Institute of Distance Learning, KNUST

Template

For

Course Material

A 3-credit course outlay

2009

Updated

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

INSTITUTE OF DISTANCE LEARNING

BSC ELECTRICAL / ELECTRONIC ENGINEERING

[EE365: ELECTRICAL SERVICES DESIGN

[Credit: 2]

EMMANUEL OBUOBI KWAME ADDO]

Publisher Information

For any information contact:

Dean
Institute of Distance Learning
New Library Building
Kwame Nkrumah University of Science and Technology
Kumasi, Ghana

Phone: +233-51-60013
+233-51-61287
+233-51-60023

Fax: +233-51-60014

E-mail: idldean@kvcit.org
idloffice@kvcit.org
kvcit@idl-knust.edu.gh
kvcitavu@yahoo.ca

Web: www.idl-knust.edu.gh
www.kvcit.org

ISBN:

Editors:

Publisher notes to the Learners:

1. Icons: - the following icons have been used to give readers a quick access to where similar information may be found in the text of this course material. Writer may use them as and when necessary in their writing. Facilitator and learners should take note of them.

Icon #1

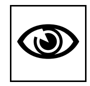
Learning Objective

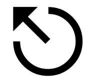
Icon #2

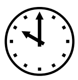

Learning Activity

Icon #3

Unit Assignments

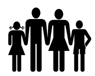
Icon #4

Review

Icon #5

Summary

Icon #6

Time For Activity

Icon #7

Self Assessment

Icon #8

Group Discussion

Icon #9

Read

Icon #10

New Terms

Icon #11

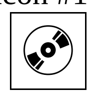
Answer Tips

Icon #12

Note/Learning Tip

Icon #13

Pause

Icon #14

Interactive CD

Icon #15

Online

2. Guidelines for making use of learning support (virtual classroom, etc.)

This course material is also available online at the virtual classroom (v-classroom) Learning Management System. You may access it at www.kvcit.org

Course Author

Mr. Emmanuel O.K. Addo, a product of Berekum secondary school (ordinary level certificate) and Sunyani Secondary School (Advanced level certificate), is a lecturer at the department of Electrical &Electronic Engineering ,Kwame Nkrumah University of Science and Technology (KNUST). He has MSc degree in Electrical engineering from Vinnitsa State Technical University, Ukraine. He also has advanced certificate in Electronic Control Engineering from Gross Gerau Polytechnic, Frankfurt, Germany. He was a former head and lecturer at the department of Electrical and Electronic Engineering of Kumasi Polytechnic (from 1997 to 2003)

He also has a great deal of industrial experience with Nexans Kabelmetal Ghana Limited the leading cable manufacturing company in Ghana where he worked as the Assistant Manager in charge of Marketing.
He is currently the coordinator of the BSc final year students projects at Faculty of Electrical / Electronic and Computer Engineering of Departments of Kwame Nkrumah University of Science and Technology (KNUST

Course developer(s):

DR. P.Y OKYERE]
PHD ELECTRICAL ENGINEERING
FORMER DEAN OF FACULTY OF ELECTRICAL AND COMPUTERENGINEERING
ELECTRICAL & ELECTRONIC ENGINEERING DEPARTMENT

MR. OPUNI OSEI
ELECTRICAL ENGINEER
FORMER LECTURER ELECTRICAL & ELECTRONIC ENGINEERING DEPARTMENT

MR. EMMANUEL ADDO
ELECTRICAL ENGINEER
LECTURER ELECTRICAL & ELECTRONIC ENGINEERING DEPARTMENT

Acknowledgement

The following individuals provided detailed critiques of the manuscript and offered valuable suggestions for improvement.

Dr. P.Y OKYERE]
Phd Electrical Engineering]
Former Dean of the Faculty of Electrical & Electronic and Computer Engineering
KNUST

Mr. Opuni Osei
Electrical Engineer]
Former Lecturer Department of Electrical & Electronic Engineering]
KNUST]

Course Introduction

Electrical service design is a course that is intended to equip electrical engineering students with the necessary practical knowledge in the pursuance of their professions as engineers. This course sets out to provide a basic grounding in the design of electrical services for buildings. Students are provided with a vivid knowledge of the nature of light and the various lighting schemes and their designs to enable them understand the idea underlying the provision of good illumination to increase production in industry, reduce accidents in factories and on roads, and makes buildings in general safe and pleasant places to work or undertake other activities. The electrical service design course equips students with techniques in determining, with appropriate accuracy, the correct ratings of cables , protection devices and luminaires so that the cost of providing the required electrical services to a given building will be minimum.

COURSE OVERVIEW

Illumination Design.

Nature of light; sensitivity of the eye; common terms used in lighting design; laws of illumination; polar curves; lighting schemes; lighting sources; filament lamps, electric discharge lamps and are lamps; effect of voltage variation; starters; efficiency and costs;

Lighting installation: interior lighting design, floodlighting design and street lighting design. Electrical Drawing for Architectural Plans: Commonly used electrical and electronic symbols; number of lamps in one circuit and number of lamps controlled by one switch; one and multi-position control of lamps; lamps, their switching and circuit connections; radial and ring circuit connection of socket-outlets; bathroom requirements for socket-outlets, and lamps switches and lamps; lighting arresters; telephone installations.

