heat energy (curve 1). This radiation is not visible. If the iron is heated further it will glow red (curve 2), then white (curve 3) and eventually blue (curve 4).

The radiation peaks have moved across the spectrum from red to blue as the temperature increases and have increased in magnitude.

Surprisingly, blue is produced at a higher temperature than red even though psychologically, we consider blue to be a “cool” colour and red a “warm” colour. White of course, is a mixture of all the colours in the spectrum.

1.3 LIGHT SOURCES

Light from natural sources such as the sun is known as **white light** and is made up from the different frequency components of the visible spectrum.

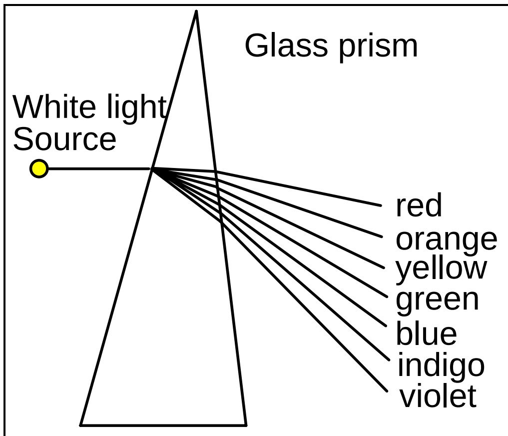


Fig. 1.3

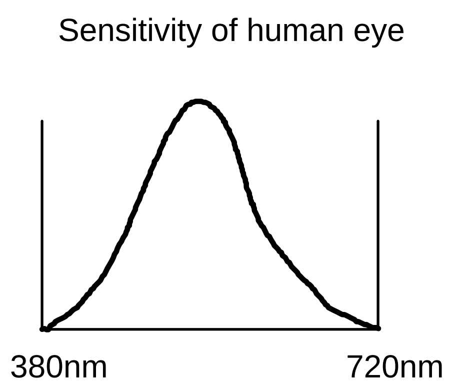


Fig. 1.4

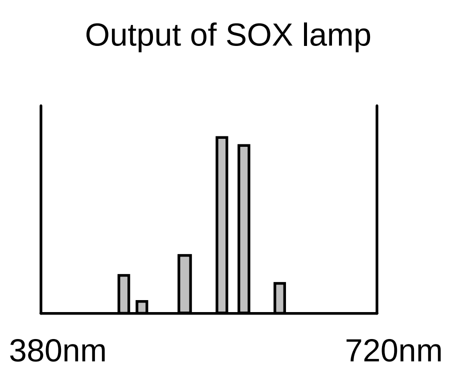


Fig. 1.5

Artificial light from sources such as candles, tungsten filaments and gas discharge lamps, etc., has a **different mix** of frequency components which produce a different colour light This is also true for indirect natural light which has been reflected or refracted and where some of the colour components have been absorbed in the process. The constituent colours in a beam of light can be seen by passing the light through a glass prism (Fig. 1.3).

The human eye has evolved over millennia under the influence of natural light. Figure 1.4. shows the sensitivity of the eye to different frequencies. This can be seen to follow closely the wave energy profile shown in Fig.1.1b. **The eye therefore, is most sensitive to colours at the centre of the visible spectrum.**

Discharge lamps have concentrated outputs at or near the centre of the visible spectrum to improve their efficiency, or to use a more exact lighting term, their efficacy. (See Fig. 1.5)

A low pressure sodium vapour (SOX) lamp for example, has a very high efficacy - up to 180 lumens per watt because its output is concentrated at the centre of the spectrum. It is not, however, capable of rendering colours at the periphery of the visible spectrum. The colour red for example will look brown under this lamp because there is no red in its light output.

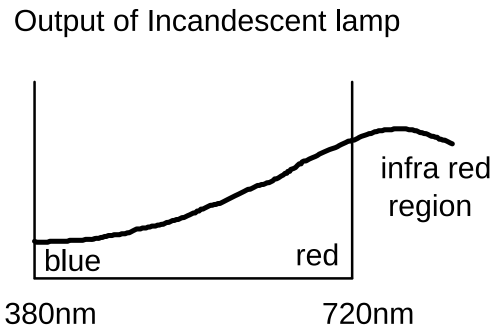


Fig. 1.6

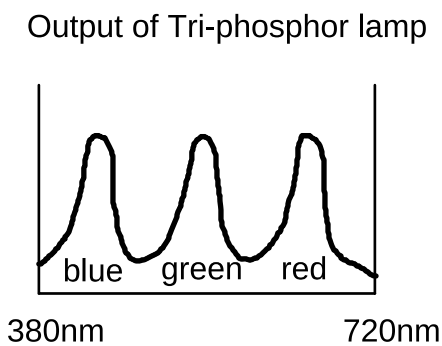


Fig. 1.7

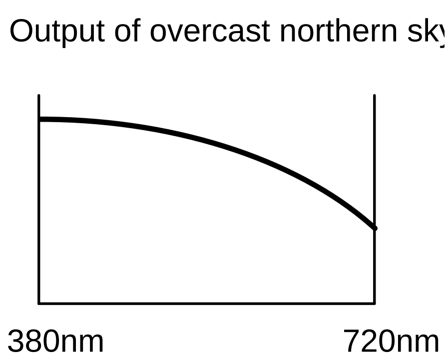


Fig. 1.8

Other discharge lamps have outputs spread over a wider spectrum so that colour rendering is improved albeit at the expense of efficacy.

The output of an **incandescent lamp** is higher at the red end of the spectrum giving it a characteristically warm output. (2800 K approx.). It will have excellent colour rendering characteristics because all of the colours of the spectrum are contained in its output,

Fig. 1.6 shows the output of an **incandescent lamp.** Note that most of its output is outside the visible spectrum and because of this it is a very inefficient lamp with a typical efficacy of **12 lumens per watt.** Heat output is of course high because of the high infra red output.

The output of a **tri-phosphor fluorescent lamp** is concentrated at the three primary colours of the spectrum (See Fig. 1.7). This provides an efficient lamp (up to 90 lumens per watt) with good colour properties. When people view objects and room interiors under these lamps they experience slightly exaggerated colours which may in fact be desirable. Exact colour rendering is not provided by these lamps.

If exact colour tasks are to be performed then **colour matching lamps** are necessary. These lamps have much lower efficacies and provide a characteristically cool colour similar to the natural light of an overcast day in the northern hemisphere. (See Fig. 1.8). The northern sky is best because there is less variation of colour and no direct sunlight.

It should be noted that exact colour rendering is not always possible under daylight conditions because of the natural light colour variation with time of day, season and weather conditions.

Colour rendering is also related to the illuminance on the task. A high illuminance (1000 Lux +) is recommended where exact colour rendering is necessary.

1.4 LIGHTING THEORY

Lighting can be considered in 4 stages, source, flow, illuminance and luminance.

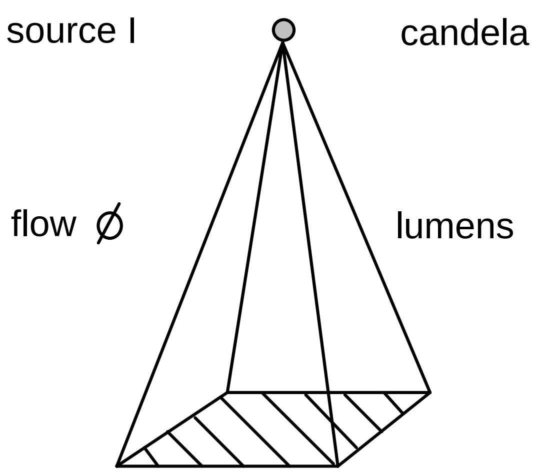


Fig. 1.9

1. SOURCE - the light source has a luminous intensity (symbol **I**) and is measured in **candela**.

2. FLOW - the flow of light, or light flux **(**symbol ϕ**)** which is measured in **lumens.**

3. ILLUMINANCE (symbol **E**) - when light falls on a surface, the level of illumination on that surface is referred to as illuminance. The unit of measurement is **lux**. (lumens per square metre)

4. LUMINANCE (symbol **L**) - The fourth stage of this process is the light leaving the surface which has been illuminated by the source.

Consider a situation where the same amount of light strikes both a “dark” surface and a ”bright” surface. The illuminance is the same in each case but due to the greater reflectance of the “bright” surface it now becomes a secondary source of light. Its luminance will therefore be much greater than that of the dark surface.

Luminance is measured in lumens emitted per sq.m. (not to be confused with Illuminance which is lumens received per sq. m.) and the unit used is “APOSTILB” which is not a S.I. unit. The luminance may be thought of as the brightness of the surface. The term brightness is a subjective term however, whereas luminance is objective.

Luminance is usually be measured in candela per square metre, the illuminated surface being considered a secondary light source.

Note: $1cd/m^2 = 3.14$ Apostilb $= 3.14\ lm/m^2$

The luminance of a surface depends upon the amount of light arriving multiplied by the per unit reflectance R (p.u.).

Example 1.1 The illuminance (E) on the working plane in Fig. 1.10 is 500 lux. The reflectance is 50%, calculate the luminance of the working plane.

$$L = E \times R(p.u.)$$
$$= 500 \times .5 \qquad = 250 \text{ Apostilbs}$$
$$= 250 / 3.14 \qquad = 80\ cd/m^2$$

Experiment to illustrate the difference between Illuminance and Luminance

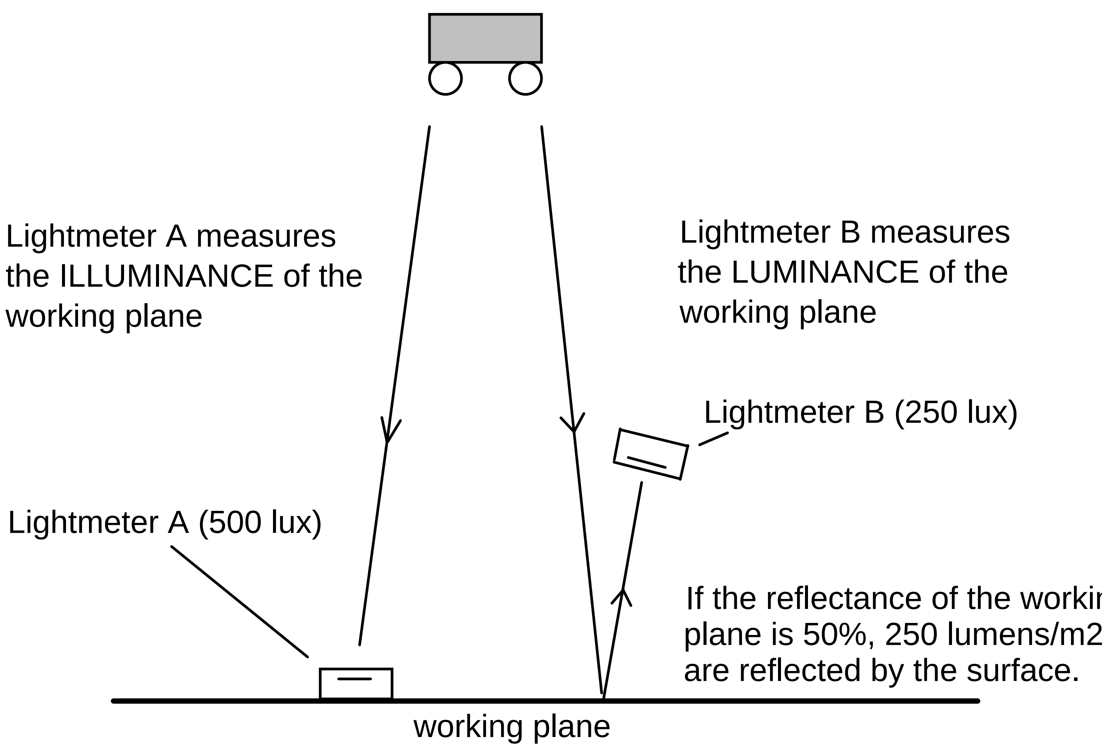


Fig. 1.10

1.5 LAWS OF LIGHT

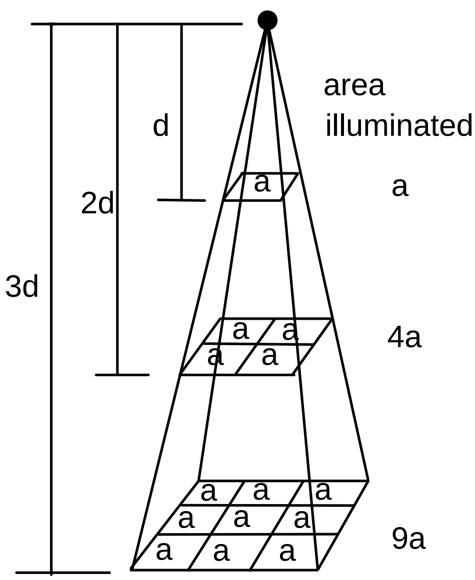


Fig. 1.11

1.5.1 Rectilinear Propagation of light.

This means that light travels in straight lines. It travels at 300,000 km/S and requires no medium for propagation.

1.5.2 Inverse Square Law

In Fig. 1.11 the area illuminated by the point light source increases in proportion to the square of the distance. It follows that the average illuminance would decrease by the same ratio.

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

where d = the distance between the source and the object.

In the example shown the illuminance reduces to a quarter of its original value when the distance is doubled. Similarly the illuminance reduces to one ninth of its original value when the distance away is tripled.

Example 1.2

A point light source has an intensity of 1,000 candela and the light falls perpendicularly on a surface. Calculate the illuminance on the surface if its distance from the surface is:
(i) two metres, (ii) four metres and (iii) six metres.

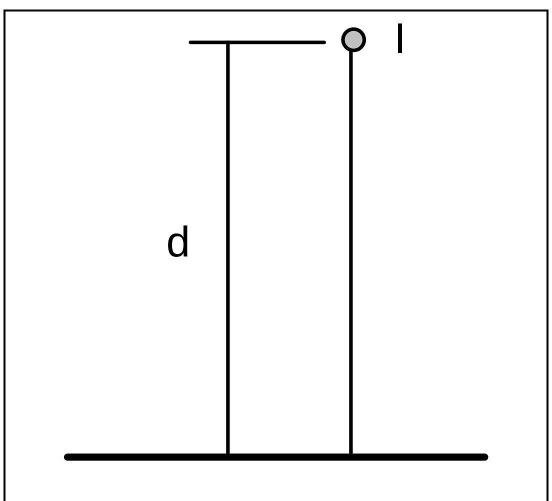


Fig. 1.12

$$E = \frac{I}{d^2} = \frac{1000}{2^2} = 250 \text{ lux}$$

$$E = \frac{I}{d^2} = \frac{1000}{4^2} = 62.5 \text{ lux}$$

$$E = \frac{I}{d^2} = \frac{1000}{6^2} = 27.8 \text{ lux}$$

1.5.3 Cosine Law

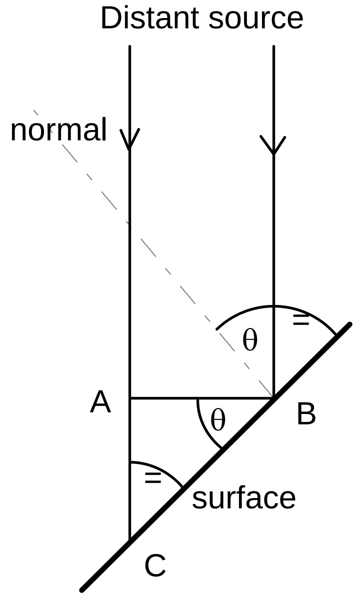


Fig 1.13

When light does not fall normally on a surface, the area illuminated increases reducing the average illuminance by the same ratio.

Fig. 1.13 shows light from a distant source striking surfaces AB and BC. The rays of incident light may be taken as parallel.

$$\frac{AB}{BC} = \cos\theta$$

where θ = The angle between the incident light and the normal to the surface BC.
Therefore the average illuminance on a surface is given by the general formula:

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

Example 1.3

A point light source has an intensity of 2,000 candela in all directions and is mounted 4 metres above a surface. Calculate the illuminance on the surface directly underneath (E_a) and at a distance of 3 metres to the side (E_b).

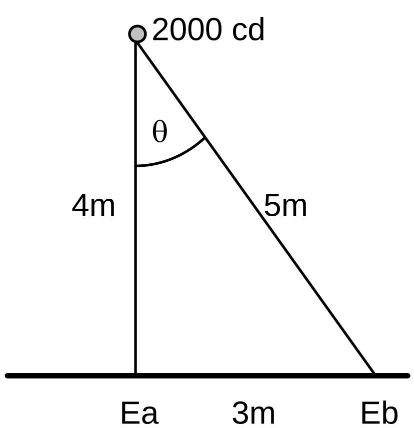


Fig. 1.14a

$$E_a = \frac{I}{d^2} = \frac{2000}{4^2} = 125 \text{ lux}$$

$$E_b = \frac{I \cos\theta}{d^2} = \frac{2000 \times 0.8}{5^2} = 64 \text{ lux}$$

Note:

$$E_a = \frac{I}{x^2}$$

$$E_b = \frac{I \cos\theta}{y^2} = \frac{I \cdot x/y}{y^2}$$

multiply above and below by x^2/y^2

$$E_b = \frac{I\,(x/y)^3}{x^2} = \frac{I \cos^3\theta}{x^2}$$

i.e. $E_b = E_a \cos^3\theta$

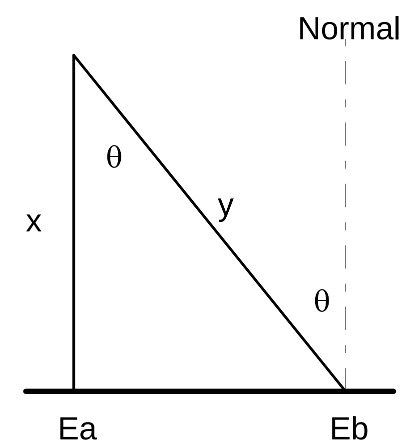


Fig. 1.14b

Example 1.4

A walkway is illuminated by Son 250W lamps each having a luminous intensity of 4750 candela in all directions below the horizontal. Each lamp is installed at a height of 6m and the distance between them is 16 metres. Calculate the illuminance contributed by each lamp:

(a) (i) directly underneath,
(ii) 8 metres from the base,
(iii) 16 metres from the base,
(iv) 32 metres from the base.

(b) The total illuminance at:
(i) the base of each lamp post,
(ii) midway between the base of each lamp post.

(c) Sketch an illuminance profile on a straight line joining the base of each lamp post.

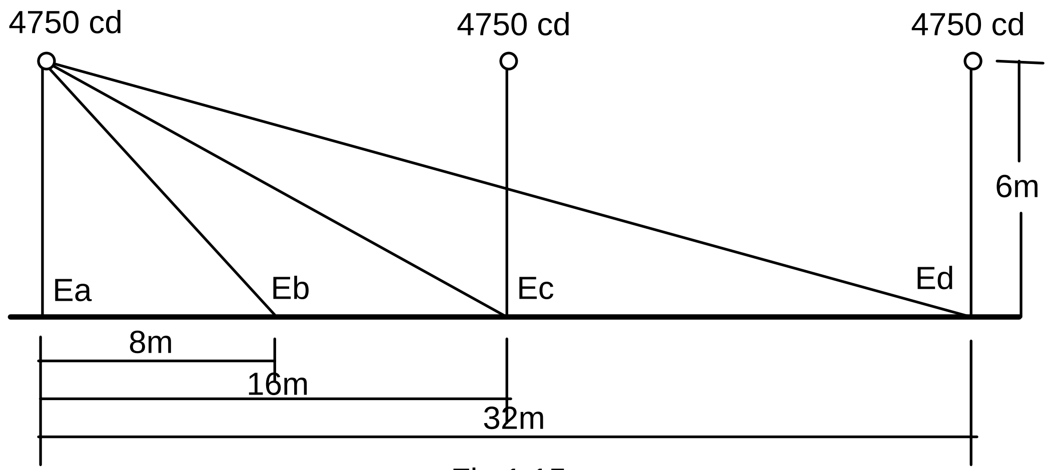


Fig 1.15a

Let the illuminance at A, B, C and D be Ea, Eb, etc., respectively.

(a)

$$E_a = \frac{I}{d^2} = \frac{4750}{6^2} = 132 \text{ Lux}$$

$$\theta\ b = \tan^{-1}(8/6) = 53.13^{o}$$

$$Eb = Ea\ Cos^3\theta\ b = 132\ Cos^3\ 53.13^{o} = 28.51 \text{ lux}$$

$$Ec = Ea\ Cos^3\theta\ c = 132\ Cos^3\ 69.44^{o} = 5.71 \text{ lux}$$

$$Ed = Ea\ Cos^3\theta\ d = 132\ Cos^3\ 79.38^{o} = 0.83 \text{ lux}$$

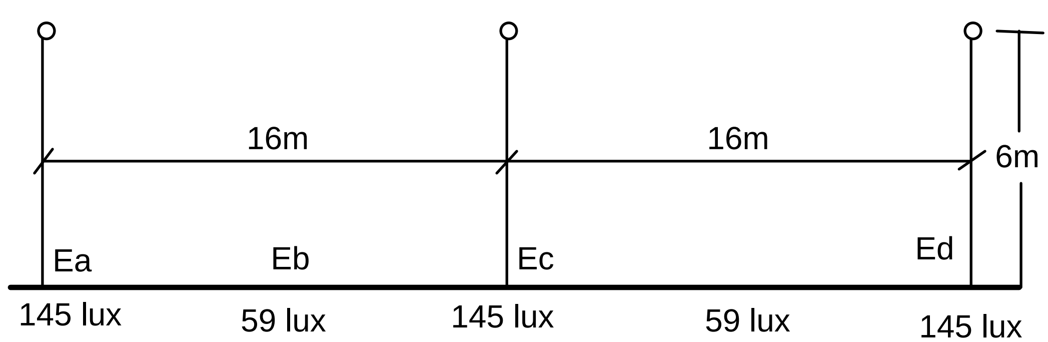


Fig 1.15b

(b) The total illuminance at:

(i) the base of each lamp post,

Ea (total)	=	Ea + 2Ec + 2 Ed
	=	132 + 11.42 + 1.66
	=	145.08 lux.

(taking A as centre and adding the contributions from two lamps either side)

(b) The total illuminance at:

(ii) midway between the base of each lamp post.

Eb(total)	=	2Eb + 2 Ed (approx.)
	=	57.02 + 1.66
	=	58.68 lux.

Illuminance profile

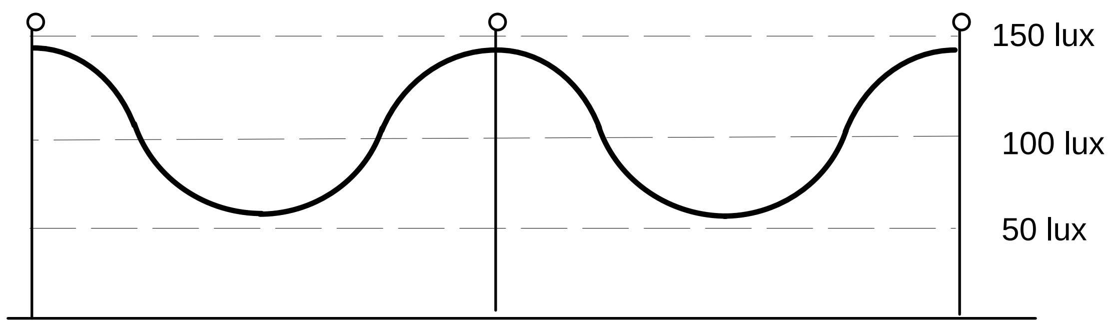


Fig 1.15c

1.5.4 RELATIONSHIP BETWEEN CANDELA AND LUMEN

The Candela. In 1948 an international standard was adopted for light intensity. The candela (pronounced “candeela”) is approximately equal to one candle power. It is defined as the luminous intensity of a point source at the centre of a sphere of 1m radius which produces an illuminance of 1 lux on the inner surface of the sphere.

The Steradian. This is like a three dimensional radian, sometimes called the unit solid angle. The steradian is the solid angle subtended at the centre of a sphere by surface areas equal to r^2.