COURSE OBJECTIVES

1. To enable students determine the illumination level of light at any given point and understand the working principles of various light sources.
2. To equip student with requisite skills for designing interior and exterior lighting schemes
3. To equip students with the appropriate techniques in accurately determining the correct ratings of electrical services materials to minimise cost of providing the services for a given building.
4. To enable students to translate their design on architectural floor plan of a building using the appropriate computer software.

COURSE OUTLINE

- Unit 1: Illumination Design
- Unit 2: Lighting Installation
- Unit 3: Load estimation and selection of electrical services equipment and devices

GRADING

Continuous assessment: 30%

End of semester examination: 70%

RESOURCES

You will require Sets of Mathematical instruments and A3 sheets for this course.

To complete this course you would need to accomplish a theory, number of practical and tutorial and obtain 2 credits

REFERENCES / READING LIST / RECOMMENDED TEXTBOOKS / WEBSITES / CD ROM

1. El Missiry, N.M, Ijumba, N.M.L , Mullise,G (1996) Advanced Electrical Engineering . Nairobi: UNESCO Office.

2. Institution of Incorporated Executive Engineers (1991) . *ASEE Illustrated Guide to IEE Wiring Regulations (16th Edition): Wix Hill House : WEST SURREY*

3. Hornemann ,E. , Heinrich, H. , Jagla,D., Larisch,J., Muiller, W. (1988) . Electrical Power Engineering Proficiency Course. New Delhi : Wiley Eastern Limited

4. Thompson ,F. G. (1987). Electrical Installation Technology, Volume 3 Second Edition . Sinapore : Longman Singapore Publishers.

5..Rigby, B ., (2005) Design of Electrical Services for Buildings, 4th Edition. New York : Spon Press

7. Hughs, E., (1987). Electrical Technology. Burnt Mill Harlow: Longmann Group U.K Ltd

Unit 1

ILLUMINATION DESIGN

Introduction

The existence of light from the sun makes it possible for people to see their way through and go about their normal duties successfully during the day .But for the invention of artificial lighting by means of electric current , performing some activities in the night will have been quite impossible.

As a matter of fact, electric lighting has brought about a significant improvement in the standard of living of mankind as whole. The availability of bright, instant illumination has made it possible for people to read, write, and do intricate work more effectively during the night time hours, without concern for the fire hazards of open flames in fireplaces or from lamps fuelled by coal gas, whale oil, or kerosene. It also made homes more secure and streets safer to travel after dark

Learning Objectives

After reading this unit ,the student will be able to:

1. Discuss the nature of light (natural and artificial)
2. Define the terms associated with light: a point source, solid angle , Mean Spherical Candle Power **,** luminous flux, luminous intensity, illuminance, luminance and luminance efficacy.
3. Calculate illumination and luminance at a given a point using the laws of illumination and as well as polar curves.
4. Identify the various lighting schemes employed in lighting design
5. Explain the principle of operation of various light sources used in lighting design.

Unit content

Session 1-1: Light

1-1.1 Nature of light
1-1.2 Sensitivity of the eye
1-1.3 Definition of common terms associated with light

Session 2-1: Laws of illumination.

2-1.1 : Inverse square law
2-1.2 : Lambert's Cosine law

Session 3-1: Polar curves.

3-1.1 General
3-1.2 : Horizontal Polar curve
3-1.3 : Vertical Polar curve

Session 4-1: Lighting Scheme.

4-1.1 : Direct lighting Scheme.
4-1.2 : Indirect lighting Scheme.
4-1.3 : Semi-Direct lighting Scheme.
4-1.4 : Semi-Indirect lighting Scheme.

Session 5-1: Lighting Sources.

SESSION 1-1: LIGHT

1-1.1 Nature of light

Light may be considered as electromagnetic waves of certain frequencies which can be detected by the human eye and converted into sensory perceptions, so that we see. . It is a form of energy which is radiated by bodies whose temperatures are increased. The radiant energy is necessarily a wave motion which is propagated in a medium in a manner similar to that of an electromagnetic wave. The velocity of propagation in a medium is 3×10^8 m/s which is constant, but the wavelength is different.. At temperatures of about 3000^{o}C (temperature at which incandescent lamps work, the wavelength of radiation is in the order of 0.4×10^{-6}m to 0.7×10^{-6}m (based on the frequency of the radiation of $10^{14} Hz$). It must be noted that only waves which have wavelengths between 0.4×10^{-6}m to $0.7.5 \times 10^{-6}$m can produce the sensation of sight.

The colour of light is determined by the wave length of its electromagnetic waves. White light contains all the colours of the spectrum..We see an object to be of a given colour because it reflects that colour component of the light source and absorbs the other colours.

For example, we see red rose as red because it reflects the red components of the light from the sun or an artificial light source. The non red components of the light are absorbed and have no effect .If a light source does not emit light of a particular wavelength , light of that wavelength cannot be reflected and the corresponding colour does not appear. Colours that can be produced by a white light are red , orange ,yellow green, blue and violet.

Table 1.1 gives the corresponding wavelengths of the colours in a white light.

Table 1.1. Wavelengths of colours in a visible light

	Wavelength in A° $\left(10^{-10}m\right)$	Colour
1	4000	Violet
2	4750	Blue
3	5500	Green
4	6000	Yellow
5	7000	Red

1-1.2 Sensitivity of the eye.

The wavelength which can produce the sensation of sight lies between 4000 A° and 7000 A°. The sensitivity of the eye to lights of different wavelengths varies from person to person and according to age. The eye is most sensitive for a wavelength of 5500 A° which corresponds to the wavelength of yellow green. Fig 1.1 shows the sensitivity of the normal human eye at different wavelengths of light.