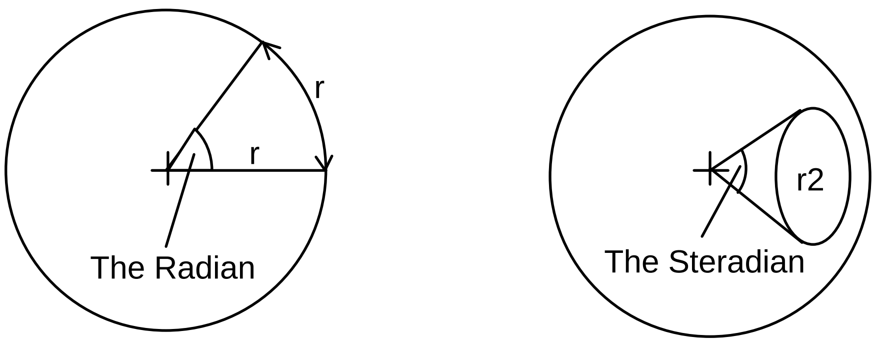


Fig. 1.16

There are 2π radians in a circle and 4π steradians in a sphere. Consider a sphere of radius one metre, with a symmetrical point light source of 1 candela intensity at its centre, the surface area of the sphere $= 4\pi r^2$

Therefore the surface area of a 1 metre radius sphere $= 4\pi\ m^2$

$$E = \frac{I}{d^2} = 1\ \text{lux} = 1\ \text{lm/m}^2$$

If there are $4\pi\ m^2$ then the source must produce 4π lumens in order to produce an average illuminance of 1 lumen/m^2 on the surface of the sphere.

CONCLUSION:
A lamp with an intensity of 1 candela produces 4π lumens of light flux.

Example 1.5 A 500 watt Tungsten Halogen lamp has an efficacy of 20 lumens per watt. Calculate its mean spherical intensity.

$$\phi = 500 \times 20 = 10000 \text{ lumens}$$

$$I = \frac{\phi}{4\pi} = \frac{10000}{4\pi} = 796.\ \text{cd}$$

1.6 POINT SOURCE CALCULATIONS

This method of calculation is particularly suitable for outdoor schemes, (see Example 1.4) with a small number of light sources and when it is necessary to calculate the illuminance at a small number of points.

Computer programmes have allowed this method to be extended to schemes with a large number of sources and where the illuminance must be calculated at a large number of points.

It may also be suitable for indoor schemes where the light reflected onto the working plane from walls, ceilings etc., is negligible. The point to point method uses the inverse square law and cosine law, the light intensity in a given direction is found from polar diagrams supplied by manufacturers.

1.6.1 POLAR DIAGRAMS

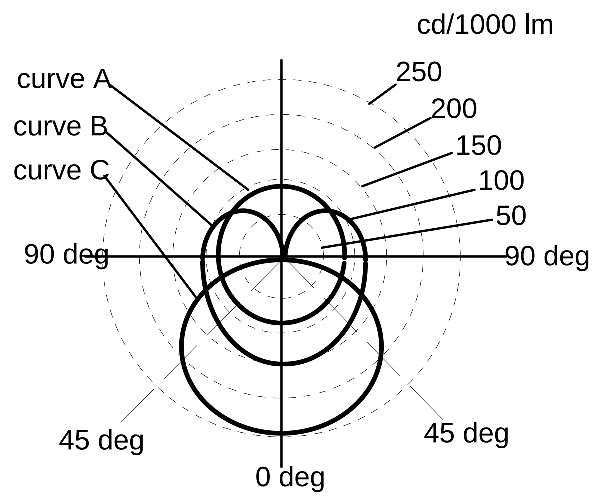


Fig.1.18

Light sources are seldom symmetrical in output. We have already seen that the light output in a given direction is called the luminous intensity.

If the light source was symmetrical in output as in example 1.4, then 80 cd/1000 lm would be its intensity in all directions as shown in Fig. 1.18 by curve A. A more realistic output for a bare lamp would be as shown in the same diagram by curve B. If reflectors were used, the output would be concentrated even more as shown by curve C.

Polar diagrams allow the lighting designer to select suitable luminaires and spacing distances based on an acceptable illuminance variation along the working plane. They are also used to provide the designer with information on light intensity in a given direction when using the point to point method of calculation.

Polar curve data is also supplied by lighting manufacturers in software packages to allow accurate calculation of illuminance in schemes with zero reflectance.

Example 1.6

A point light source has an output of 2000 lumens and intensity as shown by curve C in Fig. 1.18 calculate the illuminance on a horizontal surface which is 2 metres beneath the source:

(i) directly beneath.
(ii) 2 metres to one side.

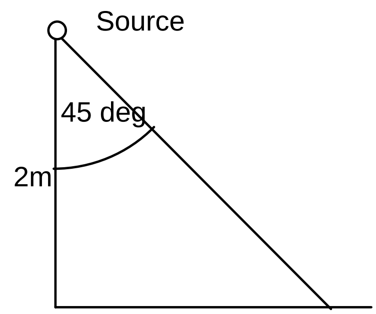


Fig. 1.18a

All values in Fig. 1.18 must be multiplied by 2 because the output of the luminaire is 2000 lumens and the values are quoted per 1000 lumens.

(i) From Fig. 1.18, the intensity directly under the lamp = 250 x 2 = 500 cd.

$$\therefore E = \frac{I}{d^2} = \frac{500}{2^2} = 125 \text{ lux}$$

(ii) From Fig 1.18a, the incident angle is 45 ^{o}. From the polar curve (Fig. 1.18), the intensity at a 45 ^{o} angle = 200 x 2 = 400 cd.

$$\therefore E = \frac{I}{d^2} \cos\theta = \frac{400 \times \cos 45^o}{2.82^2} = \frac{400 \times 0.707}{8} = 35.35 \text{ lux}$$

Example 1.7

A point source luminaire has an output as shown by the polar curve in Fig. 1.19. It is mounted 2 metres above the working plane and is fitted with an 18 Watt compact fluorescent lamp whose output is 1500 lumens. Calculate:

(i) The illuminance on the working plane directly under the lamp

(ii) The illuminance on the working plane 2 metres to one side.

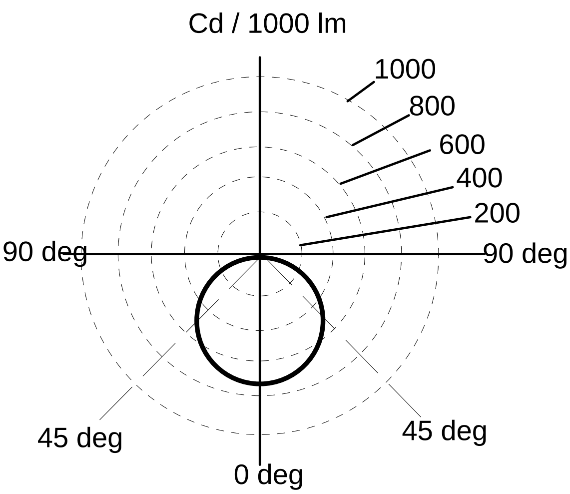


Fig.1.19

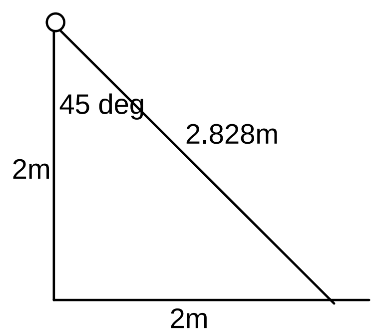


Fig. 1.19a

(i) From polar diagram I

$$I = 750 \times \frac{1500}{1000} = 1125 \text{ cd.}$$

$$E = \frac{I}{d^2} \qquad E = \frac{1125}{2^2} = 281.25 \text{ lux}$$

(ii)

$$I\_ = 450 \times \frac{1500}{1000} = 675 \text{ cd}$$

from Fig. 1.19a, $d = 2.828$ m $\cos\theta = 2/2.828 = 0.707$

$$E = \frac{I \cos\theta}{d_2}$$

$$E = \frac{675 \times 0.707}{(2.828)^2} = 60 \text{ lux}$$

1.7 TRANSMITTANCE, REFLECTANCE and ABSORPTION

When light falls on a surface, one or more of the following may occur:

1. Light is transmitted through it;
2. Light is reflected from it;
3. Light is absorbed as heat.

1.7.1 Transmittance

Most surfaces will not allow light pass through them but surfaces which do, are referred to as translucent.

1.7.2 Reflectance

We have already seen that the luminance of a surface is the illuminance on it multiplied by the surface reflectance. It therefore follows that:

$$\text{Reflectance} = \frac{\text{Reflected Light}}{\text{Incident Light}}$$

1.7.3 Absorption

The light which is not transmitted or reflected is absorbed as heat. This is the reason light coloured high reflectance clothing is preferred in summer.

Heating engineers normally consider all of the lighting load as a heat gain in the room on the basis that all of the light is eventually absorbed as heat in the totality of room surfaces.

1.7.4 Indirect Lighting Schemes

Indirect lighting schemes rely on reflected light from room surfaces to illuminate the working plane. **High reflectance surfaces are necessary if the scheme is to be efficient.** In addition, colours of surfaces must be carefully selected so that the reflected light from these room surfaces is not **colour distorted.** This can be achieved by using low chroma (pastel) colours on the room surfaces.

1.8 Illuminance (E) and Visual Performance.

1.8.1 A Historical Perspective

Research work on determining appropriate illuminance levels began in the 1930's. A link was established between the illuminance and the performance of visual tasks. Visual performance was seen to improve as the illuminance was increased up to 400 lux, at which point it levelled out. The onset of fatigue could be delayed by increasing the illuminance to levels above 400 lux.

A norm of 500 lux was recommended by the I.E.S. in 1973 for general office lighting. This value was used in the U.K., however, at the same time the recommended levels in the U.S. were 1500 to 2000 lux. This reflected a difference in emphasis and a different regard for the consumption of energy. The subsequent oil crisis brought about a reduction of recommended levels in the U.S. but those in the U.K. remained unchanged.

Modern research has also shown that visual task performance is also related to the colour of the light and contrast. In this regard vertical illuminance is also considered important. It is therefore important to consider a lighting scheme not only in terms of quantity but quality as well. (refer to vector/scalar values, modelling index, etc.)

1.8.2 Current Practice.

The CIBSE Code for Interior Lighting Design (1994) gives recommended **maintained illuminances** for a wide variety of installations. The level of illuminance required depends on 4 factors:

1. The importance of the visual task and the consequences of errors.
2. The difficulty of the visual task.
3. The duration for which the task is undertaken.
4. The eyesight of the user.

This recommended illuminance must be maintained throughout the life of the installation and must take account of the reduction of light reaching the working plane because of lamp ageing, dust collection and deterioration of the decor.

The **design illuminance (maintained illuminance)** is taken as the illuminance at the end of the maintenance period (typically 2 years). This is different to the method used in previous codes which used the lamp output at 2000 hours (LDL) to calculate the **average illuminance** over the life of the installation.

1.8.2.1 Importance of task

Performing a heart operation may not prove any more difficult visually than assembling a piece of machinery. Nonetheless if one were on the operating table one would hope there would be sufficient light to allow the surgeon perform the operation with maximum efficiency and without error. It is clear that the importance of the task is a major consideration.

1.8.2.2 Difficulty of task.

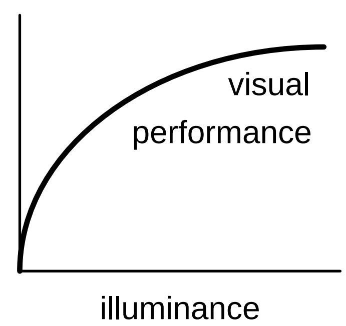


Fig. 1.20

Fig 1.20 shows the relationship between visual performance and task illuminance. It is clear that performance improves significantly up to a certain illuminance after which there is no further significant improvement. It is also clear that a higher illuminance is required as the task gets more demanding. For the average person, reading and writing is easiest when the illuminance is about 1000 lux.

In general, visual performance improves as illuminance increases, however, at very high illuminance levels glare becomes a problem and may even cause a reduction in performance.

1.8.2.3 Duration of task

The duration of the task is also important Higher task illuminances increase the optical depth of field thereby reducing the work required by the eye in adjusting focus. Fatigue can be offset by using high illuminance levels.

1.8.2.4 Eyesight of user.

Human eyesight deteriorates with age and so older people require a higher illuminance for a given task than younger people. The average 70 year old requires up to 3 times the task illuminance of the average 20 year old.

Notwithstanding the above, in current European practice, an illuminance of 500 lux is recommended for offices where the task is mostly desk based (300 lux if screen based). This seems a reasonable compromise between performance and energy conservation.

1.9 LUMEN METHOD OF LIGHT CALCULATION

This method is most suitable for interior lighting design , where a high proportion of light on the working plane is reflected by internal surfaces. For external applications or where the reflectance of the surfaces is unknown or may not be relied upon (emergency lighting schemes), a utilisation factor for zero reflectance may be used. The lumen method, sometimes called the luminous flux method of calculation, is normally used **to calculate the average illuminance on working planes, or to calculate the number of luminaires required to provide a specified average illuminance in rooms.** The following formula is used:

$$E = \frac{N\,(n \cdot \phi) \cdot MF \cdot UF}{A}$$

or

$$N = \frac{E \times A}{Mf \cdot UF \cdot (\phi \cdot n)}$$

Where:

N = Number of luminaires required

E = Maintained Illuminance (lux)

ϕ = Initial lamp output (lumens)

n = Number of lamps in luminaire

MF = Maintenance factor

UF = Utilisation factor

A = Area of room (m^2)

1.9.1 Number of Lamps / Luminaires.

N is used to represent the number of luminaires and **n** is used to represent the number of lamps in each luminaire.

1.9.2 Lamp Flux (ϕ lumens)

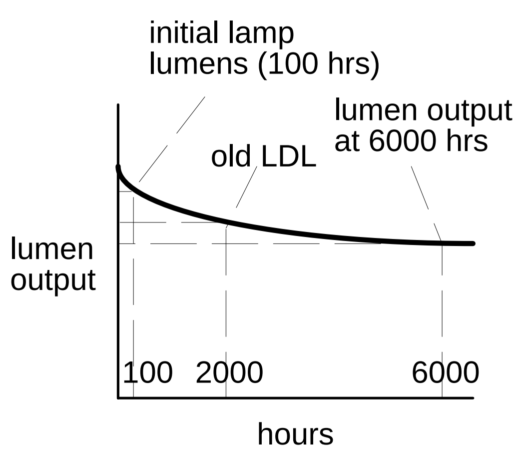


Fig. 1.21

The initial light output (100h) is now used for calculations. A factor called the **lamp lumen maintenance factor (LLMF)** is then applied to allow for the reduction in light output from the lamp during the maintenance period.

Consider an installation where lamps are to be replaced after 6000 hours use. The lamp manufacturer's data is checked to see the lamp output after 6000 hours use (as shown in Fig 1.21). This figure is now divided by the initial lamp lumens to get the LLMF.

Note: This is a change from the 1985 code which used the output at 2000h called the lighting design lumens (LDL). Calculation of the maintenance factor is detailed on the following pages.

Table 1.1

Typical recommended maintained illuminances	**Lux**	**Limiting glare index**
Corridors and stairs	100	22
Warehouses	100 - 200	25
Medium bench and machine work	500	22
Fine painting spraying and finishing	750	22
Printing inspection	1000	19
Proof reading / drawing offices	750	16
General offices (desk based)	500	19
General offices (screen based)	300	19
Supermarkets	750	22

1.9.3 Maintenance Factor (MF)

In the 1994 guide, **Maintenance Factor (MF)** is the term used to take account of the reduction in illuminance over the maintenance period due to:

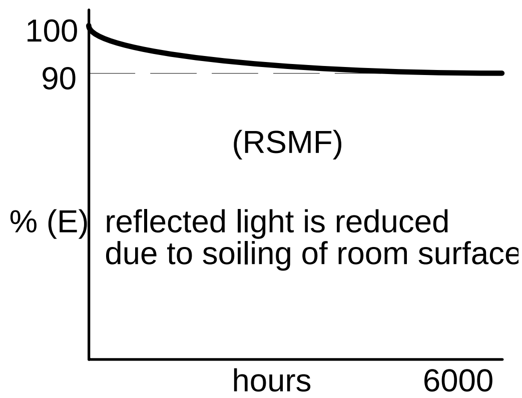


Fig. 1.22a

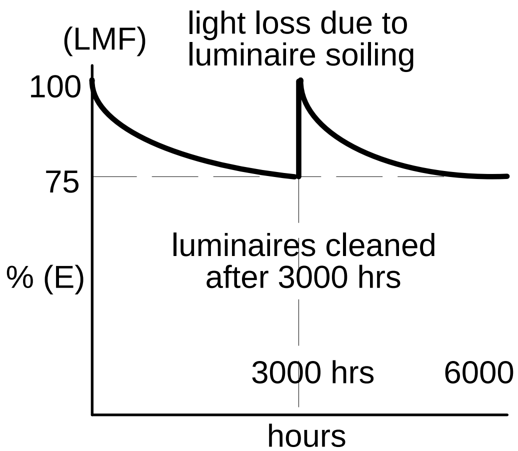


Fig. 1.22b

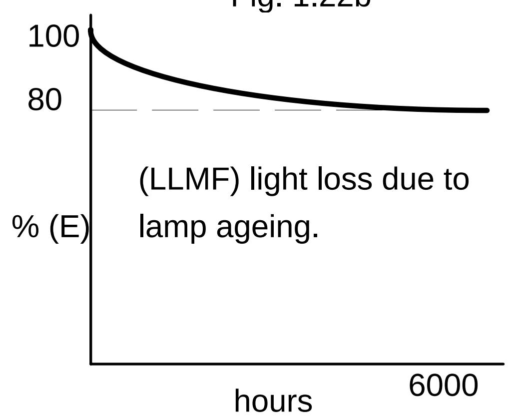


Fig. 1.22c

1. Reduced reflectances due to the accumulation of dirt and dust on room surfaces. Room Surface Maintenance Factor. (RSMF Fig. 1.22a).

2. Reduced light output from the luminaire due to the accumulation of dirt and dust on the luminaire. Luminaire Maintenance Factor.(LMF Fig. 1.22b).

3. Reduced light output due to the Lamp Lumen Maintenance Factor.(LLMF Fig. 1.21 and 1.22c)

4. Reduced light output due to lamps failing. Manufacturer data will give the percentage lamp failures for a specific number of hours operation. The Lamp Survival Factor (LSF) will be 1 if spot lamp replacement is carried out.

$$MF = RSMF \times LMF \times LLMF \times LSF$$

Note: The CIBSE Code for Interior Lighting 1985 used the term **Light Loss Factor** (now obsolete), which took account of the reduction in light output due to the accumulation of dirt and dust on luminaires, deterioration of room surfaces as well as the reduction in light output due to lamp depreciation.

Tables 1.2 to 1.6 reproduced the Code for Interior Lighting by kind permission of the Chartered Institute of Building Services Engineers.

Table 4.3
Table 4.4

Table 4.5
Table 4.6

Table 4.7

Figure 4.13

Example 1.9 Calculate the maintenance factor for an installation where the LLMF, LMF and RSMF are as shown in Fig. 1.22. The luminaires are cleaned after 3000 hours, the lamps are replaced after 6000 hours and room surfaces are cleaned after 6000 hours. Spot replacement of failed lamps is also carried out.

MF = RSMF x LMF x LLMF x LSF

Maintenance factor at 6000 hrs = 0.9 x 0.75 x 0.8 x 1 = 0.54

1.9.4 UTILISATION FACTOR

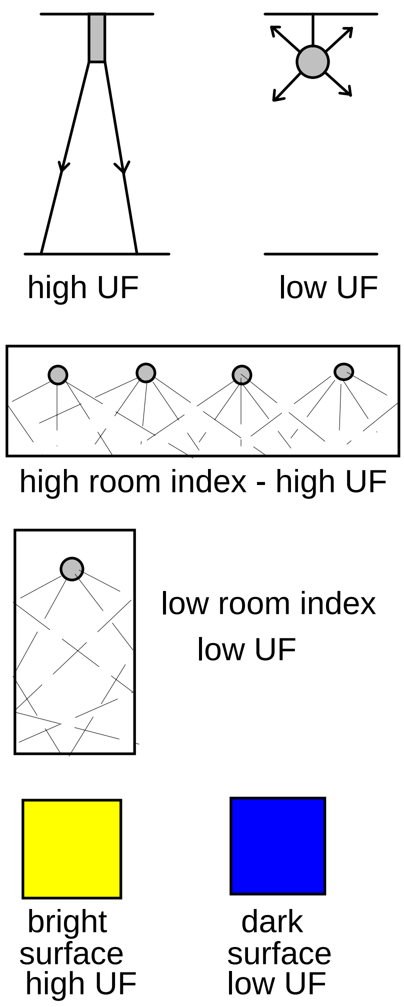


Fig. 1.23

$$UF = \frac{\text{Lumens received on W.P.}}{\text{Lumens output of luminaires}}$$

Utilisation factor takes account of the loss of light due to absorption on room surfaces. It depends on 3 factors:

1. **Type of Luminaire** A luminaire with a concentrated light output directed on the working plane will have a higher UF than a luminaire with a dispersed light output.

2. **Room index.** This takes account of the length (L) and width (W) of the room and the height of the luminaires above the working plane (H_m).

$$R.I. = \frac{L \times W}{(L + W)\, H_m}$$

3. **Reflectances of Room Surfaces.** Bright colours with high reflectances result in a higher UF. A high utilisation factor will mean fewer lamps are needed resulting in a more efficient energy usage and a lower capital cost.

To determine the Utilisation Factor:

1. Obtain reflectance factors for room surfaces from the architect or interior designer. (See Table 1.7)

2. Acquire manufacturer's data for luminaire selected. (Table 1.8)

3. Calculate room index.

4. Evaluate utilisation factor from manufacturer's data. (Table 1.8)

Table 1.7 Typical Reflectance Factors

Colour	Factor
White or Cream	0.7 or 0.8
Yellow	0.6
Light Green or Pink	0.5
Sky Blue or Grey	0.4
Beige or Brown	0.3

Table 2 Typical Manufacturer's data for a typical twin tube fluorescent luminaire used to calculate Utilisation Factors.

Room reflectances			Room index								
C	**W**	**F**	**0.75**	**1.00**	**1.25**	**1.50**	**2.00**	**2.50**	**3.00**	**4.00**	**5.00**
0.7	0.5	0.2	NA	0.61	0.65	0.67	0.70	0.71	0.73	0.74	0.75
	0.3		NA	0.58	0.62	0.64	0.67	0.69	0.71	0.73	0.74
	0.1		NA	0.56	0.59	0.62	0.65	0.68	0.69	0.71	0.73
0.5	0.5	0.2	NA	0.60	0.63	0.65	0.68	0.69	0.70	0.72	0.73
	0.3		NA	0.58	0.61	0.63	0.66	0.68	0.69	0.71	0.72
	0.1		NA	0.56	0.59	0.61	0.64	0.66	0.68	0.69	0.71
0.3	0.5	0.2	NA	0.59	0.62	0.64	0.66	0.67	0.68	0.69	0.70
	0.3		NA	0.57	0.60	0.62	0.64	0.66	0.67	0.68	0.69
	0.1		NA	0.55	0.58	0.60	0.63	0.65	0.66	0.68	0.68
0.0	0.0	0.0	NA	0.54	0.57	0.58	0.61	0.62	0.63	0.65	0.65

Example 1.9

Calculate the Utilisation Factor for a room with the following dimensions:
Length 8m; Width 6m; Height 3m; height of working plane 0.8m. The room reflectances are Ceiling 0.5; Walls 0.3 and Floor 0.2.

$$R.I. = \frac{L \times W}{(L + W) H_m} = \frac{8 \times 6}{(8 + 6)2.2} = 1.558 \text{ (say 1.5)}$$

From Table 1.8 the Utilisation factor can be read as 0.63

1.9.5 SPACE: HEIGHT RATIO (SHR)

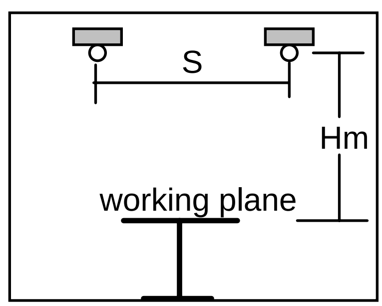


Fig. 1.24

This is the ratio of space between luminaires (S) to their height above the working plane (H_m).

Manufacturers will specify a recommended SHR for each of their luminaires. Ensuring that luminaires are spaced within the recommended value will mean an acceptable variation in illuminance across the working plane. This is expressed in terms of the Uniformity Ratio (see definitions).

Example 1. 10 A factory area is 40m long, 20m wide and is 8m high. Point source luminaires are suspended 1.5 metres below ceiling level. The working plane is 1 metre high. Calculate the minimum number of luminaires which must be installed to conform with a recommended SHR of 1.5 : 1.

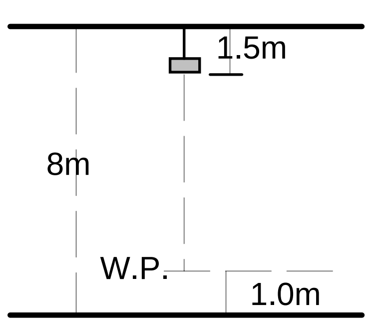


Fig. 1.25

H_m = 8 - (1.5 + 1) = 5.5m

SHR = 1.5 : 1

therefore S = 1.5 x 5.5 = 8.25m

$$\text{Min. no. of rows} = \frac{W}{S} = \frac{20}{8.25} = 2.4 \text{ (3 rows)}$$

$$\text{Min. no. of luminaires per row} = \frac{L}{S} = \frac{40}{8.25} = 4.85 \text{ (5 luminaires)}$$

This means that **the minimum number** to conform with SHR. requirement is 3 rows with 5 luminaires per row. **More than this number can be used if desired** for reasons such as balance, effect, control or ease of installation.

Assuming that three rows of five luminaires is suitable, the actual spacing is determined as follows:

$$\text{Spacing between rows (S)} = \frac{W}{\text{No of rows}} = \frac{20}{3} = 6.67\text{m.}$$

Note: The spacing between the last row and the wall should < 0.5 S. i.e.< 3.33m

$$\text{Spacing in rows (S)} = \frac{L}{\text{No per row}} = \frac{40}{5} = 8\text{m}$$

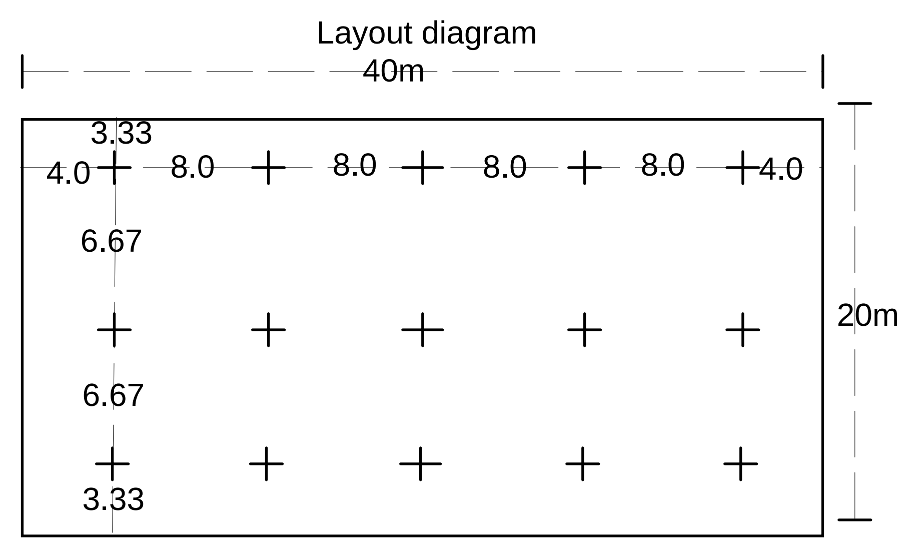


Fig. 1.26

Note: If work is to be carried out at the perimeter of the room, a spacing of 0.33 S to the wall may be used.

Linear Luminaires

The relevant spacing **maximum transverse and axial spacing** data will be supplied by the manufacturer. The spacing is usually taken between centres.

(**Note:** the maximum recommended transverse SHR is usually different from the axial SHR where linear luminaires are used).

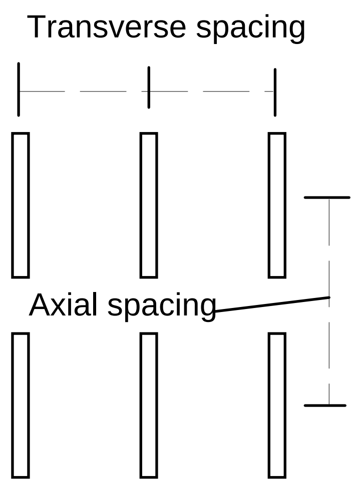


Fig. 1.27

Where high levels of illuminance are required, it is common practice to use continuous rows of luminaires with the transverse spacing at the maximum permissible. In this way, installation costs will be kept to a minimum, particularly where luminaires are suspended below the ceiling.

The lighting installation must however be co-ordinated with other services and compromise with air conditioning outlets and other ceiling mounted equipment is often necessary in practice.

Example 1.11

The factory in example 1.10 is to be illuminated using continuous rows of twin 1500mm fluorescents. Calculations indicate that 72 luminaires are required. Design a suitable layout given a mounting height above the working plane of 5.5m and the following SHR's apply.

Transverse 2.00 : 1 (spacing between rows)
Axial 1.75 : 1 (spacing in rows)

(i) Spacing between rows: H_m = 5.5m, therefore S = 5.5 x 2 = 11m

Two continuous rows of fluorescents 10 metres apart and 5 metres from each side wall would conform with the SHR requirement, this would mean using 36 luminaires per row and these **would not fit** in the 40m available.
i.e. 36 x 1.5 = 54m. which is longer than the building.

Note the actual physical dimensions of luminaires with 1.5m tubes is 1.6m approximately.

Try 3 rows of luminaires with 24 luminaires per row. $\left(\frac{40}{24} = 1.67\text{m.}\right)$ seems O.K.

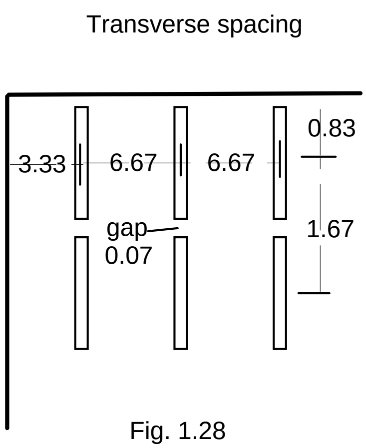


Fig. 1.28

i.e. the luminaires will be spaced 1.67m apart (centre to centre) and

$$\frac{1.67}{2} = 0.83 \text{ m from end walls}$$

The transverse spacing is now 20m divided by 3, which is 6.67m. Since this is less than the maximum spacing, the effect will give a more uniform distribution of light.

Example 1.12

An office area measures 16m x 8m and is 2.7 metres high. It is to be illuminated to an average value of 500 lux. 600mm x 600mm recessed luminaires, each containing 4 lamps are used. Each lamp has an output of 1400 lumens. Utilisation factor is 0.5 and maintenance factor is 0.75.

(i) Calculate the number of luminaires required.
(ii) Sketch a layout of the scheme indicating the spacing between luminaires.

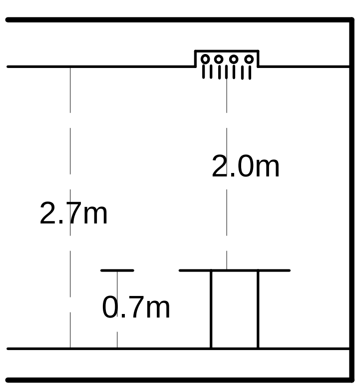


Fig. 1.29

$$N = \frac{E \times A}{MF \times UF \times (n \times \phi)}$$

E = 500 lux
A = 16 x 8 = 128m^2
MF = 0.75
UF = 0.5
n = 4 lamps
ϕ = 1400 lumens

$$N = \frac{500 \times 128}{0.75 \times 0.5 \times (4 \times 1400)} = 30.5 \text{ luminaires.}$$

Assumptions:

1. Desk height 0.7m therefore H_m = 2 m

2. SH ratio = 1.5 : 1, Therefore max spacing = 3 metres

3. There are no restrictions with regard to ceiling tile positions. (in practice tiles will normally restrict spacing to multiples of 0.6m.

$$\text{Min. no of rows} = \frac{8}{3} = 2.7 \text{ (i.e. 3)}$$

3 rows of 10 would give a spacing of 1.6m between centres.

An alternative layout would be 4 rows of 8 luminaires.

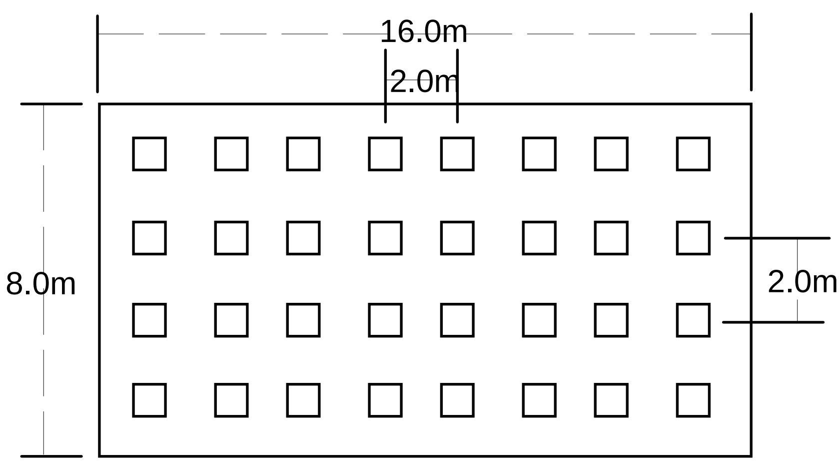


Fig. 1.30

4 rows of 8 would be preferable as they would give a square layout with identical spacings. In practice it is likely that ceiling tiles would restrict spacings to multiples of 0.6m (the size of the ceiling tiles)

Example 1.12
An office area measures 30m x 15m. The ceiling to desk height is 2 metres. The area is to be illuminated to a general level of 500 lux using twin lamp 32 watt VDT luminaires with a SHR of 1.25. Each lamp has an initial output of 85 lumens per watt. The lamps are operated for 6000 hrs (2 years) before being replaced. Lamps and luminaires are cleaned annually and the room is cleaned every 3 years.

(a) Using Table 1.9, find the utilisation factor.
(b) Using tables 1.2 to 1.6 find the maintenance factor.
(c) Calculate the number of luminaires required and design a suitable lighting scheme.

Table 1.9 Utilisation Factors SHR (nom) 1.5

Room reflectances			Room index								
C	**W**	**F**	**0.75**	**1.00**	**1.25**	**1.50**	**2.00**	**2.50**	**3.00**	**4.00**	**5.00**
0.7	0.5	0.2	0.53	0..57	0..60	0..62	0..64	0..66	0..67	0.69	0.69
	0.3		0.50	0.54	0.57	0.59	0.62	0.64	0.65	0.67	0.68
	0.1		0.48	0.52	0.55	0.57	0.61	0.63	0.64	0.66	0.67

Solution:

(a) assume a bright interior with room reflectances 70% ceiling, 50% walls and 20% floor. The top row of the table applies.

$$\text{Room index} = \frac{L \times W}{(L + W)\, H_m} = \frac{30 \times 15}{(30 + 15)2} = 5$$

from the table 1.9, U F = 0.69

(b) LLMF = 0.87 (Table 1.3 lamp lumen maintenance factor)
LMF = 0.81 (Table 1.5 luminaire maintenance factor)
RSMF = 0.95 (Table 1.6 room surface maintenance factor)
LSF = 0.95 (Table 1.3 lamp survival factor)

Maintenance Factor (M.F.) = LLMF x LMF x RSMF x LSF
= 0.87 x 0.81 x 0.95 x 0.95
= 0.636

(c) $$N = \frac{E \times A}{MF \times UF \times \phi \times n}$$

$\phi = 85 \times 32 = 2720$ lumens per lamp

$$N = \frac{500 \times 30 \times 15}{0.636 \times 0.69 \times 2720 \times 2} = 94 \text{ luminaires}$$

$H_m = 2m$; SHR = 1.25 $\therefore$ max spacing = 2.5m

$$\text{Number of rows required} = \frac{15}{2.5} = 6$$

Round off number of luminaires to 96, allowing 16 per row

$$\text{Axial spacing } \frac{30}{16} = 1.875m; \quad \text{Transverse spacing} = \frac{15}{6} = 2.5m$$

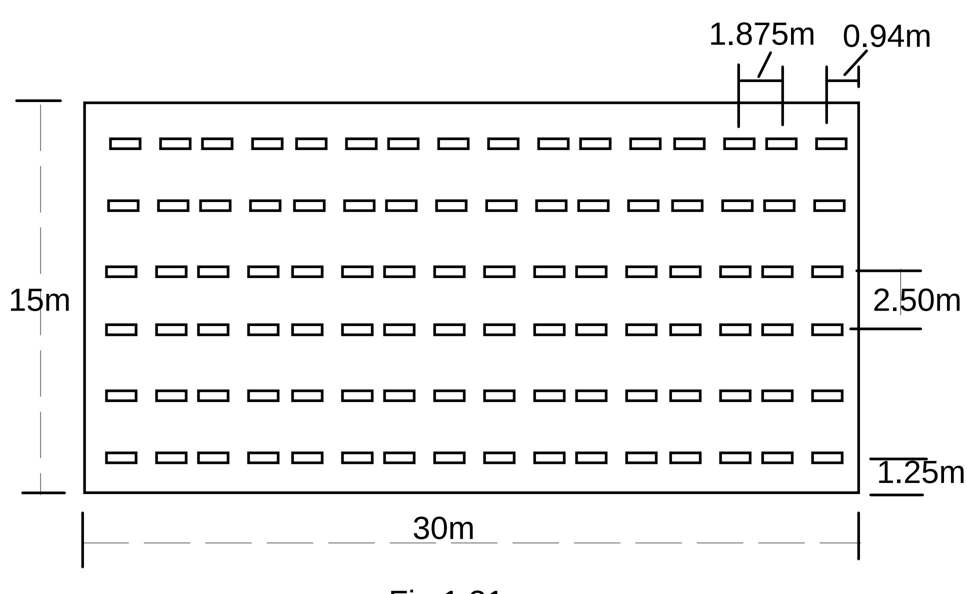


Fig 1.31

Example 1.13

A factory measures 50m x 30m x 6m high. A general lighting scheme is to illuminate the whole area to 500 lux maintained illuminance using 1000 watt metal halide lamps with an initial efficacy of 90 lumens per watt. Maintenance factor is 0.6 and utilisation factor is 0.5. A space height ration of 1.5 : 1 is recommended for the luminaire chosen and a mounting height of 5m over working plane is assumed. Design a suitable lighting scheme.

ϕ = 1000 x 90 = 90,000 lumens per lamp initially. There will be a reduction in lamp output over time but this is taken account of in the maintenance factor.

$$N = \frac{E \times A}{MF \times UF \times \phi} = \frac{500 \times 50 \times 30}{0.6 \times 0.5 \times 90{,}000} = 27.7$$

therefore 28 lamps are required.

Check space height ratios for length and width.

4 rows of 7 spaced as shown is an acceptable design.

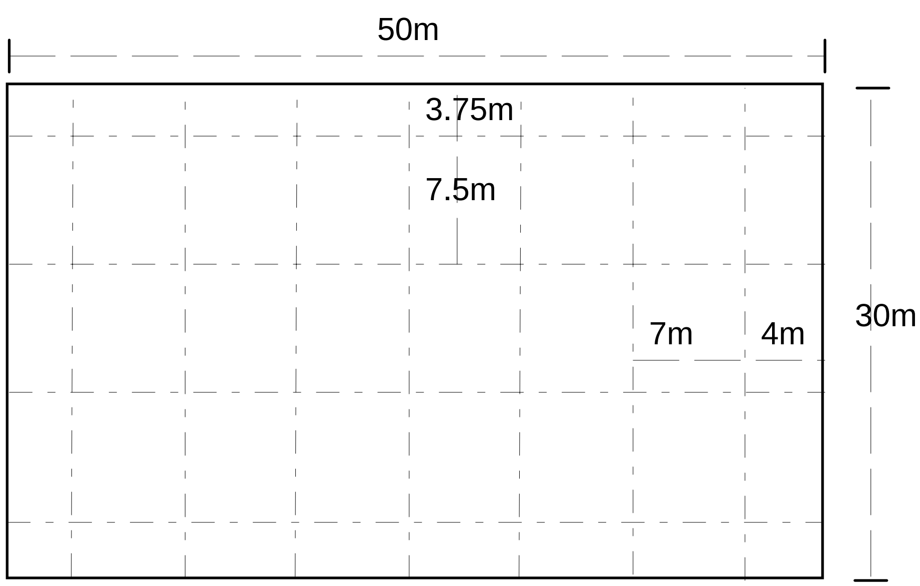


Fig. 1.32

Sample questions

1 A Factory area measures 30m x 15m and is 5m high. The factory is to be provided with general lighting to a level of 300 lux. Giving reasons for your choice, specify for the above installation:

- i two suitable lamp types
- ii two suitable luminaire types.

2 Determine the utilisation factor for the factory described in question 1 using table Q2 and assuming that the surface reflectances are: Ceiling 50%, Walls 50% and Floor 20%.

3 Using the CIBSE code for interior lighting determine the most suitable maintenance period / Maintenance Factor for the factory described in question 1

Assume that the following applies:

- i tri-phosphor lamps are used
- ii The factory works a double shift six day week
- iii The luminaires are maintenance category C
- iv The environment is described as normal
- v The luminaire flux distribution is direct/indirect

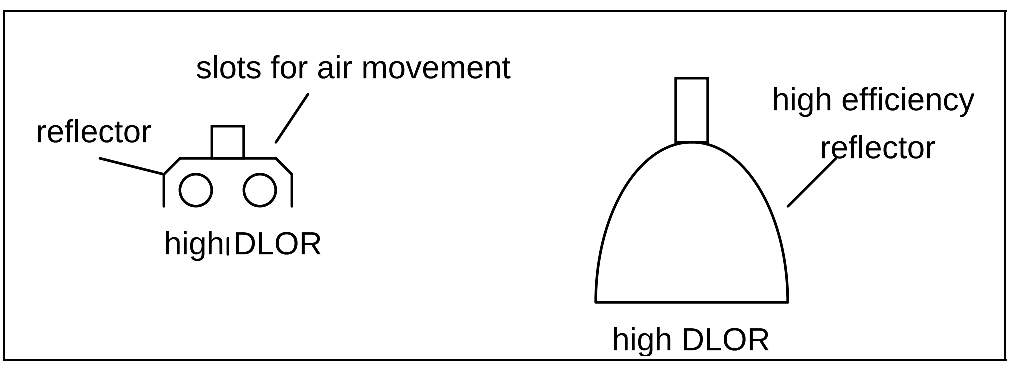
4 Design a suitable general lighting scheme for the area described in question 1 and sketch a layout of the proposal.

Solution 1:

i Lamps - LPMV - tubular fluorescent
- HPMV (MBI) - Metal Halide

Both lamps have high efficacy and good colour rendering

ii Luminaires



Reflectors ensuring a high Downward Light Output Ratio (DLOR) are recommended as these luminaires are normally suspended and/or ceiling voids often have low reflectances in factories.

Solution 2 Determine Utilisation factor.

$$\text{Room Index (RI)} = \frac{30 \times 15}{(30 + 15) \times 4} = 2.5$$

Table Q2 **Utilisation Factors**

Room reflectances			**Room index**								
C	**W**	**F**	**0.75**	**1.00**	**1.25**	**1.50**	**2.00**	**2.50**	**3.00**	**4.00**	**5.00**
0.5	0.5	0.2	NA	0.60	0.63	0.65	0.68	0.69	0.70	0.72	0.73
	0.3		NA	0.58	0.61	0.63	0.66	0.68	0.69	0.71	0.72
	0.1		NA	0.56	0.59	0.61	0.64	0.66	0.68	0.69	0.71

Utilization factor = 0.69

Solution 3 Determine the Maintenance period / Maintenance Factor

Using the data provided and tables 1.2 to 1.6.

The number of hours of usage per year = 5000 (table 1.2)
LLMF 1yr. = 0.89 2yr. = 0.85 (table 1.4)
LSF 1yr. = 1 2yr. = 0.85
Recommended cleaning period is 1yr. (table 1.4)
LMF 1 yr. cat. C = 0.81 (table 1.5)
RSMF 1 yr. (medium/large) (direct/indirect) = 0.88 (table 1.6)
MF = LLMF x LSF x LMF x RSMF

Alternative maintenance schedules:

(i) Clean every year. + group lamp replace every 2 years.
(MF = 0.85 x 0.85 x 0.81 x 0.88 = 0.51)
(ii) Clean every year. + spot lamp replace + group lamp replace every 2 year
(MF = 0.85 x 1.0 x 0.81 x 0.88 = 0.61)
(iii) Clean and group lamp replace every 1 year 3 months.
(MF = 0.89 x 1.0 x 0.81 x 0.88 = 0.63)

Select option (ii) and benefit from a maintenance factor of 0.61 (i.e. a 20% energy saving compared with option (i).

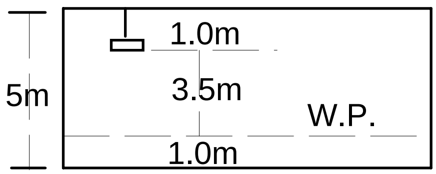
Solution 4. Using linear 58W 1500mm tri-phospor fluorescents.

lamp ϕ = 58 x 90 = 5220 lumens
assume twin tube luminaires.

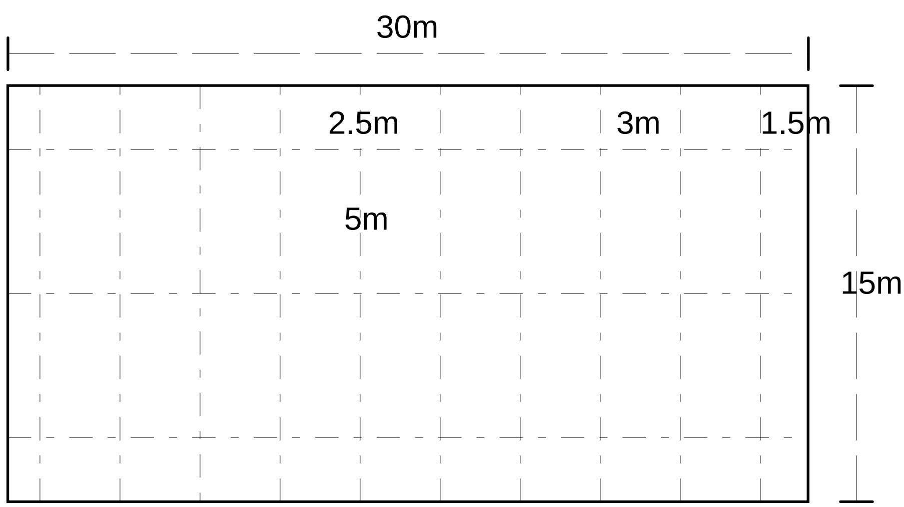
$$N = \frac{E \times A}{Mf \,.\, UF \,.\, (\phi \,.\, n)}$$

$$N = \frac{300 \times 30 \times 15}{0.61 \times 0.69 \, (5220 \times 2)} = 30.7 \text{ (say 31)}$$

Three rows of 10 luminaires would be a possible solution.



Assume mounting height (Hm = 3.5m)
and a max. SHR of 1.5
Maximum spacing = 3.5 x 1.5 = 5.85m



30 luminaires provide an overall average maintained illuminance of 293 lux which is deemed acceptable.