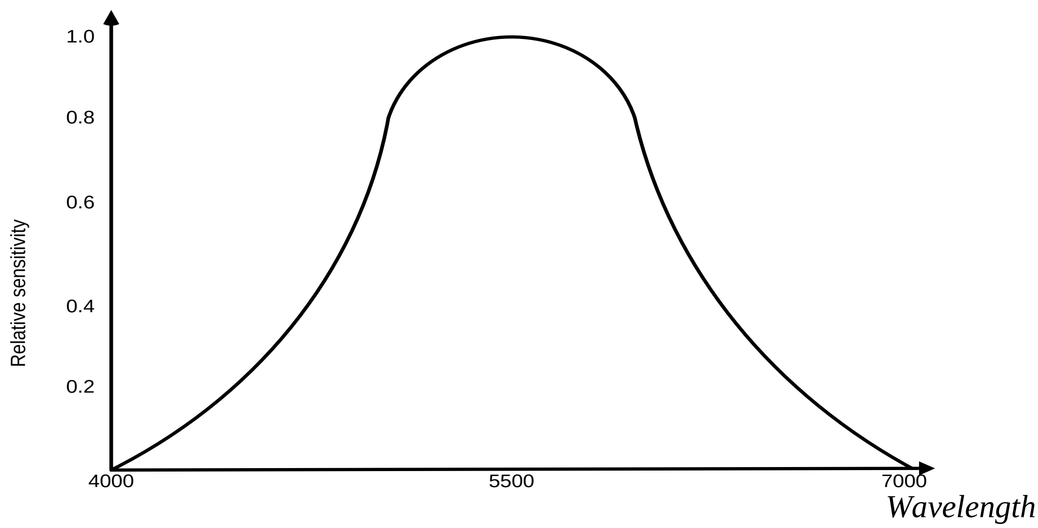


Fig 1.1 Relationship **between** wavelength and *sensitivity*

1-1.3 Definitions of common terms associated with light.

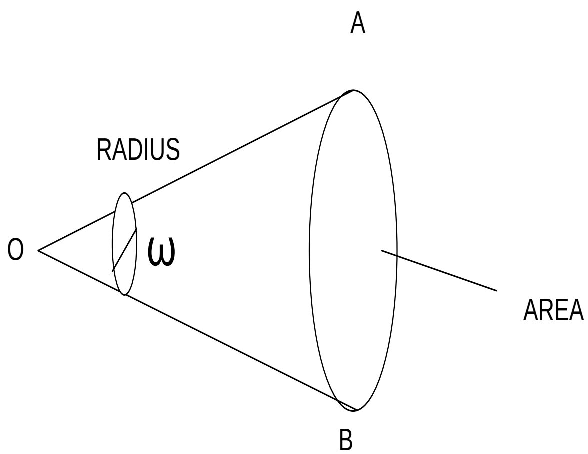
The quantities that are often used in lighting are Point source, Solid angle, luminous flux, Luminous intensity, luminance, and luminance. The definition of each of these quantities and the corresponding units are given below.

Point source: A point source of light is a source which can, with sufficient accuracy, be described as concentrated at a point. The nearest approach is the star seen from the earth.

Solid Angle

The angle subtended at a point in space by an area, is termed as solid angle. In plane angle, it is the area which is enclosed by two lines, but in case of solid angle, it is the volume which is enclosed by numerous lines lying on the surface and meeting at a point. The solid angle in steradian ω of a surface is a numerically equal to the projected area on a sphere centered at that point divided by the square of radius of the sphere.

$$Solid\,angle, \omega = \frac{Area}{Radius^2} = \frac{A}{R^2} \tag{1.1}$$



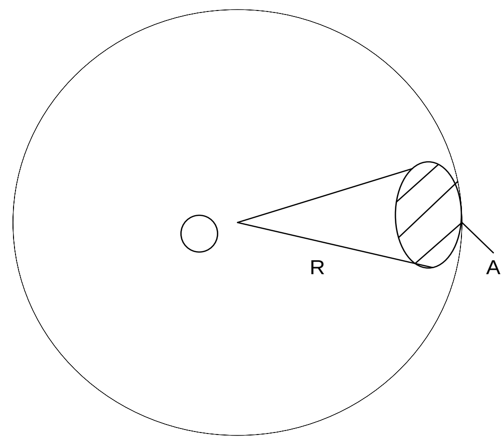


Fig 1. 2 (a) A representation of a solid angle Fig 1.2 (b) A spheres having a point light source at the centre

A solid angle is represented in fig 1.2 and it is usually denoted by ω and steradian is a measure of a solid angle. Since total surface area of a sphere of a radius $R\ is = 4\pi R^2$, the total solid angle subtended by points in view of equation (1.1) is given as

$$\omega = \frac{4\pi R^2}{R^2} = 4\pi \tag{1.2}$$

Luminous Flux – It is defined as the energy in the form of light waves radiated per second from a luminous body. It is therefore the total light power radiated in all direction by a light source. The unit of luminous flux (Φ) is ***lumens*** (lm)

Luminous Intensity – It is the luminous flux emitted per unit of solid angle in a given direction. It therefore the energy in the form of light waves radiated per second per unit of solid angle in a given direction from a luminous body.

Consider a point source of light O. Let dF be luminous flux crossing any section of a narrow cone of solid angle $d\omega$ steradians. The apex of the cone so formed is at the source. Then the luminous intensity in the direction of the cone is the ratio of the flux dF to the solid angle $d\omega$ or may be defined as the flux emitted by a source per unit solid angle.

$$I = \frac{dF}{d\omega} \tag{1.3}$$

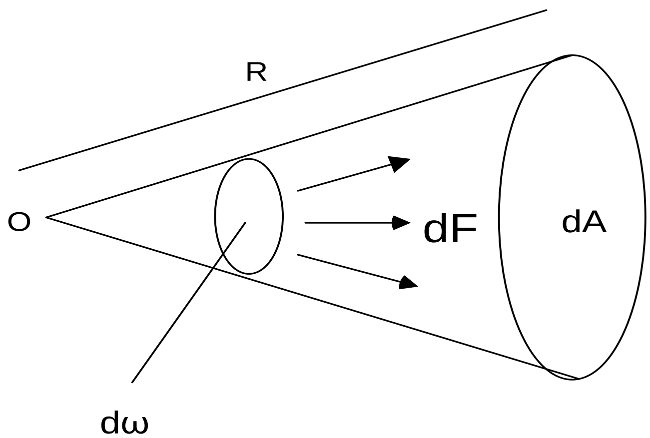


Fig 1.3 Point source of light emerging luminious flux

The unit of luminous intensity (I) is the ***candela***

Lumens is a unit of flux and is defined as the luminous flux per unit solid angle from a source of 1 candle power.

$$Lumens = Candle\,Power \times Solid\,angle = C.P \times \omega. \tag{1.4}$$

The total flux emitted by the source of 1 C.P in sphere is 4π lumens

Illuminance or Illumination.

When a light falls on a surface it is illuminated. The illuminance may be defined as the luminous flux received per unit area. If the incident flux on a small area dA is dF , then

Illuminance (E) = $\frac{dF}{dA} = \frac{Lumens}{Area} \quad (lux)$ (1.5)

In view of equation (1.4) , equation (1.5) can be written as

Illuminance (E) = $\frac{dF}{dA} = \frac{C.P \times \omega}{Area} \quad (lux)$ (1.6)

From eqn (1.1), $Solid\,angle, \omega = \frac{Area}{Radius^2} = \frac{A}{R^2}$ then

$$Illu\min ance = \frac{dF}{dA} = \frac{C.P \times \omega}{Area} = \frac{C.P \times Area}{Area \times R^2} = \frac{C.P}{R^2} \tag{1.7}$$

where R is the distance between the area and the point where the solid angle is formed.

The physical process for which illuminance is defined is known illumination. For ordinary calculation of illumination, equation (1.5) may be replaced by the average illuminations, ie

$$E_{AV} = \frac{\Phi}{A} \quad (lux) \tag{1.8}$$

Luminance (Brightness)*:* It is the luminous intensity per m^2 of the illuminated area. It is also defined as luminous intensity per unit projected area of a surface in a direction perpendicular to the source.

The corresponding unit is $Candle\,per\,m^2$ and is commonly represented by the letter L

If the illumination of a surface produced by a light source is $E \; {}^{lm}\!/\!{}_{m^2}$ and ρ is it reflectance coefficient, then

$$\Phi = \rho EA \quad lumens \tag{1.9}$$

If L is the luminance at the point then the flux passing through the diffused reflecting surface is can be expressed as

$$\Phi = \pi LA \quad lumens \tag{1.10}$$

Therefore from equations $(1.9)\, and\, (1.10)$

$$\Phi = \rho EA = \pi LA \quad \Rightarrow L = \frac{\rho EA}{\pi A} = \frac{\rho E}{\pi}$$

Hence luminance , $L = \dfrac{\rho E}{\pi}$ (1.11)

We know from experience that the same luminous flux falling on a table and on a sheet of paper on the table has different luminance effect. This is due to the different characteristics of wood and paper .Thus the total luminous flux falling on a body is the $lumens/m^2$ irrespective of the reflection characteristics of the body, whereas the luminance varies with the reflection characteristics.

Mean Spherical Candle Power (M.S.C.P)

It is the mean or average of the candle power (C.P) in all directions in all planes

$$M.S.C.P = \frac{Total\ flux\, in\, lumens}{4\pi} \tag{1.12}$$

Mean Horizontal Candle Power (M.H.C.P)

It is the mean or average of the candle power (C.P) in all directions on a horizontal plane which passes through the source.

Mean Hemispherical Candle (M.H.S.C.P)

It is the mean or average of the candle power (C.P) in all directions within a hemisphere either above a horizontal plane or below a horizontal plane .

$$M.H.S.C.P = \frac{Flux\, emitted\, in\, a\, hemisphere}{2\pi} \tag{1.13}$$

Luminous efficacy (efficiency)*:* Consider an incandescent lamp as a luminous body. The whole of the electrical power supplied to the lamp is not changed into luminous flux; some of the power is lost by heat conduction, heat convection and absorption. Of the radiant flux only a fraction is in the form of light waves which lies in between the visual range of wavelengths i.e. between 4000A^o and 7000 A^o

If we want to judge the economic efficiency of a light source it is interesting to know what proportion of the electrical power supplied to the light source is converted into light power. *Luminous efficiency* indicates the luminous flux which is generated in relation to the electrical power which is expended in generating it.