1.10 UPLIGHTING

1.10.1 Introduction. Uplighters illuminate the ceiling and upper walls. These surfaces act as secondary sources providing **soft diffused lighting** to the room. There will be no excessive glare from VDT screens irrespective of the viewers position provided there are no stark contrasts of room surface luminances, . Uplighting may be used to enhance the architectural features of interiors, however care is necessary to ensure that undesireable shadows are not cast.

Conspicuous reflections such as scalloping must be avoided. Ceilings and walls should be matt with high reflectance and white or pastel colours. Nonetheless an uplighting scheme is **less efficient** than standard ceiling mounted scheme by about 10% to 20%. A room illuminated by uplighting will appear bright and airy though perhaps a little boring. **Visual stimuli are important** such as colours and textures. These colours should not form part of the main reflecting surfaces.

1.10.2 CALCULATIONS

1.10.2.1 To Calculate number of luminaires required

The lumen method of calculation may be used but there is a change to the use of UF. The following formulae apply:

$$N = \frac{E \times A}{\phi \times n \times MF \times UF}$$

$$UF = ULOR \times TF_{CF}$$

Where:

Where:	UF	=	Utilisation factor for uplighters
	ULOR	=	upward light output ratio of luminaire
	TF_{CF}	=	transfer factor (see table 5.21 from CIBSE code for interior lighting)
	N	=	Number of luminaires
	E	=	Maintained average illuminance (lux)
	A	=	Area of room (m^2)
	ϕ	=	Initial bare lamp lumens (lm)
	n	=	Number of lamps per luminaire
	MF	=	Maintenance factor
	UF	=	Utilisation factor

The number of luminaires required can be calculated from this formula. This does not however, ensure that the illuminance variation over the working plane is acceptable. Maximum and average ceiling luminances must also be calculated to ensure a satisfactory result (see chapter 6)

Section 2

LAMPS and LUMINAIRES

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2.1.1 LAMP TERMINOLOGY

Before considering each lamp type individually and comparing characteristics it is important to become familiar with some lighting terms.

Luminous Efficacy (lumens per watt)

This is the light output of the lamp in lumens divided by the power input to the lamp in watts. The control gear power loss (10% for high frequency and 20% for low frequency lamps is not included in this calculation. The term efficiency is sometimes used but strictly speaking this is not correct because the output and input are measured in different units. The term Luminous Efficacy is now quoted for the initial lamp output (first 100 hrs). Efficacy is directly related to energy costs. The higher the efficacy - the lower will be the energy usage resulting in lower energy costs and less environmental emissions.

Lamp Life Survival Factor (LSF)
This relates to the percentage of functioning lamps in an installation after a certain period of use.

Lamp Replacement Many people relate lamp replacement to lamp failure. it should be noted that **the light output of a lamp declines with age.** For this reason, lamps will normally be replaced in bulk (group lamp replacement) after a specified number of hours operating or after a certain percentage of lamp failures. The number of lamp failures may be used as a condition monitoring parameter to determine the replacement period. The alternative is to use a calendar period as an estimate of lamp usage. The maintenance period is often made to coincide with company holidays.

Group Lamp Replacement (Planned Lighting Maintenance PLM)
This normally takes place in an installation when approximately 10% of lamps have failed. The advantages of group lamp replacement are:

1. One planned maintenance operation resulting in less disturbance and lower maintenance cost.

2. Uniformity of lamp colour.

3. Less likelihood of electrical damage to control gear because of a faulty lamp.

4. Lamp disposal is more easily planned.

5. Less lighting installed initially because the M.F. will be higher.

Correlated Colour Temperature (CCT)

This relates to the colour of the light emitted. Paradoxically the lower the CCT, the warmer is the CCT class. (See Table 2.1). Generally a warm appearance is desirable where illuminances are low - below 300 LUX.

Table 2.1A

CCT Class	
Warm	Below 3300 K
Intermediate	3300 K to 5300 K
Cool	Above 5300 K

Colour Rendering

This refers to the ability of a light source to render colours accurately. The most widely adopted method of **indicating colour rendering performance** of lamps is the **CIE colour rendering index (C.R.I.).**

The colour appearances of a surface depends upon the spectral composition of the incident light. If the light output of a lamp does not contain the colour red then surfaces which are red will become colour distorted when illuminated by this lamp. For example, a red car driving along a motorway illuminated by low pressure sodium vapour lamps will appear brown or grey because there is no red in the output of a LPSV lamp - as illustrated in Fig. 2.3.

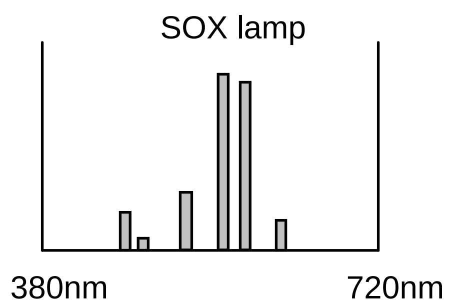
Table 2.1B

Colour rendering group	C.I.E. Colour Rendering Index (Ra)
1A	Ra = 90
1B	90 = Ra = 80
2	80 = Ra = 60
3	60 = Ra = 40
4	40 = Ra = 20

Lamps from group 1A have a colour rendering index greater than 90 and would be used where accurate colour rendering is required. Lamps from group 1B are widely used for interiors where colour is important but not critical. Lamps from group 3 will not render colours accurately but on the other hand do not produce a marked distortion of colours either. Lamps from group 4 are likely to produce a marked distortion of some colours.

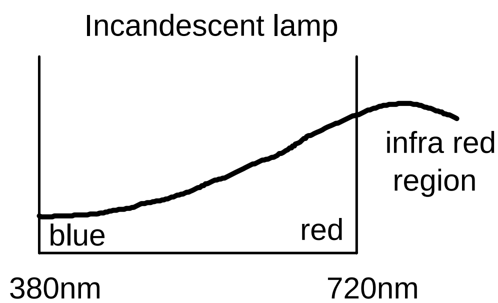
Efficacy Vs Colour Rendering

There was a general rule at one time that the more efficient a lamp was, the poorer was its colour rendering performance. In recent years lamp manufacturers have developed lamps which are very efficient and have good colour performances.



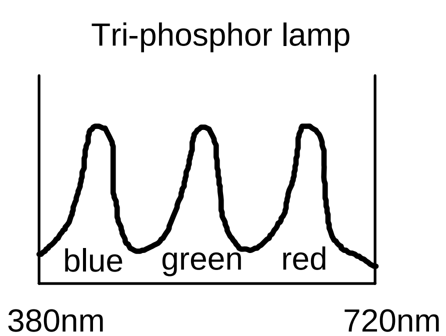
High efficacy, low colour renderir

Fig. 2.3



Low efficacy, good colour rendering

Fig. 2.4



High efficacy, good colour renderii

Fig. 2.5

Tri-phosphor fluorescent lamps emit light output which is concentrated in the 3 primary colours of the spectrum (red, green and blue), providing good colour performance (CRI IB) and high efficacy - up to 85 lumens/watt. (See Fig. 2.5). Whilst **colour rendering** with these lamps is not exact they perform well with regard to **"colour preference"**.

Colour preference is a term used to refer to human reaction when seeing objects illuminated by these lamps. Primary colours appear to have a stronger hue and this is acceptable and pleasing to the people using the interior. Exact colour rendering however, is not provided.

Stroboscopic Effect and Flicker

Stroboscopic effect is the visual phenomenon whereby rotating machinery may appear to look stationary or rotating at a different speed or direction than it really is.

Discharge lamps pass through a "Dark Period' one hundred times a second at a frequency of 50 H_Z. This flicker not only causes stroboscopic effect but also causes discomfort to people in the area and may contribute to sick building syndrome. High frequency lamps also flicker, but as this is at such a high frequency (35 kHz), it does not cause danger or discomfort.

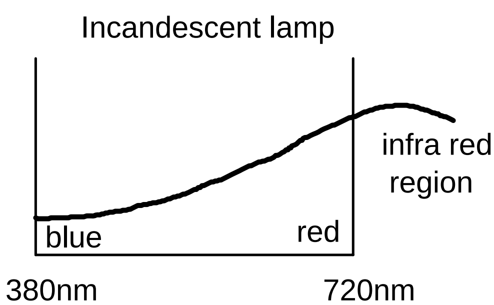
2.1.2 LAMP TYPES

Incandescent Lamps and Discharge Lamps.

Lamps fall into the general categories of (i) incandescent or (ii) discharge. The incandescent lamp emits light by reason of its temperature and the Discharge lamp emits light due to an electric current flowing in a gas

2.1.2.1 Incandescent Lamps

Light is emitted from a tungsten filament operating at a very high temperature inside a glass bulb. The operating temperature is limited by the melting point of the filament, vapourisation of the filament occurs as this point is approached and this reduces the life of the lamp. The bulb usually contains an inert gas, normally argon. The temperature of the filament is around 2800K but even at this temperature only about 10% of the energy used is emitted as light in the visible region of the spectrum - hence its inefficiency. (See Fig. 2.6)



Low efficacy, good colour rendering

Fig. 2.5

Fig. 2.7

Characteristics:

Efficacy :10-20 Lumens/Watt (Typically 13 lm/W for a 100W GLS - General Lighting Service lamp)
Lamp Life: 1000 hours. (This increases dramatically on reduced voltage)
Colour rendering: Excellent (1A)
Colour Temperature: 2700 K (Warm)
Control: Fully dimmable (though a shift to red occurs).
Advantages: Simple, compact, good colour rendering, cheap to install, instant light, no control gear.
Disadvantage: High running cost, short life, high heat output.
Applications: Domestic and short duration use in commercial and industrial installation. (e.g. cleaner's store).

Types of Incandescent Filament Lamp:

GLS, Candle, Decorative, Reflector, Pygmy, Strip, Extra Low Voltage (12V) *

* These lamps are commonly referred to as Low Voltage incandescent lamps and have the following advantages: 1) more compact; 2) longer life; 3) increased efficacy, 4) more precise beam control 5) Higher colour temperature than GLS. Balanced against this are the problems of: 1) high energy cost; 2) heat dissipation 3) transformers often prove problematic; 4) significant colour shift when dimmed.

2.1.2.1.2 Tungsten Halogen Incandescent Lamps

These lamps have a tungsten filament and operate on the incandescent principle. They have a higher operating temp (3000K) which:

(i) Increases the efficacy.
(ii) Improves the quality of light.
(iii) Tends to shorten lamp life.

The addition of halogen gas however, more than off-sets the ageing effects of higher temperature and as a result, the lamp life is doubled.

Fig. 2.8

Characteristics
Efficacy 15-25 lumens/watt
(Typically 20 lm/W for a 300W linear lamp)
Lamp Life: 2000 hours
Colour: Rendering: Excellent (1A)
Colour Temperature: 3000 K
Control: Fully dimmable (Though a shift to red occurs).
Advantages: Instant, cheap to install, excellent colour rendering.
Disadvantages: High running cost; very hot operation;

Applications for Tungsten Halogen Lamps: Security lighting, vehicle lights, short duration use e.g. T.H. are sometimes used alongside discharge lamps that require a long warm up time. The T.H. lamps only operate whilst the discharge lamps warm up. These lamps are particularly sensitive to a change in supply voltage which affects their operating temperature.

2.1.2.2 LOW PRESSURE DISCHARGE LAMPS

2.1.2.2.1 Tubular fluorescent lamps

Tubular and compact fluorescent lamps contain low pressure mercury vapour. The inside of the tubes are coated with a combination of phosphor powders. U.V. radiation is produced when an electric current passes through the gas. The U.V. radiation strikes the phosphor powders and is re-emitted as light in the visible spectrum. The spectral light distribution may be varied by changing the combination of phosphors. Control gear (ballast) is necessary to initiate the gas discharge and limit circuit current.

Fig 2.9

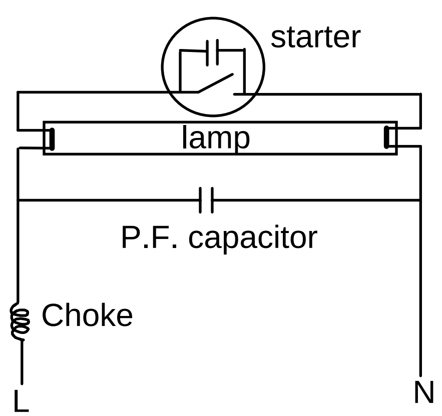


Fig. 2.10

Characteristics

Efficacy: 40-105 lumens/watt
Lamp Life:6,000-12,000 hrs. Assuming a switching frequency of 8 per 24 hrs.
Colour Rendering: Depends on lamp colour.
Colour Temperature: Depends on lamp colour.
Control: The output of HF lamps is dimmable to about 1% light output though the eye may perceive this as greater. No shift of colour occurs.
Advantages: High efficacy, good colour rendering, long life and almost instant starting.
Disadvantages: Efficacy is affected by ambient temp. Max efficacy occurs at 40^{o}C but enclosed luminaires will operate at a higher temperature.
Applications: Commercial and industrial premises.

High Frequency Fluorescent Lamps

The use of electronic control gear operating at 28 kHz approx. (compared to the normal mains frequency of 50Hz.) improves efficacy by about 10% and allows dimming. Flicker is virtually eliminated with h.f. lamps and lamp life increases by about 25%.

2.1.2.2.2 Compact Fluorescent Lamps (CFL'S)

CFL's are being used widely for the replacement of GLS lamps. Their life cycle cost is much less than GLS lamps when operated for long periods because of the massive savings in energy costs. Mass production of these lamps as they grow in popularity means their initial cost is reducing dramatically, making them even more economical. The use of CFL's allows greater flexibility in the design of point source luminaires. (See Fig. 2.12).

Fig. 2.11

2.1.2.2.3 Induction Lamps

An induction coil is located in a glass bulb having a phosphor powder coating on the inside and containing low pressure gas. A radio frequency (2.65MHz) current in the coil causes a U.V. emission in the gas. The phosphor powder converts the U.V. radiation into light in the visible spectrum. There are no electrodes required in the lamp, however, special luminaires are required to prevent electromagnetic interference (EMI).

Fig 2.12.

Characteristics:

Efficacy: 65 Lumens/Watt
Lamp Life: Expected to be in excess of 60,000 hours, because there are no electrodes or filaments. But this has to be proven. It is expected that lumen output will fall by 30% after 60,000 hours with 20% of lamps having failed, probably because of failure of electronic components.
Colour Rendering: Very good (1B)
Colour Temperature: 3000 - 4000K
Control: These lamps can be dimmed considerably without a colour shift.
Advantages: Extremely long life, good colour rendering combined with a high efficacy, no appreciable flicker or stroboscopic effect.
Disadvantage: Radio frequency interference and heat dissipation.
Applications: Where a long life lamp is desirable but applications are expected to increase dramatically over the next few years.

Tubular fluorescent lamps - new developments.

T5 lamps. These lamps were developed in 1994. The new T5 fluorescent lamp has a smaller size diameter (16mm). This brings about a large improvement in the optical performance of luminaires and a consequent improvement in utilisation factor. The efficacy is 104 lm/W and the LLMF is also improved (0.95 at 10,000hrs). The lamp survival factor at 13,000 hours is 0.9. Energy savings of up to 25% on conventional fluorescent lamps are expected.

The lamps are environmentally friendly because of the amount of material and the energy used in their manufacture is reduced.

The smaller diameter tube required a new cap design. It was decided to revise the lamp length to 1148mm allowing it to fit into a 1200mm ceiling system and a smaller luminaire.

2.1.2.2.4 Low Pressure Sodium (SOX) Lamps

A low pressure discharge lamp produces monochromatic light at the centre of the visible spectrum where the eye is most sensitive. The characteristically “orange/ yellow” output is easily identifiable. The LPSV or SOX lamp is suitable where colour performance is unimportant. (See Fig. 2.3 for output and 2.13 for circuit diagram)

Fig 2.13

Characteristics:

Efficacy: 100-180 Lumens/Watt
Lamp Life: 12000 Hrs (with 20% failure rate)
Colour Rendering: Very poor
Colour Temperature: N/A
Control: 10 min run up time
Advantage: Highest efficacy lamp available
Disadvantage: Very poor colour performance.
Application: Motorways/Dual Carriageways.

2.1.2.2.5 Cold Cathode (Neon) Lamps.

These lamps are mainly used for signs. Neon gas is frequently used and produces a characteristic red colour. The colour of the discharge may be changed by varying the gas type. . The lamps do not have a fluorescent powder coating. The tube may be shaped as desired and lamp life is up to 30,000 hours with an efficacy of up to 50 lm/W. There is no starter or choke and a high voltage transformer (10kV) is necessary to initiate the gas discharge. Special regulations apply because of this high voltage. A Fireman's Switch located outside the building, for external installations, or adjacent to the lighting installation, for internal installations, is required for isolation of the lighting installation in the event of a fire.

2.1.2.3 HIGH PRESSURE DISCHARGE LAMPS

2.1.2.3.1 High Pressure Sodium (SON) Lamps

This lamp has a much better colour rendering performance than the low pressure version. Emphasis is on the red and yellow regions providing a warm “golden yellow” output. (See Fig. 2.14)

Fig. 2.14

Characteristics:

Efficacy: 50-120 Lumens/Watt
Lamp Life: 14000 hrs.
Colour Rendering: 1B
Colour Temperature: 2000-3000^{o}K
Control: 5 min run up. Can be dimmed to about 40% output but colour shift to monochromatic occurs.
Advantages: High efficacy with reasonable colour rendering, pleasant warm colour appearance.
Disadvantages: There is a noticable "colour shift" experienced between an area illuminated by SON lamps and one using metal halide or fluorescent lamps.

Deluxe SON lamps have improved colour rendering but at the expense of reduced efficacy. “White” Son lamps have a reduced lamp life (10,000 hrs approx.)

Applications: High bay industrial lighting, Gymnasia, Street Lighting.
A range of ‘plug in’ son lamps are available as direct replacements for HPMV lamps. The plug in Son lamps have the ignitor built into the lamp. This allows easy upgrading of mercury lamps where there would be no space for additional components. These lamps would provide a higher illuminance compared with other discharge lamps for a similar wattage because of their higher efficacy.

2.1.2.3.2 High Pressure Mercury (MB) Lamps

These lamps have been in use since the 1930's. The older characteristically blue appearances of the MB lamp has given way to a whiter appearance with the introduction of the MBF (deluxe) lamp which has a phosphor coating. They are nonetheless reducing in popularity due to the higher performance of SON and metal halide lamps (MBI).

Fig. 2.15

Characteristics:

Efficacy: 40-60 Lumens/Watt
Lamp Life: 14000 hrs.
Colour Rendering Group: 3
Colour Temperature: 3300K - 4000K
Control: 5 min run up - can be dimmed to 2% of light output with a steady colour.
Advantages: Few compared to SON and metal halide lamps (MBI) which are rapidly replacing them.
Disadvantage: Lower efficacy than SON or metal halide and poorer colour rendering than metal halide.
Applications: Were used widely for street lighting.

Mercury Blended (MBT) Lamps

These lamps combine a mercury gas tube with a tungsten filament. They have a warm appearance, long life compared to incandescent lamps but a low efficacy compared to discharge lamps, (10-20 lumens/watt). MBT lamps are used where lamp replacement is difficult and where a warm colour appearance is critical.

2.1.2.3.3. Metal Halide (MBI) Lamps

These lamps have largely replaced MBF lamps because of their improved colour rendering and higher efficacy. The addition of halides improves the colour rendering to such an extent that they are widely used for sports stadia where good colour performance is important.

Fig. 2.16

Characteristics:

Efficacy: 70-90 Lumens/Watt
Lamp Life: 6000 Hours
Colour Rendering: 1A-2
Colour Temperature: 3000-6000 K
Control: 2 min run up (5-15 min restarting). Dimming to 40% possible but a shift to blue occurs.
Advantages: High efficacy combined with good colour rendering.
Disadvantages: Warm up time makes it unsuitable for occupancy on/off control.
Applications: Stadia, factories, commercial interiors, offices - mainly in uplighters.

Use of Fibre Optic cable

Compact metal halide lamps can now be used to provide a primary light source with fibre optic cabling relaying this light to secondary sources. The secondary sources may be used in place of low voltage incandescent lamps. The primary source is located so that the heat produced can be prevented from entering the space being illuminated. The ultra violet and infra red radiation content in the secondary light is negligible. Making use of a high efficacy MBI light source has obvious advantages for energy savings.

Advantages: No specialist skill is necessary to relocate or reassemble the secondary sources. They can be located very close to the subject being illuminated. They are used to light security cabinets thereby eliminating the need for relamping. They are also suitable for use in heat sensitive applications such as food display. Sparkle is easily provided with jewellery and glass displays and artefacts are conserved because there is no ultra violet or infra red radiation.

2.1.3 ENVIRONMENTAL EFFECTS OF LIGHT SOURCES

The life chain of a lamp includes:

1. Exploration and extraction of raw materials.
2. Transformation into materials;
3. Production;
4. Packaging;
5. Use;
6. Waste Disposal

An environmental study within the lighting industry considered items 3 to 6 above in detail as they related to light sources. Energy use for all steps of the life chain were calculated along with the emissions involved.

The study concludes that light sources will be rated in reverse order of luminous efficacy. For example, incandescent lamps are the least efficient and are top of the league with regard to emissions. Similarly the most efficient lamps will produce least emissions in this order:

1. Low pressure sodium (SOX)
2. High pressure sodium (SON)
3. Tubular fluorescent
4. High pressure mercury vapour
5. Compact fluorescent lamps

Note: Metal halide lamps were not considered.

CONCLUSION

The environmental effects of light sources are mainly determined by the energy consumed during the service period of the lamp.

The lighting designer should always select the lamp with the highest efficacy consistent with the other requirements of the installation e.g. colour rendering etc.

For further details see section 5.11 of CIBSE code for interior lighting.

2.1.4 NEW LAMP DEVELOPMENTS

2.1.4.1 Sulphur Lamps

These lamps were invented in 1990 by scientists in America working for the Department of Energy and NASA.

At the present state of development, a 5900 watt lamp which is the size of a golf ball provides an output of 450,000 lumens, (i.e. 76 lm/W). The main difficulty is in controlling this large light output from such a small source. Present developments use light pipes to spread the light over the area to be illuminated. It is important that this very bright source is shielded from view in order to prevent glare. A significant portion of the input energy is released as heat and dissipation of this heat from such a small source is a problem.

Efficacy is expected to be 120 lumens/watt when fully developed.

Colour Rendering. Good

Light quality Ultra violet light content is low and there is no flicker.

Correlated Colour Temperature can be varied between 4000 and 9000 K.

Lamp life is expected to be 100,000 hours.

Section 2.1.5 Table 2.3

SECTION 2.2 LUMINAIRES

2.2.1 Luminaire Constructional Features.

Luminaires provide support, protection, and electrical connection to the lamp as well as control of light output. It is the latter characteristic that lighting designers are most interested in, but before considering that let us first consider BS 4533.

In this standard luminaires are classified according to:

1. Degree of protection afforded against electric shock.
2. The material of the supporting surface for which the luminaire is designed.
3. Degree of protection afforded against ingress of dust and moisture.

2.2.1.1Protection against shock.

Class	
0	Basic insulation
I	Basic insulation plus provision for connection of protective conductor
II	Double insulation
III	Luminaire supplied at safety extra low voltage (SELV)

2.2.1.2 Material of supporting surface.

Materials of the supporting surface are listed in BS4533. This standard does not include luminaires for use in hazardous environments. The CIBSE guide **“Lighting for hostile and hazardous environments”** should be consulted for further information on these luminaires.

2.2.1.3 IEC Classification system for enclosures.

This classification system is specified so as to protect personnel from contact with live or moving parts inside enclosures, to prevent the ingress of solid foreign bodies including dust, and to prevent the ingress of moisture. **I P stands for "Ingress Protection"**

The **“IP” system -** is taken from IEC publication 529. The first digit indicates the degree of protection against contact by persons with parts inside enclosures as well as that of the protection against ingress of solid foreign bodies. The second digit indicates the degree of protection against ingress of moisture. e.g. The designation IP 64 means that the luminaire is completely protected from dust and projections of water from all directions.

TABLE 2.4
IP CLASSIFICATION SYSTEM FOR ENCLOSURES

2.2.2 CONTROL OF LIGHT DISTRIBUTION

Notwithstanding all of the above requirements for the luminaire, the decision facing most lighting designers is whether the luminaire to be selected should have a reflector, a diffuser or a louvre - and if so which type. Let us first consider various types of fluorescent luminaire. The light output for each type is shown on the accompanying polar diagrams.

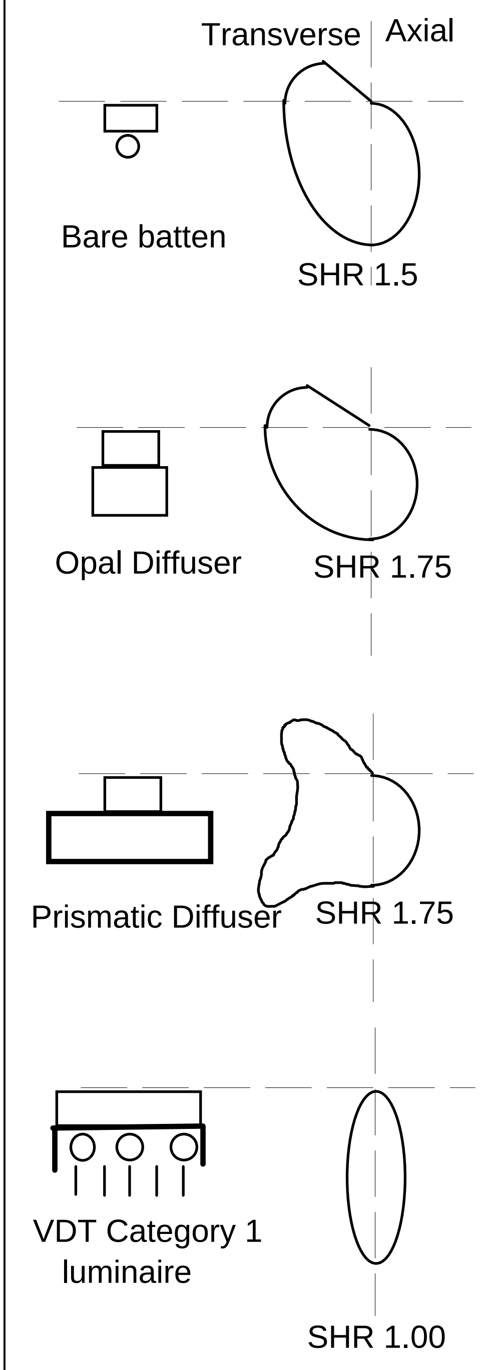


Fig. 2.17

Bare batten fluorescent luminaires would be used where installation cost is be minimised and glare is not an important factor, e.g. stores, toilets.

Opal white diffusers are used where the limiting glare requirements are low and installation costs are to be minimised.

Reflectors are used on suspended luminaires or where dark ceilings would absorb much of the upward light. The U.F. is improved but the glare produced is relatively high. Applications include factories, warehouses etc.

Prismatic diffusers refract or bend the light in such a way as to allow luminaires be spaced further apart. A space to height ratio of 1.75 : 1 or even 2 : 1 is possible with these luminaires because of their "Batwing" light output.

This type of luminaire was very popular in offices in the 1970's before the use of visual display terminals (VDT's). The widespread use of VDT's nowadays precludes the selection of any of the above types of luminaires in modern offices because the glare produced by veiling reflections would be unacceptable. Prismatic luminaires are suitable for use where there is little or no use of VDT's and only moderate glare control is necessary. Where VDT's are used, special low brightness luminaires are required.

2.2.5.2 Uplighting Luminaires

The light from luminaires is projected onto the room surfaces and reflected light from these surfaces then illuminates the room and working plane.

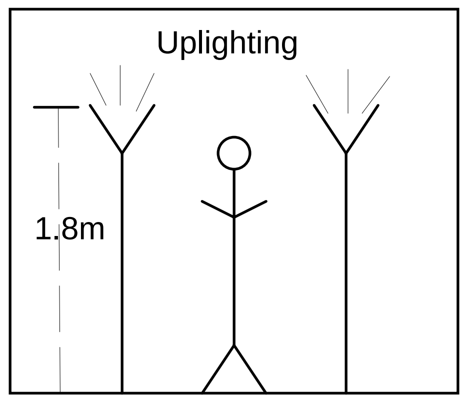


Fig. 2.19

Although indirect lighting is inherently less efficient than direct lighting, it should be noted that this system allows the use of highly efficient lamps (normally metal halide) and luminaires with an extremely high light output ratio. Nonetheless uplighting will normally be about 10% less efficient than downlighting.

Uplighting is unsuited for use with occupancy detectors where metal halide lamps are used because their restrike time is high (up to 15 mins).

Uplighting results in a bright room with walls and ceilings having a non-uniform but nonetheless high luminance. Glare from VDT screens will be acceptable provided there are no sharp contrasts of luminance reflected in the screen. The geometry of the viewing angle is irrelevant in uplighting schemes.

2.3 MANUFACTURERS' TECHNICAL DATA (for lamps and luminaires)

Each manufacturer will present their technical data in different ways. It may be necessary to select equipment suitable for locations which vary from offices to hazardous areas containing explosive or corrosive substances. There is a wide variety of equipment to meet the different requirements. Many manufacturers provide computer programs to assist in the design and selection. Information necessary to enable manual calculations is also provided.

The following terms are commonly used in manufacturers' catalogues:

2.3.1 Lamp Data:

i **Initial lumen output -** lamp output after 100h

ii **Lighting design lumen output -** lamp output after 2000h

iii **Correlated Colour Temperature -** Colour of lamp expressed as temperature K (See definitions).

iv **Colour Rendering Index** (Ra) 100 to 0 (see table 2.1B) p42

v **Colour Rendering Group.** 1A, 1B, 2, 3, 4. (see table 2.1A) p42

vi **Physical dimensions.** The length and diameter of the tube.

vii **Ballast type -** Standard, low loss or high frequency.

viii **Power rating -** Power in watts, with and without ballast.

The CIBSE Code for Interior Lighting (1994) recommends the use of **the initial lumen output** for lumen method calculations. This figure is 10 to 15% higher than the Lighting Design Lumen output used in previous codes, however, calculation of the new maintenance factor (1994 code) takes account of this change.

Diagram
tubular triphosphor fluorescent lamps

full page

full page diagram

compact fluorescent lamps

power consumption

groups and ranges

2.3.2 Luminaire Data:

i **Light output ratio (LOR) -** The ratio of the **total light output** of the luminaire to the light output of the lamp/lamps.

ii **Downward light output ratio (DLOR) -** The ratio of the total light output of the luminaire **below the horizontal** to the light output of the lamp/lamps.

iii **Upward light output ratio (ULOR) -** The ratio of the total light output of the luminaire **above the horizontal** to the light output of the lamp/lamps.

iv **Downward Flux Fraction -** The ratio of the DLOR to the LOR of the luminaire.

v **Space Height Ratio -** Recommended Spacing to height ratio given in the transverse and axial planes in order to achieve the required uniformity ratios in the task area.

vi **Luminous Intensity Distribution -** This information shows the luminous intensity from different viewing angles in the transverse and axial planes. The information is shown in the form of a polar curve or a table.

vii **Utilisation factor -** This is used as a means of determining the amount of light which will reach the working plane. It will depend on the light distribution from the luminaire, the light output ratio, the shape of the room, the luminaire mounting height, the height of the working plane and surface reflectances. It is provided in the form of a multiplier and can be extracted from a table.

viii **Physical Dimensions -** Length, width and depth.

ix **Type -** surface, recessed, air handling, flameproof etc.

x **Mechanical characteristics -** These include materials, Ingress Protection, fire protection, temperature classification, etc.

xi **Electrical characteristics -** These include rated voltage, frequency and safety class.

Luminaires should be selected and spaced in a room so as to meet aesthetic as well as functional requirements. To this end, the final location of luminaires may be determined by ceiling tile position or location of other services such as ceiling diffusers from the air conditioning system. Co-ordinated design is essential and a compromise with architectural requirements or mechanical services is normal in these situations.

The illuminance variation is determined by the type, number and layout of the luminaires. The maximum illuminance is usually at the centre of the room and the minimum illuminance is usually in the corners. The ratio of maximum to minimum illuminance **in the task area** should not be less than 0.7 (ignoring the effects of daylighting). The task area may not include the corners of the room, in which case, it is easier to meet this requirement.

Isolux diagrams can be generated using computer programmes and this will allow the designer establish whether the illuminance variation requirement is met in a particular installation. Alternatively, chart 5 on page 69 can be used as a guide.

Fig. 2.20 (Cymap drawing)

Photograph of luminaire
full page diagram

full page diagram

luminous intensity

utilisation factor

illuminance uniformity

2.3.3 Nameplate markings

full page diagram

name plate

safety classes

2.3.4 Safety classes

2.3.5 Fire Protection

The fire behaviour of the mounting surfaces and of the surroundings of the luminaires must be considered when selecting luminaires. Luminaires marked with F are suitable for direct mounting on surfaces which retain their shape and remain stable at temperatures up to 180 degrees C. (e.g. wood, plasterboard, etc.). If it is possible for highly flammable materials such as dust , fibres from industry etc. to collect on the luminaires, they must use luminaires marked F F (limited surface temperatures)

full page diagram

ip markings

fire protection

2.3.6 Ingress Protection.

full page diagram

ip markings

2.3.7 Using manufacturers' data to design a lighting scheme

Using a Trilux luminaire type 5401 RPH/58, design a suitable lighting scheme for an office with the following dimensions: length 10m, width 8m, height 3m.

height of working plane		0.8m
maintenance factor		0.7
reflectances	ceiling	70%
	walls	50%
	floors	20%
recommended illuminance		500 lux

Select a 58 W triphosphor fluorescent lamp, CCT class intermediate, colour rendering group 1B, initial lumen output 5400 lm.

$$\text{Room index} = \frac{L \times W}{(L + W)\, H_m} = \frac{10 \times 8}{(10 + 8)\, 2.2} = 2.02$$

Utilisation factor = 0.7 x 0.95 = 0.665 (table 4, page 75)

$$\text{Number of lamps (n)} = \frac{500 \times 10 \times 8}{5400 \times 0.7 \times 0.665} = 15.9\ (16)$$

Height above working plane	=	2.2m		
SHR	=	1.75 (nom)		
therefore maximum spacing	=	2.2 x 1.75	=	3.85m

try 4 rows of 4:

spacing of luminaires (axial)	=	10 / 4	=	2.5m
spacing of luminaires (transverse)	=	8 / 4	=	2m

The actual SHR is less than 1.25, therefore, the illuminance uniformity requirement will be met. (see table 5, page 75).

Table 2 indicates that the maximum limiting glare index is 10.9 for the reference room, the dimensions of which are, width 7.2m, length 14.4m and height 3m. It contains 32 luminaires. The illuminance in the reference room is 775 lux, which is 50% higher than the office in the example. This indicates that the actual glare will be less than the reference glare. The recommended maximum limiting glare index is 19 for general offices and 16 for areas with VDT 's. It follows that this scheme will meet either requirement. (see diagram on page 73)

Section 3

LIGHTING CONTROLS

3.1 Introduction

3.2 Grouping of circuits

3.3 Types of control

3.4 Integrated Lighting Controls

Section 3 LIGHTING CONTROLS

3.1 Introduction:

The type of lighting control with which one is most familiar is the simple manual on/off switch. Although there now is a choice of remote, manual or fully automatic light controls available, the simple on/off switch is not to be under-valued. The user feels in control and this is a very important psychological factor in producing user satisfaction. Modern lighting controls operate automatically but should always have a manual over-ride so that users can assert their control when necessary. The system will then revert to automatic mode after a pre-determined period.

The challenge for designers is to implement modern cost saving control systems in a user friendly way so that there is no dissatisfaction generated when the controls operate automatically. Luminaires which suddenly switch off are likely to cause annoyance, notwithstanding the fact that the illuminance remaining may be well in excess of the minimum recommended design figure. The alternative of using fluorescent lamps with high frequency electronic ballasts, which gradually dim the luminaires so that their output (and power consumption) may be as low as 10% of normal, will go un-noticed by the user because the eye is able to adapt to the changed illuminance within the dimming period.

A typical problem situation, which modern lighting control systems seek to address, is when all lights in a building are switched on at the start of the working period and turned off at the end, taking no account of occupancy, contribution from daylight, effects of lamp ageing, maintenance or cleaning. It is possible, by using an efficient lighting control system, to reduce lighting energy costs by 30 to 50 %.

It should also be noted that the time of maximum daylight contribution is usually the time of maximum direct solar heating gains, so that, by taking account of daylight contribution and reducing the lighting load, the peak cooling load will also be reduced. This may be a critical factor in determining whether or not there is a need for costly air-conditioning systems.

A good lighting control system can also be cost effective in installation terms because it does away with the need for costly rewires when alterations in layout occur. Other significant benefits are: reductions in running costs, improved quality of lighting scheme and the added prestige which results from a high-tech office.

3.2 Circuiting arrangements for Luminaires

The luminaires must be properly grouped before they can be properly controlled. For example, luminaires adjacent to windows should be on the same circuit. Practical considerations, such as the size of terminals, dictate that lighting circuits may not be supplied by electrical cables larger than 2.5 sq. mm. cross sectional area. The sizes normally used are 1.5 sq. mm. and 2.5 sq. mm. The following table shows the size of cable, protective device and nominal power rating of the circuits (60m. run approx.) which are required in order to comply with the wiring regulations.

Table 3.1

Size of cable	size of MCB	nominal power rating	number of points
1.5 mm^2	6 amp	500 Watts	10
2.5 mm^2	10 amp	1000 Watts	10

Consider the reflected floor plan of a lighting installation shown in Fig. 3.1 The luminaires used are Class 2, 125 Watt, 600mm. square modular, suitable for use in an office using VDU's. They may be supplied by either, 1.5 sq. mm. with four per circuit or 2.5 sq. mm with eight per circuit.

In an open plan office, the luminaires should be grouped to allow bi-level lighting, i.e. level 1 (50 % lights off) for maintenance and cleaning and level 2 (all lights on) for normal business.

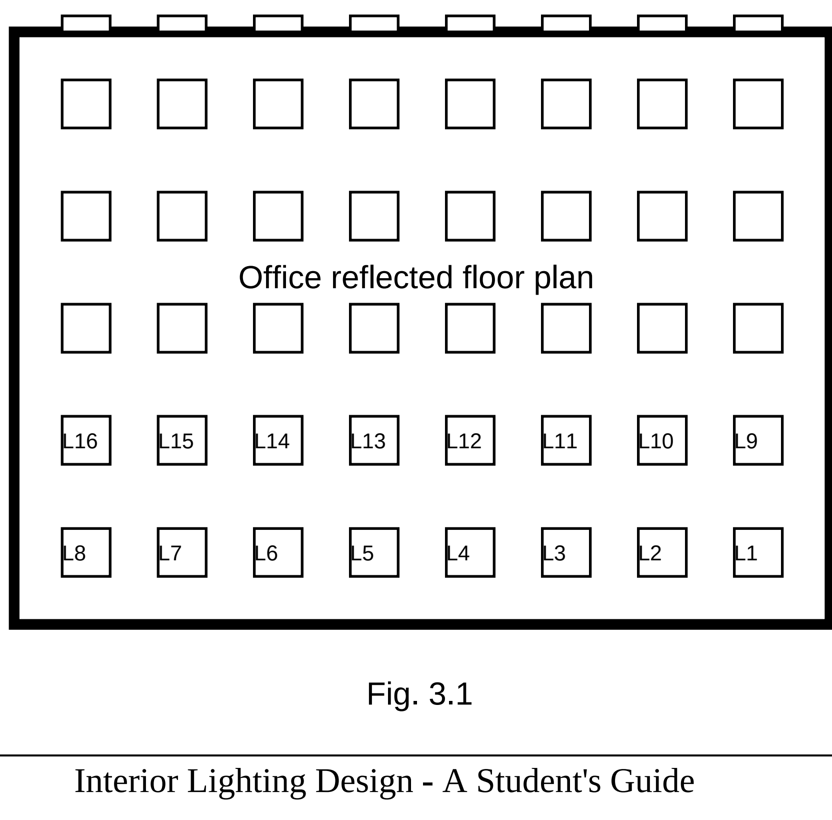


Fig. 3.1

Table 3.2

Possible circuit arrangements	**application**
(L_1 L_2 L_9 L_{10})	partitioned office (one circuit per office)
(L_1 L_2) + (L_9 L_{10})	partitioned office with daylight control on (L_1 L_2) (one circuit, two switch wires)
(L_1 L_2 L_3 L_4 L_5 L_6 L_7 L_8) + (L_9 L_{10} L_{11} L_{12} L_{13} L_{14} L_{15} L_{16})	open plan office with daylight control on window luminaires (two circuits)

It should be borne in mind that offices may be changed from open plan to partitioned. This indicates that L1 + L2 should be grouped with L9 + L10. Ideally, L1 + L2 should have their own control so that they may be dimmed or turned off when daylight levels permit while at the same time, L9 + L10, being further from the window, may be left on.

In an area such as a factory, it is common to provide general lighting plus task or localised lighting. The same considerations apply to the general lighting as apply to the office area described above, however, a third level of lighting may be required for security.

Note: The requirements of emergency lighting should be considered separately, however, the emergency lighting usually forms an integral part of the general lighting scheme.

The foregoing paragraphs indicate that there is not a single solution that will apply successfully to all situations. Expensive "rewires" were inevitable when new tenants moved into an office block before the advent of modern controls.

It is now possible to provide the flexibility required by using lighting control systems in which the luminaires are wired in groups of two to a programmable local control unit which can be stand alone or part of an integrated system. Expensive switch drops can be eliminated by using hand held infra red remote units which activate ceiling mounted receivers. Changes to the system can be accommodated by reprogramming the local control unit.

3.3 Types of Control:

The types of control can be divided into two broad categories, manual and automatic. Many systems have a combination of both, sometimes with advanced central control from a building management system.

Manual Control:
- (i) On /Off from single or multiple positions using fixed switches.
- (ii) On /Off using infra red remote controller.
- (iii) On /Off / dimming from fixed switch position.
- (iv) Multiple lighting scene control using infra red remote controller.

Automatic Control:
- (i) Time switch
- (ii) Occupancy sensors
- (iii) Daylight sensor
- (vi) Dimming
- (v) Reduced voltage

3.3.1 On /Off from single or multiple positions using fixed switches.

Individually switching up to 20 circuits for a floor in an office block can be very tedious on a daily basis and very often, the main switch/isolator for the lighting distribution board is used for switching on and off all the lighting with local switching hardly ever carried out in practice. This tends to result in all lighting being switched on in the morning, left on all day and switched off again by operating the main switch in the evening.

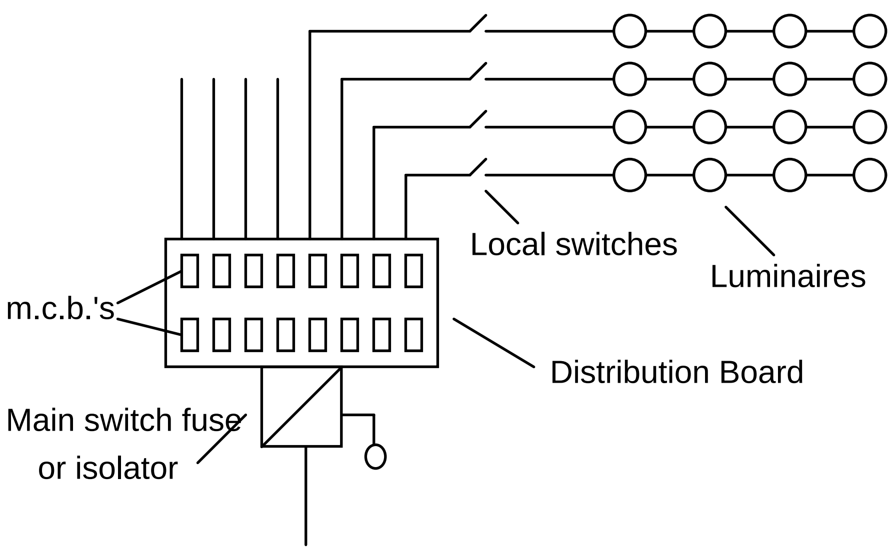


Figure 3.2

This same operation can be carried out by the use of a main contactor, the operating coil of which is controlled by a remote fixed switch (fig 3.3).

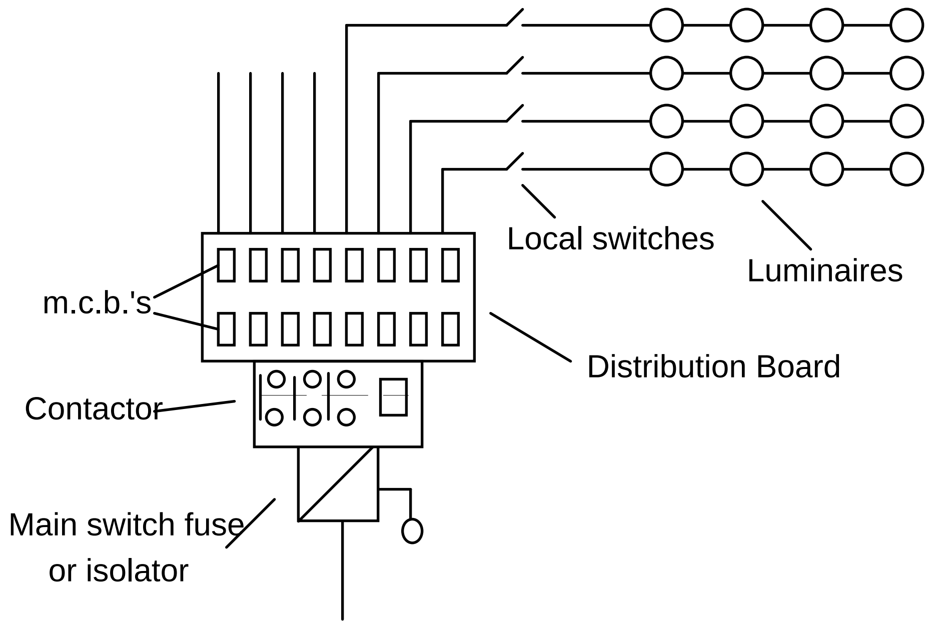


Figure 3.3

Smaller contactors can be clipped on to the DIN rail in the Distribution Board for controlling groups of circuits. A typical arrangement would have three such contactors controlling illuminance levels for security lighting, cleaning / maintenance and full occupation.

It should be noted that emergency lighting will require a mains supply at all times in order to keep the standby batteries fully charged and also to prevent the emergency lights from turning on (they are usually triggered on by failure of the mains supply). It is therefore not possible to turn off all lights using the mains switch if emergency lights are on the same distribution board.

3.3.2 On /Off using infra red remote controller.

This system uses infra red transmitters, ceiling mounted receivers and local control units. The system layout is as shown in fig. 3.4 The IR transmitters are highly directional and of 12m range approx. in order to avoid the accidental operation of ceiling receivers other than those intended. They are not coded, however, and all receivers may be operated by any transmitter within range. Several local units would normally serve a large open plan area. One local unit can serve several smaller offices, each office being individually controlled through its own IR receiver.