Luminous efficacy, $$\eta = \frac{\Phi}{p} = \frac{lm}{W} \tag{1.14}$$

For example, a general purpose incandescent lamp rated 100W which generates a luminous flux of 230 lumens has a luminous efficacy of $\frac{230}{100} = 2.3\frac{lm}{W}$

Table 1.2 gives the appropriate overall efficiency of incandescent tungsten and fluorescent lamps

Table 1.2 Luminous efficiencies of incandescent, tungsten and fluorescent lamps

Tungsten Lamp			*Fluorescent*			
Power Input	*Luminous Flux*	*Efficacy*	*Power Input*	*Luminous Flux*	*Length in cm.*	*Efficacy*

in watts	*in Lumens*	*In Lumens per Watts*	*in watts*	*in Lumens*		*In Lumens per Watts*
10	80	8.0	4	75	15.25	18.75
40	460	11.5	8	325	30.50	40.63
60	840	14.0	20	950	16.24	47.50
100	1630	16.3	30	1500	91.50	50.00
200	3660	18.3	40	2300	122.00	57.50
500	9250	19.9	100	4400	183.00	44.00

WORKED EXAMPLES 1-1

Example 1.

A lamp having a mean spherical candle power of 800 is suspended is suspended at a height of 20 metres. Calculate a) the total flux of the light b) the illumination just below the lamp

Solution 1

The total solid angle subtended by a point source in a sphere is given as $\omega = \frac{4\pi R^2}{R^2} = 4\pi$.

But $Mean\,Spherical Candle\,Power = \frac{The\,total\,lines\,of\;\;flux}{The\,solid\,angle} = 800$

Hence the total line of flux supplied = 800×4π=10053.94 lumens

Example 2.

When a 250 V lamp takes a current of 0.8 amperes it produces a total flux of 3250 lumens .

Calculate (a) MSCP of the lamp b) the efficacy of the lamp.

Solution 2

a) $Mean\,Spherical\,Candle\,Power = \dfrac{The\,total\,lines\,of\;\;flux}{The\,solid\,angle} = \dfrac{3250}{4\pi} = 258.63$

$b)Efficacy\,of\;\;the\,lamp = \dfrac{lumens\,radiated\,by\,lamp}{total\,electrical\,power\,supplied\,to\,lamp} = \dfrac{lumens}{power} = \dfrac{3250}{250\times 0.8} = 16.25\dfrac{lm}{W}$

Self Assessment 1-1

1. Determine the frequencies of the colours at the extreme ends of the spectrum of visible light.

$Hint \quad f = \dfrac{v}{\lambda}$

2. Explain why road construction workers at work in the night wear yellowish greenish uniform.

3. a) Define the following terms and the units in which they are measured:

i) Luminous intensity ii) Luminous flux iii) luminance

b) A metal filament gas filled lamps takes 0.42 A from a 230 –V supply and emits 1120 lm.

Calculate i) the number of lumens per watt ii) the mean spherical luminous intensity (MSCP)

of the lamp and iii) the mean spherical luminous intensity (MSCP) per watt.

$Ans: 11.6\dfrac{lm}{W};\;\; 89.2\,cd;\;\; 0.923\,{cd}/{W}$

4. Six lamps are used to illuminate a certain room .If the luminous efficacy of each lamp is 11 lm / W and the lamps have to a total of 10000 lumens calculate a) MSCP per lamp and b) cost of energy consumed in 4hrs if the charge for electrical energy is 52 pesewas/ kWh

$Ans: 32cd; 18.92p$

5. A filament lamp is enclosed in a fitting that absorbs 25 percent of the light flux from the lamp and distribute the remainder uniformly over the lower hemisphere. The lamps may be assumed to have luminous efficacy of 12 lm / W. The fitting is suspended 2m above the centre of a horizontal surface 3m square. Determine the necessary rating (in watts) of the lamp if no point on the horizontal surface is to have an illuminance less than 18 lux .Reflected light from other surfaces may be neglected. $Ans: 155.5W; 55.7lx$

SESSION 2-1: LAWS OF ILLUMINATION

2-**1.1** Inverse square law

Consider a point source of light S as shown in fig1.4. Let within a solid angle ω three parallel surfaces of areas A_1 ,A_2 and A_3 be placed at a distance *d* , *2d* and *3d* from a source one by one as shown . Let I be the intensity of illumination of the source in that direction.

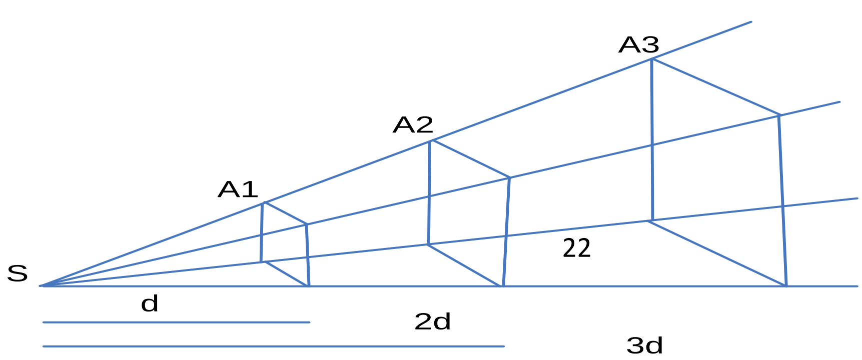


Fig 1.4 Illustration of inverse square law

The total flux on the areas A_1 ,A_2 and A_3 is the same and is given by

For area A_1, $F_1 = I\omega$ lumens

But solid angle for area A_1 is $\omega = \frac{A_1}{d^2}$ => $F_1 = \frac{I\,A_1}{d^2}$ (1.15)