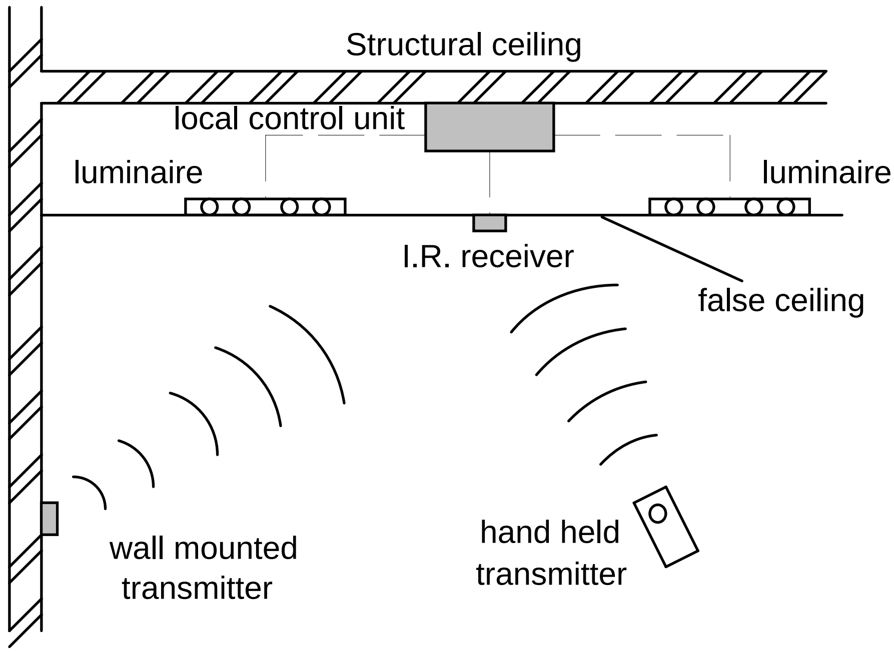


Fig. 3.4

The Local Control Unit is programmable and usually contains automatic control functions as well as the Remote IR on/off functions. The luminaires are connected to the output terminals and the control devices are connected to the input terminals.

This type of control does away with the need for wiring to switch positions (switch drops) on walls or partitions. Any other changes to wiring required by alterations of layout can be easily accommodated in the false ceilings which are normal in modern offices.

3.3.3 On /Off / dimming from a fixed switch position.

This is a common arrangement which is used to control the output from luminaires. The control is essentially variable voltage control which is carried out electronically using S.C.R 's. Incandescent filament lamps lend themselves most readily to dimming although a colour shift is unavoidable. High frequency discharge lamps can be electronically dimmed very successfully to 10% output without colour shift but mains frequency fluorescent lamps are not suitable for electronic dimming. Most high frequency ballasts have "passive" and "active" dimming control inputs. For "passive control", rotary or slide 10 K potentiometers can be connected to the inputs and for "active control", a control voltage 0 - 10 V D.C. from an external source is used.

3.3.4 Multiple lighting scene control using infra red remote controller.

This system is designed for conference centres, boardrooms, auditoria, theatres, showrooms, shop display etc. A typical system would have up to 16 pre-set lighting scenes which allows sophisticated lighting effects to be selected instantly to meet specific requirements, such as, group discussions, informal meetings, slide and overhead presentations, video projection and T.V. viewing. The system can be expanded to include the control of blinds and projector screens etc.

The different lighting scenes can be achieved by selective switching or dimming of incandescent, halogen, fluorescent, metal halide lamps, etc. Fig 3.5 shows a typical system layout.

Fig 3.5 Diagram courtesy of Philips Lighting

3.3.5 Time switch automatic control:

The most common type of timer now used is the programmable timer. It is a microprocessor with a rechargeable standby battery for memory hold-up and maintaining time in the event of a mains failure. It can be programmed to take account of working day requirements, Bank Holidays, weekends, hour going backward and forward as the seasons change, etc. All of these devices should have a manual over-ride facility so that they may be turned on or off manually at any time irrespective of the position of the time switch. This is usually provided by a three position (On/Off/Auto) switch.

The mechanical clock time switch is outdated technology. It has severe deficiencies, in that it is likely to get out of synchronism with real time because of seasonal changes and mains failures. Many types have a seven day cycle and a back up spring to maintain correct time during mains failure.

The switched outputs of a time switch can be used to control the luminaires directly (up to a certain load limit) or they may control the coil of a main contactor (Fig.3.3).

3.3.6 Occupancy sensors for automatic control.

Occupancy sensors are passive infra red (PIR) movement detectors which activate when they detect a change in the background infra red radiation. A person emits infra red radiation at a different level to the background, a change of its position in the detection field therefore creates the conditions for an activation of the PIR. An activation produces a change in output from an on-board relay which in turn operates an input in the local control unit.

The controls are arranged so that the luminaires will switch on immediately when presence is detected but will delay for a period of 10 - 25 minutes before turning off when no presence has been detected.

The life of a lamp is a function of the number of times it is switched on and off. It can be anticipated that the **running hours life** of the lamp will be reduced by using occupancy sensors but this may be more than offset because the lamps will be on for fewer hours in a given period.

It is important that designers are aware of the safety implications of installing lighting controls which may suddenly turn off. Care should be taken that sufficient background lighting is available to prevent danger should the sensors fail to detect presence and turn off.

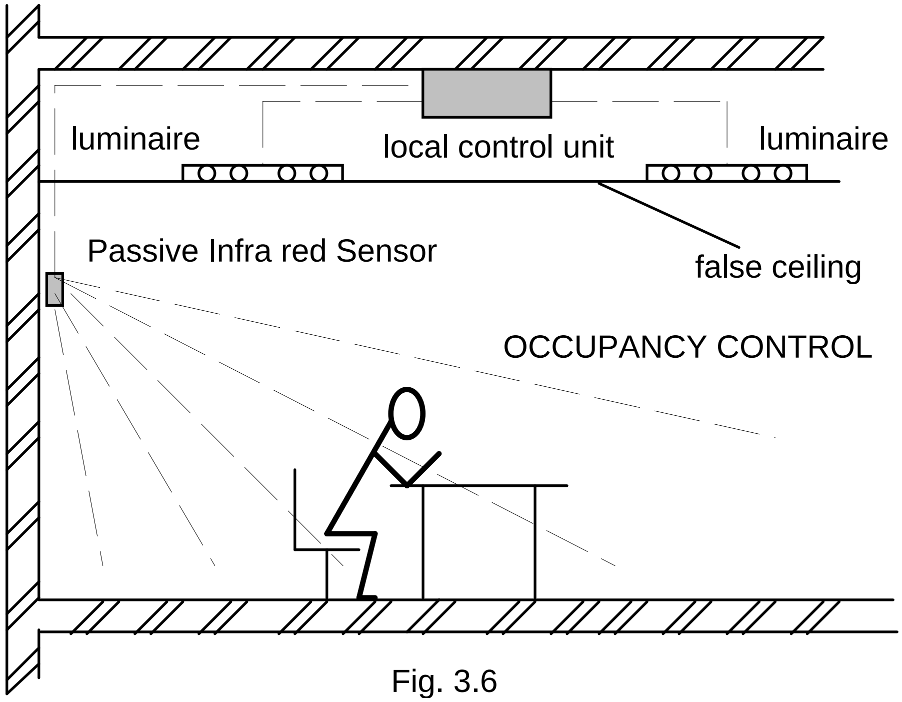


Fig. 3.6

An essential part of the PIR detector is the optical lens which determines the detection field. This can be 360, 180, 90 or 5 degrees field of view. The units are designed for store rooms, offices, corridors etc. Sometimes more than one detector is required in a given space to ensure adequate coverage. The PIR units can be mounted on walls or ceilings depending on the application. A PIR unit is available which combines as an ordinary switch. The existing switch can be removed and replaced by the combined unit.

PIR DETECTION FIELDS

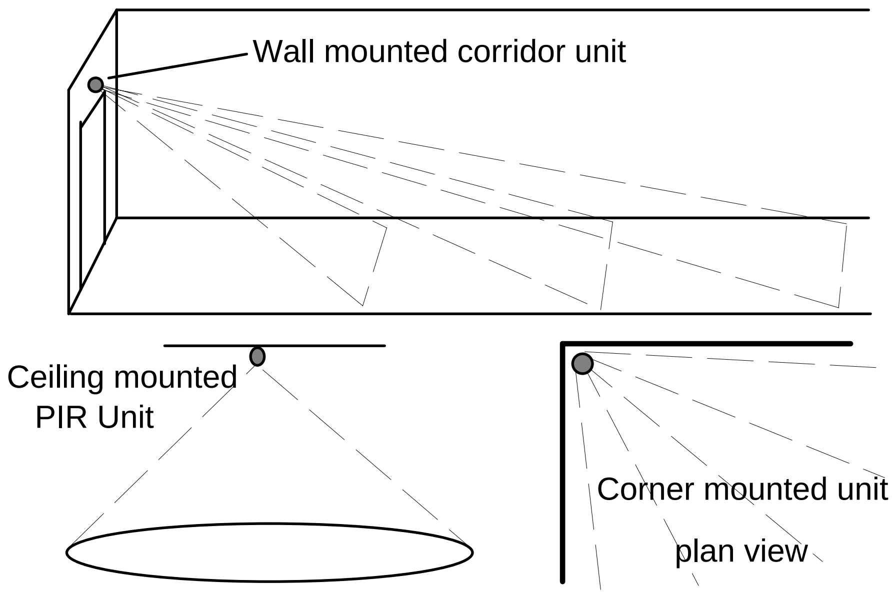


Fig. 3.7

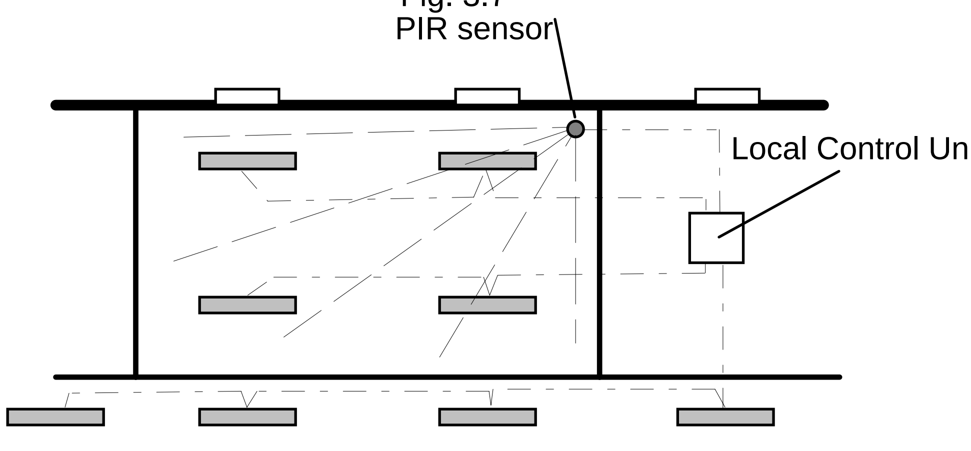


Fig. 3.8

3.3.7 Daylight sensors for automatic control

Inorder to take advantage of daylight it is necessary to introduce the appropriate controls. Daylight linking requires a daylight sensor linked to a controller. Contrary to expectations, the daylight sensor is directed to the interior and is screened from direct daylight. The sensor which is located about 1.5m from the window, senses the reflected light from the interior surfaces and modulates the light output from the luminaires accordingly thus constituting a classical closed loop control system.

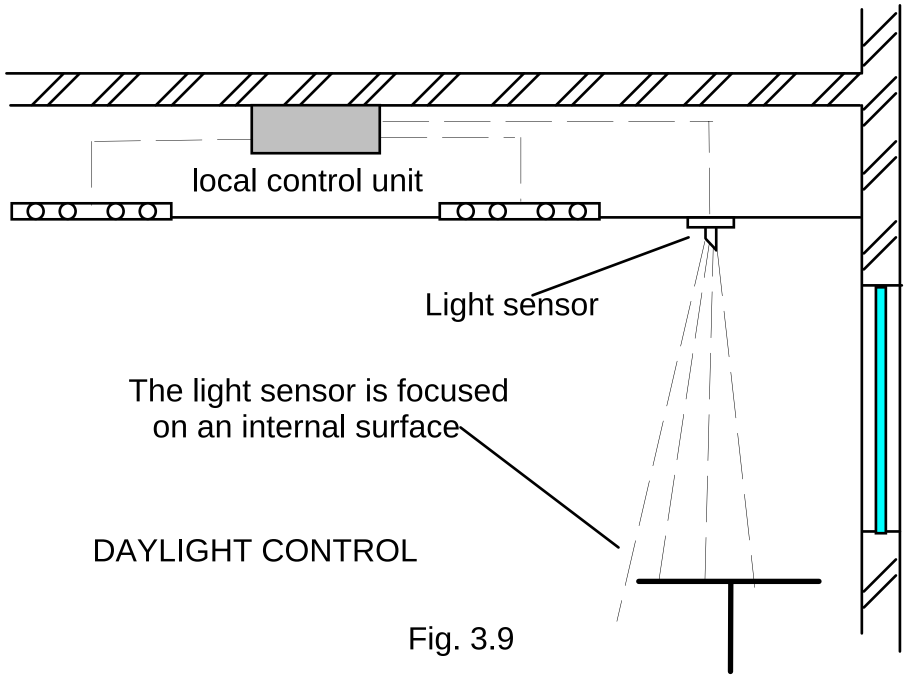


Fig. 3.9

High frequency fluorescents are most suitable for dimming. The luminaires closest to the windows are usually controlled in this way because the greatest benefit is derived in this area (reductions in energy consumption up to 60%.). Master / Slave dimming is also possible so that the luminaires furthest from the windows (slave luminaires) are dimmed to a lesser degree, the amount being determined during commissioning.

Diagram of daylight linking

Diagram of daylight linking courtesy of Philips Lighting

3.3.8 Automatic dimming control.

When a lighting installation is new, the light output can be as much as 25% higher than design requirements (See section 1.8.4 re maintenance factor). This will gradually reduce as dust gathers and lamp depreciation takes place. It will increase immediately after periodic cleaning and gradually reduce again until the installation is relamped. The control system can be set up to maintain the illuminance at design values throughout the life of the installation thus saving 12 - 15% in energy costs at a stroke.

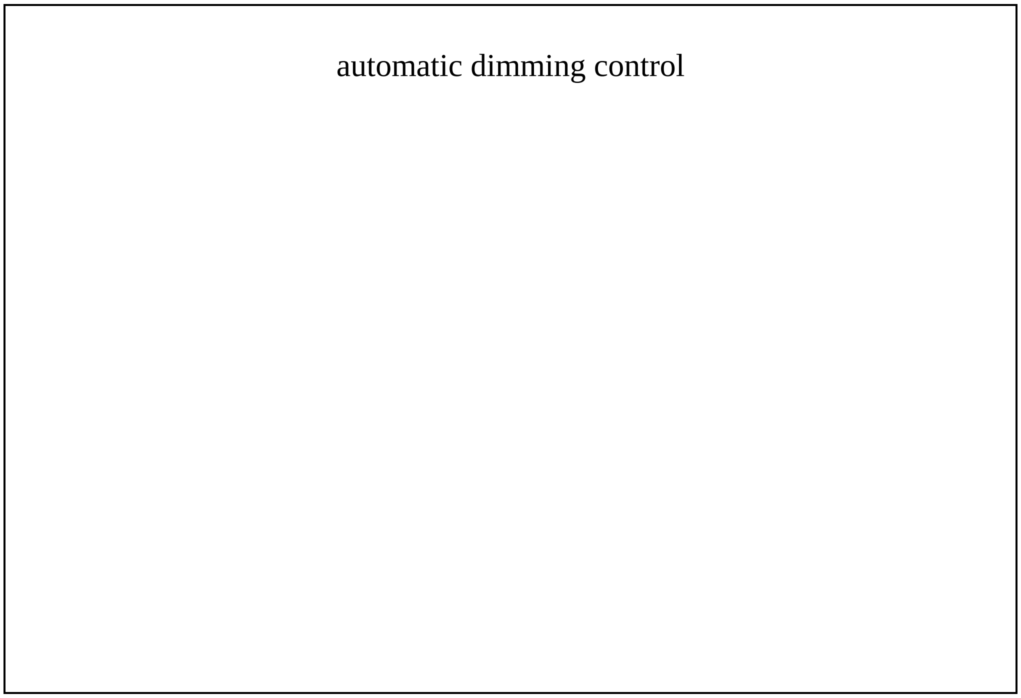


Fig. 3.11 Diagram courtesy of Philips Lighting

3.3.9 Reduced voltage Control.

It takes a few minutes for normal fluorescents to reach full light output after being switched on. The reduced voltage control system reduces the applied voltage after a time delay by 10 % approximately. This has the effect of reducing the energy consumption by 20% approx. and the light output by 10%.

This relatively inexpensive system is used in stores and warehouses which are occupied infrequently. An occupancy sensor may be used to switch on to full output when presence is detected.

3.4 Integrated lighting control systems:

These systems are modular in concept and combine all of the control functions previously described. Fig 3.12 features a mini control unit and local units connected by means of a two wire communication bus. Operational features are as follows:

(i) Centralised management of up to 300 luminaires.
(ii) Local switching pattern that is centrally re programmable to allow for changes in office layout.
(iii) Daylight linking of luminaires.
(iv) Occupancy control by PIR sensors.
(v) Manual control by push button or remote IR unit
(vi) Central control from the mini control unit
(vii) Programmable timer control for fixed time of day / day of year
(viii) Centralised maintenance diagnosis.

Fig. 3.12 Diagram courtesy of Philips Lighting

Larger units which can be expanded to manage up to 2400 luminaires. In addition to the features described above, the advantages of a full Building Management System can be implemented such as:

(i) Measurement of energy consumption
(ii) Ability to define more than one user per system

(iii) Individual billing

diagram IFS 800

Fig. 3.13 Diagram courtesy of Philips Lighting

Example 3.1

A building has a floor area of $600m^2$ and a lighting load of 20 W/m^2. The lighting runs for 3000 hours per year and the cost of electricity is 7.5 pence per kWh. Automatic dimming control is used to take account of the Maintenance Factor and daylight contribution. The additional cost of installing the dimming controls is £1200.00. If the Maintenance Factor is 0.75 and the maintenance period is one year, calculate:

i The annual energy saving.

ii The simple payback period.

Assume that the light output from the luminaires decreases uniformly over the maintenance period and a 15% saving acrues from daylight contribution.

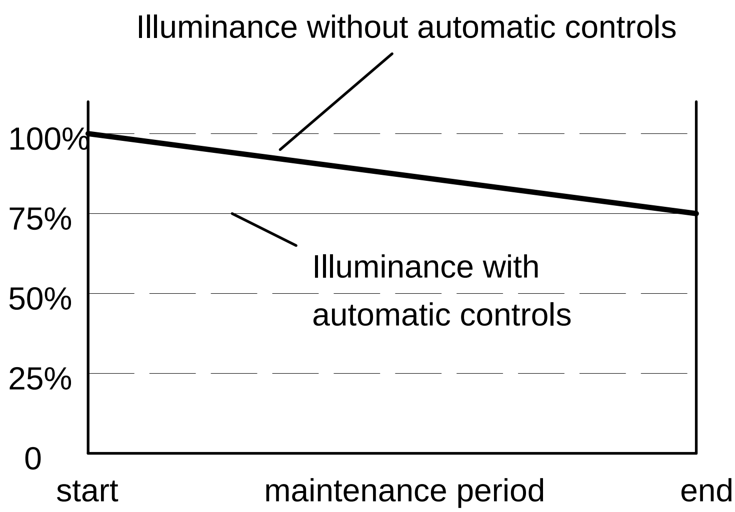


Fig. 3.12

i The annual energy saving.

Electrical load	=	600 x 20	=	12,000 Watts
Annual energy consumption		12 x 3000	=	36,000 kWh
Annual running cost	=	36,000 x 0.075	=	£2,700
Average reduction over full period is 12.5%			=	2,700 x 0.125
			=	337.5
Daylight contribution (15%)			=	2,700 x 0.15
			=	405
Total annual saving	=	337.5 + 405	=	742.5

ii The simple payback period.

$$\text{payback} = \frac{\text{additional cost}}{\text{annual savings}} = \frac{1200}{742.5} = 1.6 \text{ years}$$

SECTION 4

DAYLIGHT IN INTERIORS

CONTENTS:

Section 4.1 Introduction

Section 4.2 Visual Comfort

Section 4.3 Daylight Quantified

Section 4.4 Energy Cost

Section 4.5 Daylight Factor

Section 4.6 Control of Artificial Lighting

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Section 4.8 Overall Design

Section 4.9 Depth of a room

Section 4.10 Calculations of average Daylight Factor

Section 4.11 Calculation of daylight at a point.

4. DAYLIGHT IN INTERIORS

4.1 Introduction:

No modern analysis of interior lighting would be complete without considering the penetration of daylight into interiors.

Until the 1950's, buildings were designed to allow natural light reach virtually all parts of the building interior. With fluorescent lamp development and cheap energy, taller deeper plan buildings grew in popularity particularly in city centres where land was extremely expensive. In addition, air and noise pollution made it necessary to keep windows closed and provide air conditioning.

The energy crisis of the 1970's made designers think again. In the 1990's public awareness of environmental issues has made engineers even more aware of the importance of conserving energy.

Sick building syndrome (SBS) was another factor which moved designers away from wholly artificial indoor environments. **Daylight deprivation** is a significant factor in people's dissatisfaction with buildings and hence SBS. Research shows that people value the variety of daylight, enjoy the presence of sunlight in a building and want some view of the outside world.

Buildings of the 21st century are likely to rely more on natural daylight, with **supplementary artificial lighting** being automatically controlled but with local override facilities provided for staff.

There are 3 reasons to provide daylight:

1. Healthier and more satisfactory indoor environment;
2. Economic advantage in energy savings;
3. Conserves earth's resources and improves company's "Green Image".

4.2 Visual Comfort

Daylight is the natural light to which the human eye has become adapted over millions of years. In particular colour rendering by **daylight is the subjective standard** by which we normally measure the colour performance of an electric lamp.

Daylight in a building, even though it is constantly changing in intensity and colour, will provide very good colour rendering. Where **exact colour rendering** of a colour critical task is necessary however, the variation of daylight may cause difficulties. For this reason, colour matching lamps are used in this case and daylight is excluded. The colour critical task is normally carried out in a test room.

The natural variation of daylight in intensity and colour over time provides variety and interest in interiors. When side windows are used, good modelling is provided by the cross vector of daylight. An outside view provides information on the external climate, this provides psychological benefit and allows our metabolic rhythms to synchronise with the time of day.

4.3 Daylight Quantified

Current work on a European daylighting design guide suggests that there will be a necessity for about **30 daylighting design zones for Europe.**

Daylight varies with latitude, season, coastal or inland location, climate and air quality. The Building Research Establishment in Britain (BRE) provide information on illuminance due to daylight in London. This shows that mean horizontal **diffuse illuminance** varies from 35 kilolux at midday in summer to about 10 kilolux at midday in winter - assuming an unobstructed sky (buildings, trees etc.,).

It is common practice in the UK and Ireland for lighting designers to use a figure of 10 kilolux for external illuminance when calculating the level of illuminance due to daylight. **A minimum of 10 kilolux will be provided for about 70% of the working day at a latitude of 52% N, which is approximately the latitude of the British Isles**

The amount of daylight received within a building depends on its orientation, the presence of obstructions and the reflectance of adjacent structures. The area in a room to which daylight will be considered to contribute significantly to task illuminance extends to about twice the window height - provided glass is clear, there are no obstructions (inside or outside) and the window sill is not significantly higher than the working plane. (Clear glass in high windows however, is likely to cause problems of glare.)

It is important to remember that "daylight" is considered to be diffuse light provided by the sky as a whole and not direct sunlight. The term **"skylight"** is often used instead of "daylight".

4.4 Energy Cost.

The cost of energy for artificial lighting is a substantial part of the total energy for most buildings. Typically, light energy would be between 20% and 50% of the total energy bill.

In HI-TECH air conditioned offices with widespread use of computers, the air conditioning load is nearly always a cooling load. Heat generated by artificial lighting contributes to this cooling load.

When lighting levels are reduced, there is a reduction in the mechanical cooling load for the building as well as the electrical load. In some cases, automatic control of artificial lighting combined with good daylight penetration may even tilt the balance between the need for air conditioning or natural ventilation for some buildings.

The substitution of daylight for artificial light can produce savings of 30% - 70%* if artificial light is well controlled. Care must be taken however, to shield occupants from direct effects of sunlight by providing blinds or other shading devices which can be controlled by occupants.

***Source**: **"Daylighting in Buildings"** issued by the European Commission Directorate-General for energy, as part of **The Thermie Action Programme.**

4.5 Daylight Factor.

Due to the constant variation of daylight, calculations are normally based on a percentage daylight factor. Daylight factor is the amount of daylight reaching an interior as a percentage of the external illuminance.

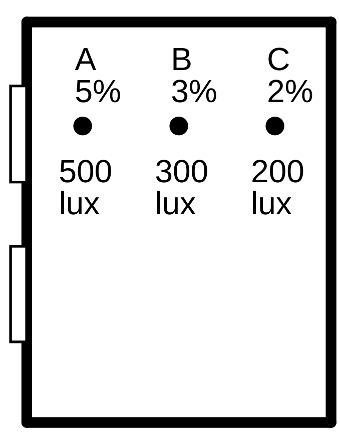


Fig. 4.1

Example 4.1

The daylight factor at 3 points A, B and C in an office are 5%, 3% and 2% respectively. Calculate the illuminance at each of these points assuming an external horizontal illuminance of 10,000 lux.

5% of 10,000 lux = 500 lux
3% of 10,000 lux = 300 lux
2% of 10,000 lux = 200 lux

Studies have shown that staff react negatively to sudden interruption of artificial lighting. If artificial lighting is switched off when the contribution from daylight is less than twice the illuminance provided by artificial lighting, there is likely to be complaints from staff. Shadows in the interior and high contrast areas around windows are created which may lead to irritation of staff in that area. As people become more accustomed to increased daylight in buildings however, their tolerance for illuminance and luminance variation is likely to increase. Nonetheless in Northern Europe, daylight will normally be supplemented with artificial light for most of the day.

4.6 Control of Artificial Lighting

The ideal control system will modulate artificial light levels in each area with the level of daylight. Dimming should operate very slowly in response to increasing daylight. In this way transient variations in daylight are ignored and people working in the area will not notice the artificial light level decrease.

Automatic switching of lights as daylight levels increase is likely to be annoying to staff; manual switching by staff in the area is acceptable however, because they feel they have control. If artificial lighting is reduced to 20% output when daylight levels are high then occupants will have the impression that artificial lighting is "on" and they will not feel any sense of deprivation.

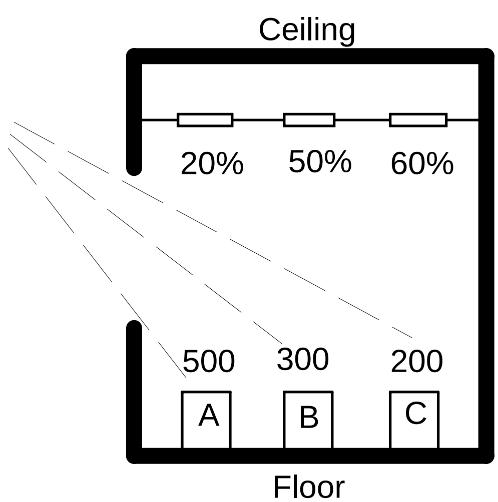


Fig. 4.2

Example 4.2

Artificial lighting in an office provides an average of 500 lux on the working plane. Daylight provides 500 lux at point A, 300 lux at point B and 200 lux at point C. The lighting over point A is dimmed to 20% output, the lighting over point B to 50% output and the lighting over point C to 60% output calculate the total illuminance at A, B and C.

Illuminance due to	Daylight	Artificial Light	Total
at A	500 lux	100 lux	600 lux
at B	300 lux	250 lux	550 lux
at C	200 lux	300 lux	500 lux

Example 4.3

An office area is 1000 m^2. It caters for 100 personnel at an average salary of £15,000 per annum. The installed lighting load is 20 Watts per m^2 and operates for 3000 hours per annum. Energy costs 10p per kWh.

Calculate:

(a) The annual light energy bill.
(b) The saving if artificial light is reduced to an average of 60% output throughout the year.
(c) The annual salary bill for the company.

(a) 20 Watts/m^2 x 1000 = 20 kW

Energy consumed per annum = 20 kW x 3000 hrs = 60,000 kWh

Cost = 60,000 x 10p = £6,000 p.a.

(b) Average Output = 60%
Average Saving = 40%

Cost benefit = £6,000 x 40% = £2,400 p.a.

(c) Salary Bill = £15,000 x 100 = £ 1,500,000

The benefit of introducing energy control is significant at £2,400 per annum. The benefit must be kept in perspective however, because the total light energy bill is 0.4% of the salary bill.

It is clear from this that any annoyance to staff must be eliminated for a control system to be of benefit to a company. It is equally clear that it is good value to provide a good quality lighting scheme which staff will appreciate, because a 1% improvement in productivity will pay for even a top quality lighting scheme in a short time.

People have become more “green” in their attitude to the use of energy and in general staff do not like wasteful lighting systems. Usually they want a good quality scheme and automatic control with override facilities.

4.7 Daylight Control

It is necessary to reach a reasonable compromise between ensuring good daylight penetration and reducing the negative aspects of sunlight. High daylight factors enable reductions in light energy costs but glare must be controlled and people must not be subjected to direct sunlight to the extent that their thermal comfort is affected.

Lightwells, lightshelves, roof lights, roof monitors, lightpipes, lightducts and transparent insulation are all used to enable daylight to penetrate deeply into buildings.

Blinds, shades, overhangs, darkened or reflected glass are all useful aids to control daylight. Special consideration of the selection and positioning of display screen equipment is necessary in buildings with large arteas of fenestration (windows) (see chapter 6)

4.7.1 Atria

These are used in modern buildings as inhabited lightwells. One of the aims with an atrium is to reduce space heating load whilst improving daylight penetration into the building. How successful it will be will depend on its orientation, geometry, internal reflectances and the nature of the roof and glazing. An atrium acts as a thermal buffer and windows facing into it may be larger than they may otherwise have been. In cities it may be possible to open a window onto an atrium where it would not be possible to open one onto a street because of noise and/or air pollution.

4.7.2 Light Shelves

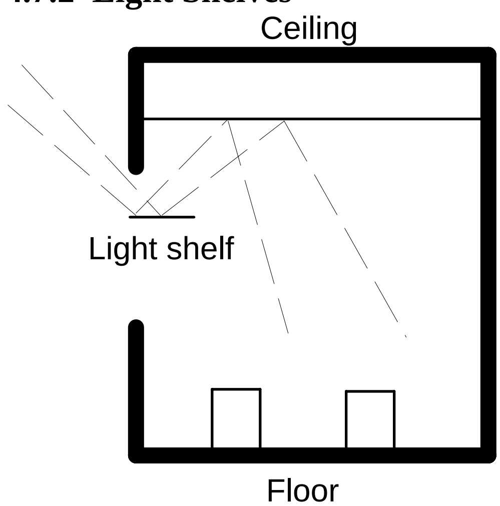


Fig. 4.3

Light shelves are increasing in popularity in modern buildings.

Lightshelves are placed at the window above eye level. Incoming daylight is redirected onto the ceiling improving daylight factor at the inner part of the room. The lightshelf also provides shading from direct sunlight to people close to the window. (See Fig. 4.3)

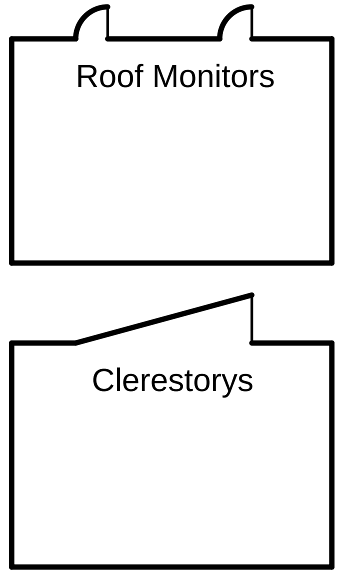


Fig. 4.4

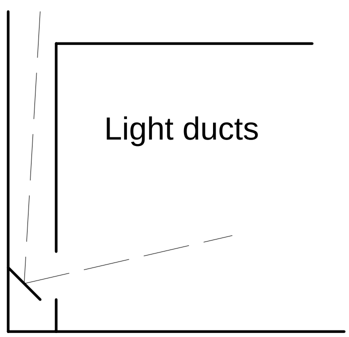


Fig. 4.5

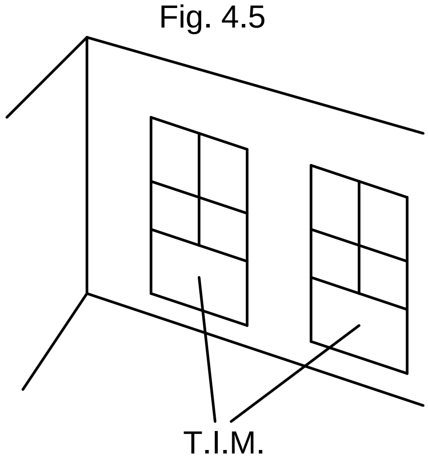


Fig 4.6

4.7.3 Roof lights

Roof lights are best for daylight penetration whilst minimising heat loss. Horizontal rooflights admit 3 times more daylight than vertical windows of a similar size. In addition, light is cast in a more uniform way. The disadvantage of roof lights is that they admit more light and heat in summer than in winter. For this reason, vertical or near vertical roof lights as well as roof monitors or clerestorys are often used instead of horizontal roof lights.

4.7.4 Lightpipes and Lightducts

Sunlight is collected by heliostats (mirrors controlled by tracking devices), concentrated by means of mirrors or lenses and then directed to the core of the building through shafts or acrylic rods or fibre optic cables. They are cost effective only in regions where blue skies are guaranteed for most of the year. Energy efficient back up lamps may be substituted for sunlight during overcast conditions. Recent development of thermo hydraulic tracking systems powered by solar cells should improve the viability of these devices in the future.

4.7.5 Transparent Insulation Materials (TIM)

These materials are translucent rather than transparent and are used mainly as insulating materials for wall structures. They reduce heat loss from the building whilst permitting solar radiation to reach a heat storing inner leaf. Light transmission varies from 45% to 80% and it costs about three times the price of double glazing.

4.7.6 Daylight Controlling Devices

The type, size and positioning of any shading device will depend on latitude, building orientation and climate. External shades are the most effective in reducing heat gains. Interior shades only protect the occupant from direct sunlight and glare. Internal surfaces absorb the sunlight thus increasing the demand on the cooling system. Internal shades are cheaper, however, and cost less to maintain. Adjustable horizontal louvres (venetian blinds) with a specular finish on the upper surface, can be angled to redirect sunlight in the same manner as light shelves. this ensures protection of people near windows from direct sunlight, whilst increasing daylight penetration into the inner parts of the building. These blinds provide control locally to occupants and they are the most popular choice in Northern Europe.

4.8 Overall Design

Daylight and artificial light must not be considered in isolation to the other energy using aspects of a building. A building which allows high daylight penetration will also have high solar gains. A saving in artificial lighting energy may be negated by an increase in air conditioning cooling load. The Architect, Electrical and heating/ventilating engineers and the rest of the design team must operate as an integrated team producing a comfortable low energy building in which occupants feel they have adequate control of their environment.

4.9 Depth of a Room.

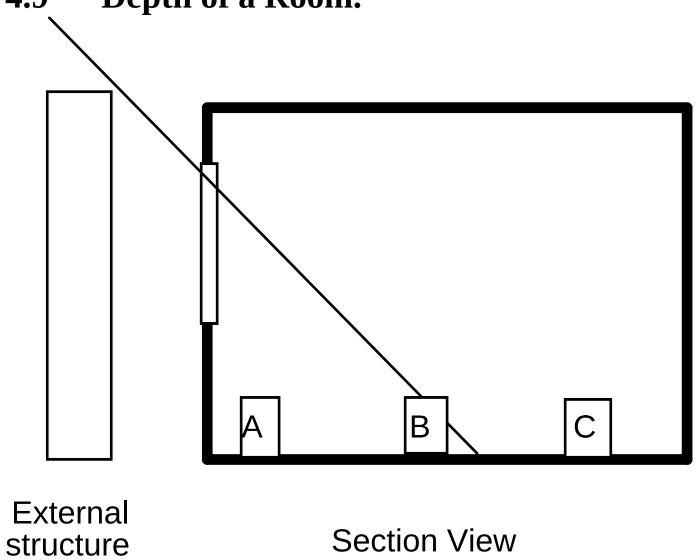


Fig. 4.9

A well established rule of thumb for assessing the area in a room which will have acceptable daylight is to determine the "No Skyline Point". This is the point at which the skyline is no longer visible (see Fig. 4.9). All points further from the window are not considered to have acceptable daylight

Desks A and B are OK but desk C does not have adequate dayight

As a general rule of thumb, the depth of a room should be limited to meet the following condition:

$$\frac{L}{W} + \frac{L}{H} < \frac{2}{(1 - Rb)}$$

Where L = Depth of a room
W = Width of a room
H = Height of the window head above the floor
Rb = Area weighted average reflectance in back half of room (typically 0.5 for an office)

4.9 Calculation of Average Daylight Factor (D)

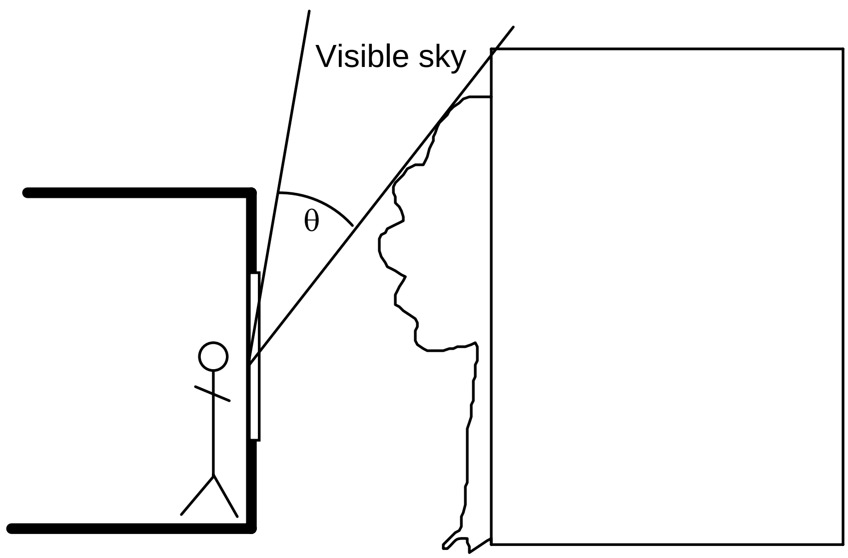


Fig. 4.7

$$D = \frac{W}{A} \frac{T\theta}{(1 - R^2)}$$

Where D = Average daylight factor
W = Window area in m^2 (use table to correct for framing)
A = Area of all surfaces in the room in m^2 (floor, ceiling, walls, and windows).
T = Glass transmittance (from table)
θ = Visible sky angle in degrees
R = average reflectance of (floor, ceiling, walls, and windows).

Table 4.1 Correction factor for type of frame

Type of frame	Cg
Metal patent glazing	0.9
Metal frame - large pane	0.8
Wood frame - large pane	0.7
Wood frame - small pane	0.6

Table 4.2 Correction factor for Glass transmission

Type of glass	Ct
Clear 6mm single glazing	0.8
Clear 6mm double glazing	0.65
Tinted bronze	0.46
Tinted Grey	0.39
Tinted Green	0.66
Strongly reflecting	0.18

Table 4.3 Correction factor for Dirt on Glass

Location	Cd
Clean	0.9
Industrial	0.7
Very dirty	0.6

4.11 Calculation of Daylight Factor at a point.

A sample point is normally selected in a room and a calculation is made of the daylight factor at that point. Daylight factor is quoted as a percentage of the outside illuminance. Computer programmes can calculate daylight factors at various points in a given room with great ease and speed. Isolux diagrams of the illuminance throughout the room can be produced once a value of external daylight illuminance is input along with room and window data.

Daylight factor (D) is calculated as follows: $D = Cg\ Ct\ Cd\ (Dc + De + Cr\ Di)$

Where Dc = Direct sky component;
De = Externally reflected component;
Di = Internally reflected component.
Cg = Correction factor for glazing bars which reduce glass area;
Ct = Correction factor for glazing materials other than clear glazing;
Cd = Correction factor for dirt on windows;
Cr = Correction factor for dirt on internal surfaces.

4.11.1 Sky Component (Dc)

This is the light reaching a point in a room directly from the sky. The BRE (building research establishment - in Britain) provide a sky component table which is reproduced in the CIBSE code for Interior Lighting (Table 5.16 of CIBSE Code for Interior Lighting).

Table 5.16

Example 4.5

An office has a row of desks at cill height 2 metres from a window which is 1.2 metres high and 2.4 metres wide. Using table 4.5, calculate the direct sky component:

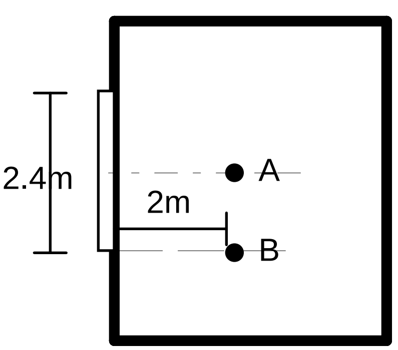


Fig. 4.8

(a) On the desk opposite the centre of the window.

(b) On the desk opposite the side of the window.

h	=	Height of window = 1.2m
d	=	Distance from window = 2m
W1	=	Width of window to one side
W2	=	Width of window to other side

(a) $\frac{h}{d} = \frac{1.2}{2} = 0.6$

$\frac{W1}{d} = \frac{1.2}{2} = 0.6$ (From Table Dc = 1.3%)

This is the percentage daylight factor from one side of window only. The benefit from the other side is the same therefore.

Total Direct Component = 1.3% x 2 = 2.6%

(b) $\frac{h}{d} = \frac{1.2}{2} = 0.6$

$\frac{W}{d} = \frac{2.4}{2} = 1.2$ Therefore Dc = 1.9%

Example 4.6

Calculate the illuminance due to the direct sky component at points A and B in Example 4.4 when the external horizontal illuminance is 10,000 lux.

(a) 10,000 x 2.6% = 260 lux

(b) 10,000 x 1.9% = 190 lux

Example 4.7

Calculate the direct sky component and the illuminance due to Dc if external illuminance is 10 kilolux for points A, B and C. in Fig 4.7. The window is 1.2m high.

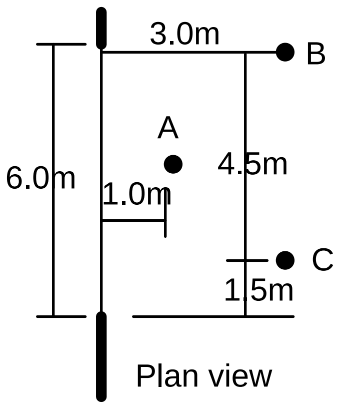


Fig. 4.9

At point A h = 1.2m; d = 1m; W1 = W2 = 3m

$$\frac{h}{d} = \frac{1.2}{1} = 1.2 \qquad \frac{W}{d} = \frac{3}{1} = 3$$

Dc = 6.2% x 2 = 12.4%

E due to direct sky component at point A = 10,000 x 12.4% = 1240 lux

At Point B h = 1.2m; d = 3m; W1 = 6m; W2 = 0

$$\frac{h}{d} = \frac{1.2}{3} = 0.4 \qquad \frac{W1}{d} = \frac{6}{3} = 2$$

Dc = 0.96%

E due to direct sky component at point B = 10,000 x 0.96% = 96 lux

At Point C h = 1.2m; d = 3m; W1 = 4.5; W2 = 1.5m

$$\frac{h}{d} = \frac{1.2}{3} = 0.4 \qquad \frac{W1}{d} = \frac{4.5}{3} = 1.5$$

Dc = 0.95% due to benefit from one side

$$\frac{h}{d} = \frac{1.2}{3} = 0.4 \qquad \frac{W2}{d} = \frac{1.5}{3} = 0.5$$

Dc total at point C = 0.95% + 0.54% = 1.49%

E due to direct sky component at point C

= 10,000 x 1.49% = 149 lux

Example 4.8

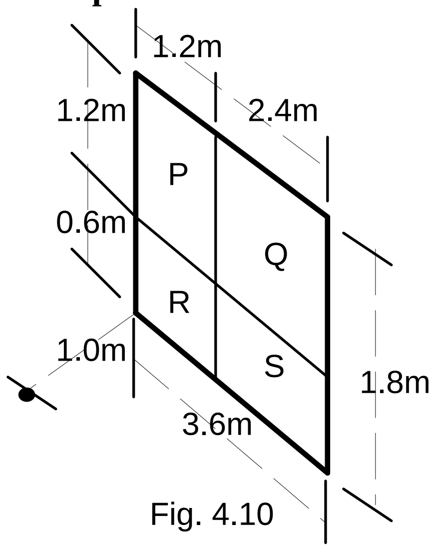


Fig. 4.10

The examples considered so far have calculated the sky component at cill height opposite some part of the window. Consider point P in Fig. 4.8. In order to calculate the direct sky component at point P from window Q, it is necessary to also consider wall areas P, R and S. Treat these wall areas as though they were windows as follows:

1. Calculate Dc for PQRS
2. Calculate and subtract Dc for PR
3. Calculate and subtract Dc for RS
4. Calculate and add Dc for R

Q = PQRS - PR - RS + R

1. **PQRS** h = 1.8 m; d = 1m ; W1 = 3.6m.

$$\frac{h}{d} = \frac{1.8}{1} = 1.8 \qquad \frac{W}{d} = \frac{3.6}{1} = 3.6$$

Therefore Dc = 9.4%

2. **PR** h = 1.8m; d = 1m; W = 1.2m

$$\frac{h}{d} = \frac{1.8}{1} = 1.8 \qquad \frac{W}{d} = \frac{1.2}{1} = 1.2$$

Therefore Dc = 7.8%

3. **RS** h = 0.6m; d = 1m; W = 3.6m.

$$\frac{h}{d} = \frac{0.6}{1} = 0.6 \qquad \frac{W}{d} = \frac{3.6}{1} = 3.6$$

Therefore Dc = 2.1%

4. **R** h = 0.6m; d = 1m; W = 1.2m.

$$\frac{h}{d} = \frac{0.6}{1} = 0.6 \qquad \frac{W}{d} = \frac{1.2}{1} = 1.2$$

Therefore Dc = 1.9%

Dc at P = 9.4 - 7.8 - 2.1 + 1.9

= 1.4%

4.11.2 Externally Reflected Component (De)

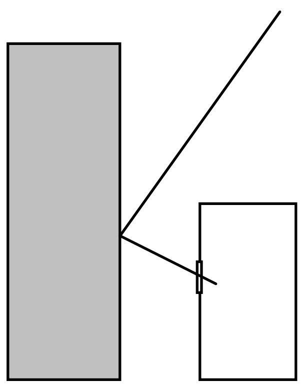


Fig. 4.11

This is the reflected daylight reaching a point in a room from external structures and surfaces. **It is only necessary to calculate De if direct daylight is severely limited** by an external structure.

It is seen from Fig. 4.9 that the external structure is restricting the amount of daylight entering the window W. In this case it will be necessary to calculate De.

$$De = Dc \times \frac{\text{Luminance of Obstruction}}{\text{Luminance of Sky}}$$

For example if Dc = 2% and the luminance of the obstruction is one tenth of the luminance of the sky.

$$\text{Then } De = 2\% \times \frac{1}{10} = 0.2\%$$

4.11.3 Internally reflected component (Di)

This is the light reaching a point after reflection from surfaces within a room. The amount of inter reflected light varies with the distance from the window but the average internally reflected component for side lit rooms is:

$$Di = \frac{0.85\ AW}{A(1-R)}(CRfw + 5\ Rcw)$$

Where:

W = area of windows;
A = area of ceiling, floor and walls (inc windows)
R = average reflectance of ceiling; floors and walls (inc windows)
Rfw = average reflectance of floor and walls below the plane of mid height of the window (excluding window wall).
Rcw = average reflectance of ceiling and these parts of the wall above mid height of window (exc window wall)
C = coefficient dependent on the obstruction outside the window.

Values for C vary between 0 and 39, depending on the obstruction outside (39 is used when there is no obstruction).