In view of eqn (4), E_1 can be written as

$$E_1 = \frac{F_1}{A_1} = \frac{I\,A_1}{d^2} \times \frac{1}{A_1} = \frac{I}{d^2} \quad (1.16)$$

Also for area A_2, the solid angle, $\omega = \frac{A_2}{(2d)^2}$ and therefore

$$E_2 = \frac{I\,A_2}{(2d)^2} \times \frac{1}{A_2} = \frac{I}{(2d)^2} \quad (1.17)$$

Similarly, illumination on A_3, $E_3 = \frac{I}{(3d)^2}$ (1.18)

Thus illumination of areas A_1 ,A_2 and A_3 are in the ratio

$$E_1 : E_2 : E_3 = \frac{I}{d^2} : \frac{I}{(2d)^2} : \frac{I}{(3d)^2} \quad (1.19)$$

Hence the illumination of a surface is inversely proportional to the square of the distance of the surface from the source of light. This is based on the assumption that the light source is a point source.

2-1.2 Lambert’s cosine law

While discussing the inverse square law it was presumed that the surface was normal to the light flux, but in practice this is not always possible. The illumination for such case is given by Lambert's cosine law. Let, F be the total light flux falling on the area.

Thus in fig 1.5 (a) the angle between normal to the surface and the line of flux is zero.

Intensity of illumination $E_0 = \frac{F}{AREA_{\ ABCD}}$. (1.20)

In fig 1.5 (b) , the angle between the line of flux and normal is Θ

Intensity of illumination $E_\Theta = \frac{F\ Cos\Theta}{AREA_{\ abcd}}$. (1.21)

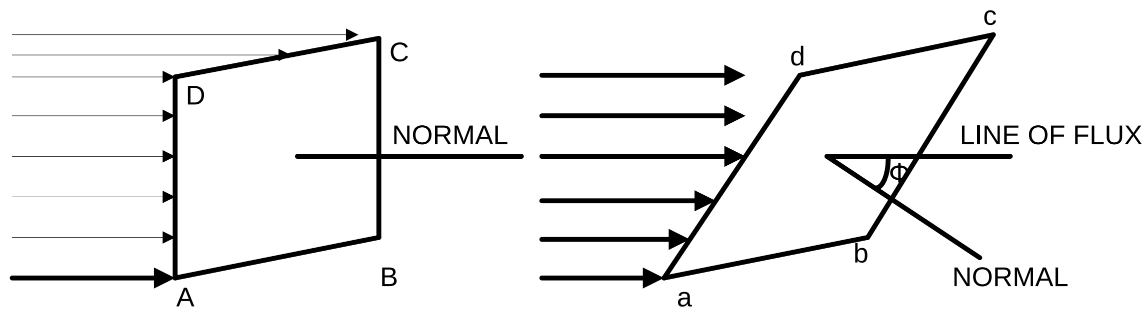


Fig 1.5 Illustration of Lambert's cosine law

Thus it will be observed that the illumination is proportional to the cosine of the angle between the normal and the line of the flux.

The above results can also be represented in a different form as shown in fig (1.6) below.

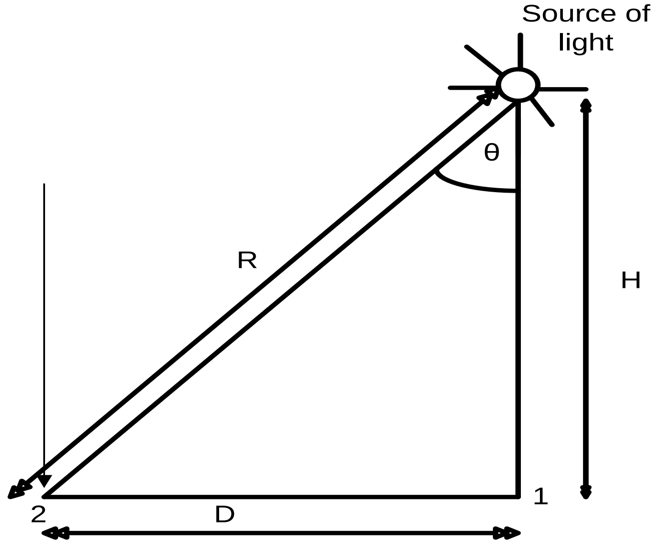


Fig 1.6 Illustration of Lambert's cosine law (Cos^3 θ)

Suppose the luminous intensity of the light source is I candela, then illumination radiated by the light source at point 1 is given as

$$E_1 = \frac{I}{H^2} \tag{1.22}$$

The illumination radiated by the light source at point 2 is given as

$$E_2 = \frac{I}{R^2} \times \text{Cos } \theta \tag{1.23}$$

But Cos θ = $\frac{H}{R}$. Therefore eqn(1.17) can be rewritten as

$$E_2 = \frac{I}{R^2} \times \text{Cos } \theta = \frac{I}{R^2} \times \frac{H}{R} = \frac{I}{R^2} \times \frac{H^2}{H^2} \times \frac{H}{R} = \frac{I}{R^3} \times \frac{H^3}{H^2}$$

$$= \frac{I}{H^2} \times \text{Cos}^3 \theta \tag{1.24}$$

This is also known as Cos^3 θ law. The law can be stated as

The illumination of any surface at any point is dependent upon the cube of cosine of the angle between the line of the flux and the normal at that point.