Angle of obstruction	**Coefficient C**
No obstruction	39
10 degrees	35
20 degrees	31
30 degrees	25
40 degrees	20
50 degrees	14
60 degrees	10
70 degrees	7
80 degrees	5

Formulae and Tables supplied courtesy of BRE

4.11.4 Correction Factor

The same correction factors apply as for the calculation of average daylight factor. (tables 4.1, 4.2 and 4.3 page 105)

4.11.5 Daylight Factor (D) This is the aggregate of the Direct Sky, the Externally Reflected and the Internally Reflected components and can be calculated as follows: **D = Cg Ct Cd (Dc + De + Cr Di)**

For most buildings, the direct sky component Dc is the most significant aspect of daylight penetration.

Example 4.9.

A room measures 6.5m x 4m x and is 2.7m high. It contains one window measuring 2m high by 2.5m wide located at the centre of the 4m wall. The cill height is 0.5m. The window glass is clear with a transmittance factor of 0.8. The minimum external horizontal illuminance due to daylight may be taken as 10,000 lux and there are no external obstructions.

Room reflectances are: Lower surfaces 0.4
Upper surfaces 0.6
Overall average 0.5

Calculate:

- (a) The average daylight factor in the room
- (b) The daylight factor and the daylight illuminance at a point in the room located 5m normal to the centreline of the window at cill height.
- (c) The average daylight illuminance in the room
- (d) Comment on the above results in relation to the design of the artificial lighting as well as its control.

(a)

$$D = \frac{W}{A} \frac{T\,\theta}{(1 - R^2)}$$

$$D = \frac{5}{108.7} \frac{0.8 \times 80}{(1 - 0.5^2)} = 3.92\%$$

(b) **Df = Dc + De + Di**

De = 0

$$Dc = \frac{h}{d} = \frac{2}{5} = 0.4 \qquad \frac{W}{d} = \frac{1.25}{5} = 0.25$$

From Table 5.16 Dc = 0.295 x 2 = 0.59 %

$$Di = \frac{0.8W}{A(1-R)}(CRfw + 5\ Rcw)$$

$$Di = \frac{0.8 \times 5}{108.7(1-0.5)}(39 \times 0.4 + 5 \times 0.6) = 1.36\%$$

Total Df at point X = 0.59 + 1.36 = 1.95%

(c) Eav = 3.92% of 10,000 = 392 lux

E point x = 1.95% of 10,000 = 195 lux

(d) Permanent supplementary artificial lighting is required in rooms where the average daylight is less than 5%. Modulation of artificial light will be desirable to reduce energy costs. Automatic dimming could provide gradual control down to 20% output. When daylight levels are high, automatic switching off of artificial lighting would not be recommended for a room where the average daylight factor is less than 5%.

SECTION 5

INTEGRATED LIGHTING DESIGN

CONTENTS:

Section 5.1	**Introduction**
Section 5.2	**Daylight**
Section 5.3	**Lighting Levels**
Section 5.4	**Modelling**
Section 5.5	**Illuminance Variation**
Section 5.6	**Adaptation**
Section 5.7	**Glare**
Section 5.8	**Colour Performance**
Section 5.9	**Choice of System**
Section 5.10	**Lighting Guides**
Section 5.11	**Choice of scheme for Office Lighting**

5.1 Introduction

When designing any interior lighting scheme reference should be made to the **"Code for Interior Lighting"** issued by the **Chartered Institute of Building Services Engineers (CIBSE) 1994.**

The code should not be thought of as simply a reference to check the recommended illuminances for installations but as a code of good practice in the design of lighting schemes. The lighting of any interior **should fulfil three functions:**

1. To ensure the safety of people using the building.

2. Enhance the visual environment.

3. To facilitate the performance of the variety of visual tasks required. Allowance must be made for age and poor eyesight, the duration of the task and the consequences of any error.

Safety is paramount, but most well lit interiors will have sufficient light to ensure safety. **Emergency lighting** must be provided in case of power failure in most buildings. Whether the emphasis will be task oriented or the enhancement of the interior will very much depend on the type of premises considered. The design of lighting for a factory will concentrate on the task, whereas the design of lighting for a reception area in a building will concentrate on visual appearance.

Mood or atmosphere should be considered in all designs; even if it is of less importance than the other criteria. Too often in the past, design was based on an average horizontal illuminance with no thought given to vertical illuminance or the quality of the lighting scheme. Good lighting design involves incorporating **all** of the above objectives into the design of the scheme.

5.2 Daylight

The incorporation of daylight into interior lighting design is desirable for the following reasons:

1. Energy costs are reduced if good control of artificial lighting is provided.

2. A room which does not provide a view of the outside where one could have been reasonably expected, will be considered unsatisfactory to most building occupants.

3. Daylight from a window provides a cross vector of light which will improve modelling and provide a desirable vector/scalar ratio.

4. Colour rendering will be improved in most interiors with good daylight penetration. If exact colour rendering is necessary however, account must be taken of the changing spectral composition of daylight with time of day and change of season.

5. The natural variation of daylight provides information about the weather and time of day which occupants will deem desirable.

Note:

Modern lighting controls allow the simulation of external conditions in interiors where daylight is excluded. Not only is illuminance varied with the time of day but so also is the colour appearance of the lamps used. Some discharge lamps have a natural colour shift when dimmed and this effect is used to advantage in these schemes. Nonetheless these artificial schemes are never as satisfactory to building occupants as a real view of the outside.

5.3 LIGHTING LEVELS

5.3.1 Lighting for Safety

Hazards must be made visible. In the event of power failure sufficient light must be provided to allow safe escape from the building, prevent panic and illuminate hazards which may be dangerous to personnel.

5.3.2 Lighting to Enhance Visual Environment

This will depend on the quantity and quality of light as well as surface characteristics and reflection factors.

To enhance an interior, light will normally be varied in colour, level and source. Variations of illuminance and accentuation of certain areas or objects may be desirable. Experience and judgement will replace calculation and science in this type of design. Co-ordination with the architect or interior designer is very important here. The selection of strong colours for large parts of the interior would be better suited to a direct lighting scheme than an indirect one. Indirect lighting reflected from bright coloured interiors would become colour distorted.

Notwithstanding this, small areas of strong colour are often necessary to provide visual stimulation in indirect lighting schemes. These areas should not be used to reflect light to the interior.

5.3.3 Lighting for Performance of Task

The task should be provided with adequate illuminance taking account of age of operatives, task difficulty and duration as well as the consequences of error. **It should be remembered that the task is not always on the horizontal.**

5.3.3.1 Vertical Illuminance

The illuminance on a vertical surface can be calculated using the point to point method or for a regular array of symmetrical luminaires:

Average wall illuminance =
average horizontal illuminance X wall to task illuminance ratio.

Note: For further information see Section 5.2 of the CIBSE Code for Interior Lighting (1994)

5.3.3.2 Scalar Illuminance

This is the average illuminance over the surface of a very small sphere at a given point in a room. It takes account of all room surface reflectances.

5.3.3.3 Mean Cylindrical Illuminance

This is the average illuminance over a very small cylinder at a point. It is normally closely related to scalar illuminance but it ignores floor reflectance.

5.4 Modelling

This is the ability of light to reveal shape in three dimensions. Strong modelling is achieved by directing light of different intensities from different directions on a subject. Contrast with the background is also a significant factor.

Light from a predominantly vertical direction will create contrasts and shadow. The best effects are produced by a number of sources.

See Fig 1.17 CIBSE code for interior lighting.

5.4.1 Vector Illuminance

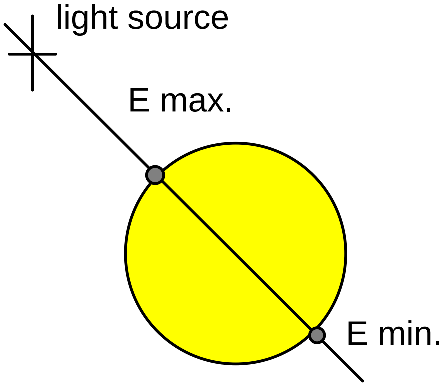


Fig. 5.1

The magnitude and direction of light can be described in terms of an **illuminance vector**.

Imagine a sphere which is illuminated from one side. The direction of the axis of the sphere which also passes through the source represents the direction of the illuminance vector because there will be a maximum difference of illuminance at opposite ends of this axis. The magnitude of the illuminance vector is the difference in illuminance (E max. - E min.).

In a downlighting scheme the vector will be vertical with the magnitude largely dependent on room reflectances.

5.4.2 Vector/Scalar Ratio and Index of Modelling

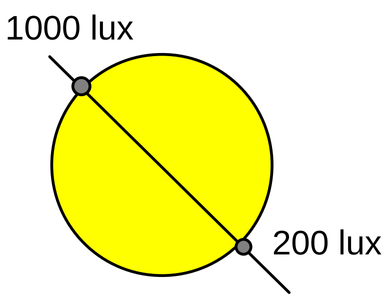


Fig. 5.2

In the example shown, say the scalar illuminance is 600 lux
The vector illuminance is 1000 - 200 = 800 lux at an angle of about 30 degrees.

The vector scalor ratio is 800/600 = 1.33

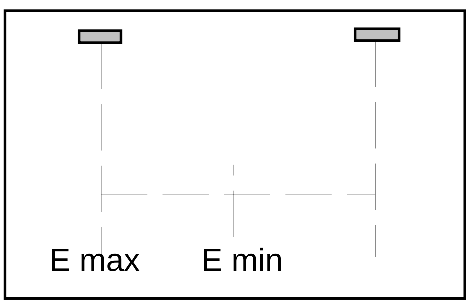
For most installations the preferred direction of the vector lies between 15^{o} and 45^{o} from the vertical i.e. flow of light predominantly from above and to one side as shown in Fig. 5.2.

The preferred ratio depends on the direction of the vector as well as the purpose and character of the interior. As a rule of thumb the preferred range would be from 1.2 to 1.8 for general lighting schemes where the perception of faces is important.

5.5 Illuminance Variation (space or time)

5.5.1 Time Variation. There may be **short term variation** in illuminance occurring naturally as a result of changing daylight or occurring either manually or automatically by the operation of lighting controls on the supplementary lighting. **Long term variation** occurs as a result of light loss due to lamps ageing or dirt accumulating on luminaires or room surfaces. This last factor has already been discussed under "maintenance factor" in section 1.8.4.

5.5.1 Spatial Variation: Spatial variation means variation of illuminance over a task area or throughout an interior. Variation of illuminance at the **task** will normally be acceptable provided the spacing between luminaires comply with the manufacturer's recommended Space : Height ratios.



E min. > 0.8 E Ave.
E min. > 0.7 E max.

Fig. 5.3

An average illuminance of 500 lux, a maximum illuminance of 600 lux directly under luminaires and a minimum illuminance of 400 lux at the mid point between luminaires would be quite acceptable. It is of course desirable that the general illuminance throughout the interior would be varied to provide variation and interest.

Excessive variation of room surface luminances however, should be avoided, otherwise transient adaptation problems may cause discomfort and affect visual performance. **Transient adaptation** occurs when a person's field of view changes from one level of luminance to another, requiring the eye to adjust. In the short term before adaptation occurs, a discomfort situation may arise. Nonetheless the task should be of a higher illuminance than the immediate surround but there should not be a sharp contrast. (for recommended ratios, see section 5.7)

Early interior lighting designers felt that a large number of ceiling luminaires providing a uniform illuminance over the working plane would be the most acceptable lighting design in working interiors. The term "shadow free" lighting was introduced. The problem with this theory was that it produced a bland uninteresting lighting scheme. Present thinking suggests that the careful introduction of shadow and sparkle will enhance the appearance of a lighting scheme greatly without affecting task illuminance unduly. Further information on illuminance / luminance variation is contained in section 2.4.4 of CIBSE code for interior lighting.

5.6 Adaptation

It is possible for the eye to adapt to widely varying levels of illumination. For example, a bright day may provide an illuminance of 100,000 lux whilst at night, the human eye can adapt well and provide a reasonable performance at 0.1 lux - the approximate illuminance provided by moonlight.

The eye however, needs time to adjust to these changes. Providing a bright reference point in a dark room can lead to glare. Most problems with glare in interiors is caused by windows or luminaires either directly or indirectly.

5.7 Glare

The human eye can adjust from 100,000 lux in bright sunlight to 0.1 lux under moonlight - a ratio of 1,000,000 to 1. However, it takes time to adapt fully from from one lighting level to another. When moving from a bright exterior to a dark interior, the eye can cope well with a ratio of 200:1. It takes about 90 seconds for the first 70% of that adjustment to occur and a further 15 minutes for the remainder. This accounts for the difficulty the human eye experiences when simultaneously coping with different surface luminances - the phenomenon known as glare.

With internal lighting design care must be taken to ensure there are no excessively bright sources within the normal field of vision of people using the installation. If a bright source is visible to the eye, the lens of the eye will close in proportion to the brightness of the source. A bright source in an otherwise bright interior may not present difficulty but a bright source in an otherwise dimly lit interior will certainly present problems.

Care must be taken by lighting designers to ensure that bright light sources are not placed in the field of vision. The source can be direct as in the case of a luminaire or window or indirect, reflected from a working surface such as a display screen. Glare can also be caused by excessive contrast such as a dark background coupled with a bright foreground.

Glare from luminaires is reduced by decreasing the luminance of the source. With opal and prismatic diffusers the source luminance is reduced by increasing the area of the source. Special low glare luminaires utilise louvres to shield the lamp from direct view. (see special category luminaires, Chaper 6)

Glare occurs whenever one part of an interior in the field of vision is much brighter than the general interior. A task to immediate background ratio of 3:1 and task to general background ratio of 10:1 is recommended by the CIBSE Code for Interior Lighting. Glare can be subdivided into disability and discomfort glare.

5.7.1 Disability Glare occurs when vision is actually impaired. It can be the cause of accidents and a serious reduction of visual performance. This is a more extreme form of glare and is most likely to occur when there is an area close to the line of sight which has a very high luminance. The most common causes of glare indoors are windows and electric light sources which are seen either directly or indirectly by reflection. Glossy magazines and visual display terminals (VDT's) are common causes of indirect disability glare because of their reflective surfaces.

5.7.2 Discomfort Glare often occurs, after continuous exposure to high background contrast or high source luminance either directly or indirectly from say VDT's. It can cause eye fatigue, headaches and other symptoms related to "Sick Building Syndrome".

5.7.3 Glare Index of discomfort

The CIBSE code for interior lighting uses a glare index system. This is a numerical index which may be calculated for lighting schemes. Section 2.6.4 of the CIBSE guide provides limiting glare indices for most building interiors.

Example 5.1
A room has the following dimensions:
length = 24m
width = 16m
height = 3.2m

Luminaires are installed at 2m centres as shown in the diagram, each containing two lamps with a luminous flux per lamp of 5,500 1m. Using the uncorrected glare index table and the correction factors provided, determine the glare index for the installation for:
(i) long view
(ii) short view

Height correction factor: = $4 \log_{10} H - 1.2$

Total lamp luminous flux correction factor: = $6 \log_{10}(nF) - 18$

where H = height of luminaires above eye level (1.2m)
n = number of lamps per luminaire
F = luminous flux per lamp

Ceiling reflectance = 0.7
Wall reflectance = 0.5
Floor reflectance = 0.2

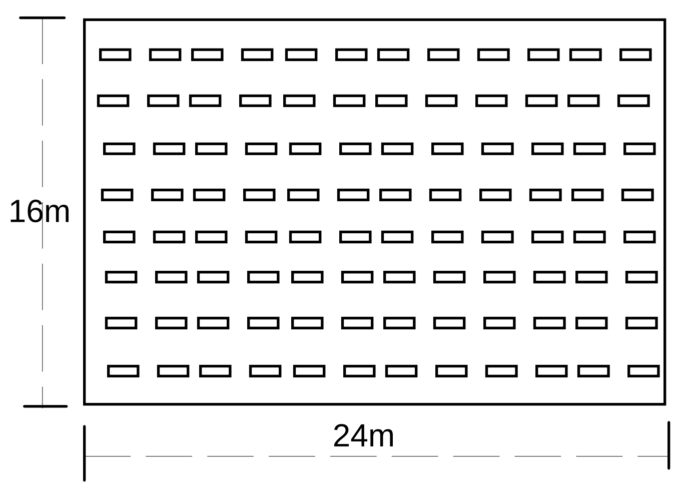


Fig 5.5

table 4.11 cibse code

(i) long view (refer to CIBSE code)

x = 8H
y = 12H

Viewed end-wise, the uncorrected glare index from Table 4.11	=	14.2
Height correction factor (from (1))	=	0
Total lamp luminous flux factor (from (2))	=	6.2

Glare Index	=	20.4

(ii) short view (refer to CIBSE code)

x = 12H
y = 8H

Viewed cross-wise, the uncorrected glare index from Table 4.11	=	15.3
Height correction factor (from (1))	=	0
Total lamp luminous flux factor(from (2))	=	6.2

Glare index	=	21.5

Note: If luminaires are turned the other way, the glare index rises to 22.2

Typical limiting glare indices are:

- Drawing offices (16)
- General offices (19)
- Supermarkets (22)

Therefore this lighting scheme would only be suitable for a supermarket.

5.7.4 Unified Glare Rating (UGR) System

The "Commission Internationale de l'Eclairge" (CIE) have proposed this system to provide an internationally agreed numerical rating. Like the glare index system, discomfort glare is ranked numerically in order of severity. Discomfort glare for specific installations will be prescribed in a unified glare limit rating.

5.8 COLOUR PERFORMANCE

5.8.1 Colour Appearance

This relates to the colour temperature of the lamp. Some interiors require a warm appearance. Reception areas in offices and hotels are examples of this. Where the illuminance is less than 300 lux a warm colour is normally preferred.

Where there is a high level of daylight penetrating the interior an intermediate correlated colour temperature (CCT) source should be used. Where a cool appearance is required, say in a surgery or clinic, a high CCT source should be used.

Note: The higher the correlated colour temperature the cooler the source

Table 2.1A

CCT Class	
Warm	Below 3300 K
Intermediate	3300 K to 5300 K
Cool	Above 5300 K

5.8.2 Colour Rendering

When exact colour rendering is necessary lamps of group 1 A should be used in a test room which excludes daylight. The inspector or operator must be given time to adapt to the room before carrying out colour critical tasks. In addition:

1. The room must have a minimum task illuminance of 500 lux.
2. Areas surrounding the task must be of weak chroma and medium reflectance.

In areas where good colour rendering is necessary and the appearance of the interior is important lamps of group 1B should be used. These lamps sometimes exaggerate slightly the primary colours but this is welcomed by most people.

Note:
Lamps in colour rendering group 1A have a CIE colour rendering index (Ra) > 90
Lamps in group 1B have an Ra between 80 and 90 (See Table 2.2 in Section 2)

Lamps such as High Pressure Sodium (SON) which has an Ra of 65 may distort some colours. In addition, people moving from an area illuminated by SON lamps to one illuminated by fluorescent lamps may suffer "colour shift" problems.

5.9 CHOICE OF SYSTEM

5.9.1 General Lighting

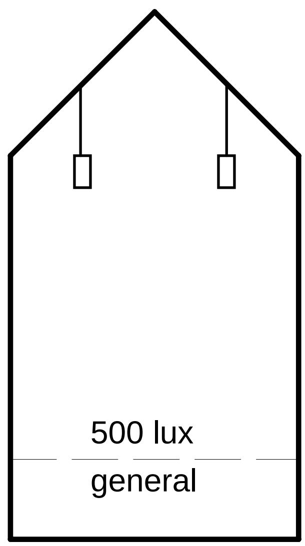


Fig. 5.6

This is probably the most commonly used artificial lighting system. A regular array of luminaires provide an average maintained illuminance on the working plane (see Fig. 5.6). This type of system will normally provide a rather bland “shadow free” lighting installation but great flexibility of work stations is possible as tasks can be moved around. Some of the bland effect can be reduced by introducing some sparkle and contrast into the design. Point sources provide sparkle whilst directional or indirect lighting provide contrast. The main disadvantage of general lighting schemes is their high energy costs because the whole area is illuminated to the highest level of illumination required for the single most difficult task.

5.9.2 Localised Lighting

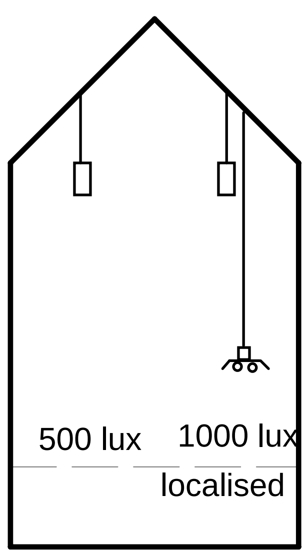


Fig. 5.7

If the location of a particular work area is known then localised lighting can be used to raise the illuminance on this area whilst maintaining general illuminance at a lower level. The average general illuminance should be at lease one third of the task illuminance where localised lighting is provided. Localised lighting tends to provide a more interesting design with emphasis placed on the work station. Localised lighting is more efficient with regard to energy costs because of the more efficient use of light, however, good maintenance of these schemes is essential.

5.9.3 Local /Task Lighting

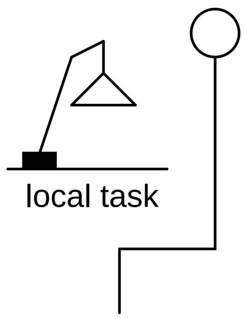


Fig. 5.8

This is the term used for lighting which illuminates a specific individual workstation. General illuminance should be at least one-third of the local illuminance. The light should be positioned to minimise shadows, veiling reflections and glare. A desk would typically be illuminated from the left hand side (for a right handed person) so that there are no distracting shadows or veiling reflections. The eye should be protected from the lamp itself by the use of a “shade”. Local lighting ensures efficient use of light energy. Local individual control should be provided. Disadvantages are that low wattage lamps are normally less efficient and maintenance costs are generally higher with local lighting.

5.10 LIGHTING GUIDES

Apart from the CIBSE code for interior lighting the student's attention is drawn to the following guides - all of which are available from the Chartered Institution of Building Services Engineers.

LG 01	The industrial environment
LG 02	Hospitals and health care buildings
LG 03	The Visual Environment for Display Screen use
LG 04	Sports
LG 05	Lecture Theatre and conference rooms
LG 06	The outdoor environment
LG 07	Office lighting
LG 08	Museums and art galleries
LG SSR	Ship building and ship repair
LG HHE	Lighting in hostile and hazardous environments

It is not possible, with the limitation of space available here, to detail designs for all of the above installations, but consideration will be given to the choice of lighting scheme for a modern office in the next chapter.

Section 2.1.5 **Table 2.3** **Summary of Lamp Data**

Lamp type	**Life to 50% survival (Hours)**	**Hours to 70% Lumen Maintenance (Hours)**	**Efficacy * Lumens /watt**	**Colour Rendering Index CRI**	**Colour Temperature K**	**Control**	**Restrike time**	**Applications**
Tungsten Filament	1000		10-20	1A	2700	Fully dimmable	Prompt	Security and Vehicle lamps
Tungsten Halogen	2000		15-25	1A	3000	Fully dimmable	Prompt	Security and vehicle lamps
Tri-Phosphour Tubular Fluorescent	600-120000	12000-24000	40-105	See table 3.3 of CIBSE code for interior lighting	See table 3.3 of CIBSE code for interior lighting	Not easily dimmable	few seconds	Offices / factories
High Frequency Tubular Fluorescent	7500-15000	15000-30000	80-95	See table 3.3 of CIBSE code for interior lighting	See table 3.3 of CIBSE code for interior lighting	dimmable	Prompt	Offices
Induction	60 000 (80% survival)	60 000	60-70	1B	3000-4000	Can be dimmed considerably without colour shift	Prompt	Where long life is necessary
Metal Halide	6000-13000	6000-13000	70-90	1A-2	3000-6000	Dimmable to 40% but shift to blue	1-2 min run-up with 5-15 min restart	Offices /Shops/Factories/Stadia
SON	5000-30000	6500-31000	70-140	N/A	2000-3000	Dimmable to 40% but colour shifts to mono	5 min run-up and more than 1 min. restart	Road Lighting / Factory and Warehouse
SOX	15000-23000	15000-30000	100-180	N/A	N/A	Not usually dimmed	10 min	Dual carraigeways / motorways

* Depends on Lamp Wattage Note: More exact lamp data is provided on pages 65 / 66