WORKED EXAMPLES 2-1

Example 1.

A lamp of 500 candle power is placed in the centre of a room 20m× 10m×5m.

Calculate the illumination in each corner of the floor and a point in the middle of a 10m wall at height 2m from the floor .

Solution 1

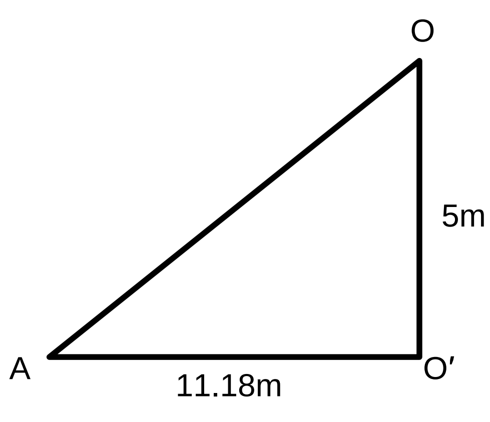
Fig 1.18 shows the position of the lamp in a room . Lamp is placed at O and O'is the position , just below the lamp. The diagonal length of the room AC $=\sqrt{20^2+10^2}$ $=\sqrt{400+100}$ = $\sqrt{500}$ =22.36. Length A Ocentre'= $^1/_2$ AC = 11.18m

The length from where the lamp is suspended O to corner A , AO $=\sqrt{AO"^2+OO"^2}$

$=\sqrt{11.18^2+5^2}=\sqrt{125+25}$ = 12.25m

Let Φ be the angle between the normal on the floor and the line flux

Therefore Cos Φ = $\frac{OO"}{OA} = \frac{5}{12.25} = 0.408$



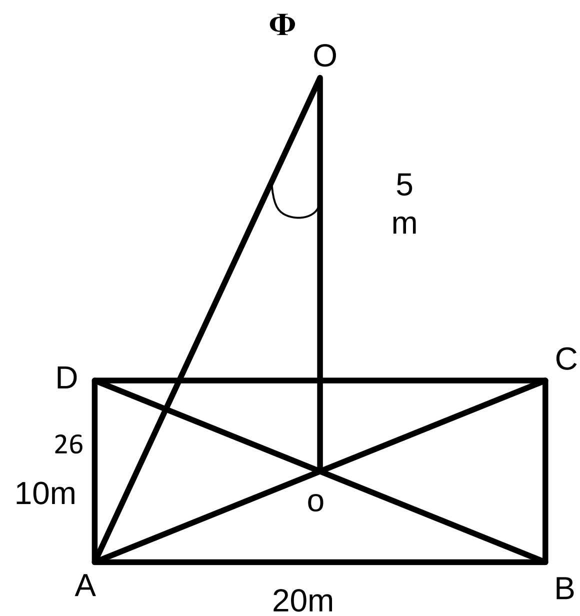


Figure 1.18. To illustrate Example 3

The illumination in each corner in view of eqn.(1.23) $=\frac{C.P}{R^2} \times Cos\mathbf{\Phi} = \frac{500}{12.25} \times 0.408 = 1.361$ *lux*

b) Let P be the point (at a distance of 2m from the bottom) where the illumination is required

Length P O $=\sqrt{10^2+3^2} = \sqrt{100+9} = \sqrt{109}$ = 10.44m

The illumination at that point P will be proportional to the cosine of the angle between the line of the flux and normal at that point

Cos $\mathbf{\Phi} = \frac{10}{10.44} = 0.955$

∴ The illumination at point P $= \frac{C.P}{R^2} \times Cos\mathbf{\Phi} = \frac{500}{10.44} \times 0.955 = 4.38$ *lux*

Example 2.

A lamp giving 300 candle power in all direction below the horizontal is suspended 2m above the centre of a square table of 1 metre side. Calculate the maximum and minimum illumination on the table

Solution 2

The maximum will occur directly under the lamp and minimum illumination will occur at a corner .

The of a diagonal of a square table of sides 1 m $=\sqrt{1^2+1^2} = \sqrt{2}$ =1.414 m

Length of half of the diagonal = $1/2 \times 1.414 = 0.707$

a) Maximum illumination = $\frac{C.P}{R^2} = \frac{300}{2^2} = 75$ *lux*

b) The distance between lamp and corner $=\sqrt{2^2+0.707^2}=\sqrt{4.5}=2.121$ m

c) Let Θ be the angle between the normal on the floor and the line flux

$\therefore \quad \Theta = \frac{2}{\sqrt{4.5}} = \frac{2}{2.121} = 0.943$

$\therefore$ Illumination at a corner $= \frac{300}{\sqrt{4.5^2}} \times \text{Cos } \Phi = \frac{300}{\sqrt{4.5^2}} \times 0.943 = 62.87\ lux$

Example 3

Two lamps of 200 candle power and 400 candle power are arranged as shown below in fig 1.19.

Calculate the illumination at the point between the lamps.

Solution 3

a) Illumination at a point P due to the lamp A = $\frac{C.P}{R^2} \times Cos\boldsymbol{\Theta}_1$

But length AP $=\sqrt{15^2+50^2}=\sqrt{225+2500}=\sqrt{2725}=52.20$m

$Cos\boldsymbol{\Theta}_1 = \frac{15}{52.20} = 0.2873$

$\therefore$ Illumination at point P due to lamp A = $\frac{C.P}{R^2} \times Cos\boldsymbol{\Theta}_1 = \frac{200}{52.20^2} \times 0.2873 = 0.0211\ lux$

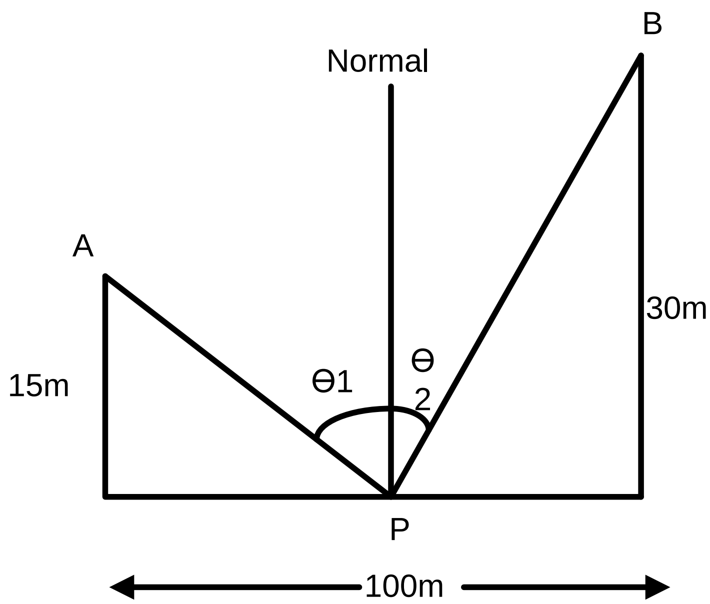


Fig 1.19

Illumination at a point P due to the lamp B = $\frac{C.P}{R^2} \times Cos\theta_2$

But length BP =$\sqrt{30^2+50^2}$ =$\sqrt{900+2500}$= $\sqrt{3400}$ =58.31m

$Cos\theta_2$ = $\frac{30}{58.31}$ =0.515

∴ Illumination at point P due to lamp B = $\frac{C.P}{R^2} \times Cos\theta_2 = \frac{400}{58.3^2} \times 0.515$ =0.0515 *lux*

∴ Total Illumination at point P due to lamps A and B = 0.0211+0.0515 =0.0817 *lux*

Example 4

A hypothetic lamp has a candle power of 100 measured in any direction below the horizontal plane through the centre of the lamp and zero above the plane . Draw the vertical polar curve. What is the output of the lamp in lumens?. Calculate the intensity of the illumination on a horizontal surface 3.048 m below the lamp at point 4.572m away from the vertical plane through the lamp

Solution 4

The candle power in the plane above the lamp is zero is uniformly distributed in the lower hemisphere ie below the lamp. Its vertical plane curve will be semi-circle with radius 100 C.P as

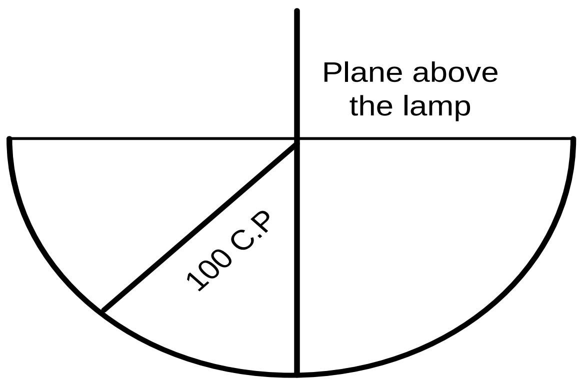


Figure 1.20

For calculating the intensity of the illumination at a distance 4,572 m from the lamp in a horizontal direction make out the arrangement as shown in fig 1.21

In view of eqn (1.24)

Illumination at C $=\frac{C.P}{(AH)^2} \times \text{Cos}^3\,\theta = \left(\frac{100}{(3.048)^2} \times \frac{3.048}{\sqrt{3.048^2+4.573^2}}\right)^3 = 1.837$ lumens/m^2

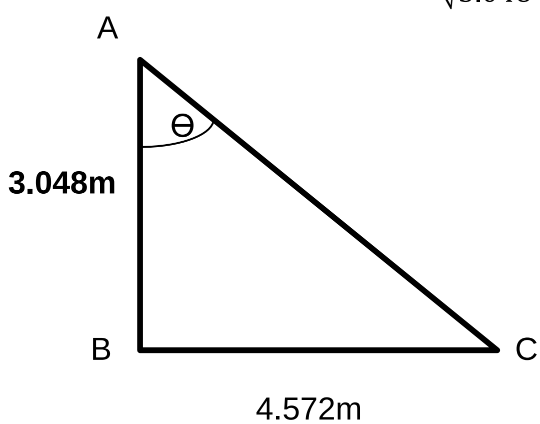


Fig 1.21

Example 5

Along the centre line of a corridor, number of lamps is fitted with reflectors. The distance between the two adjacent lamps is 7.5 metres and the height of each lamp from the floor is 5 metres. The candle power of each is 100 in all directions below the horizontal .Determine the maximum and minimum illumination along the centre line and draws a graph showing the variation of the illumination along this line between the two lamps.

Solution 5

Consider that there are 5 lamps fitted in the corridor as shown in Fig 1.22.

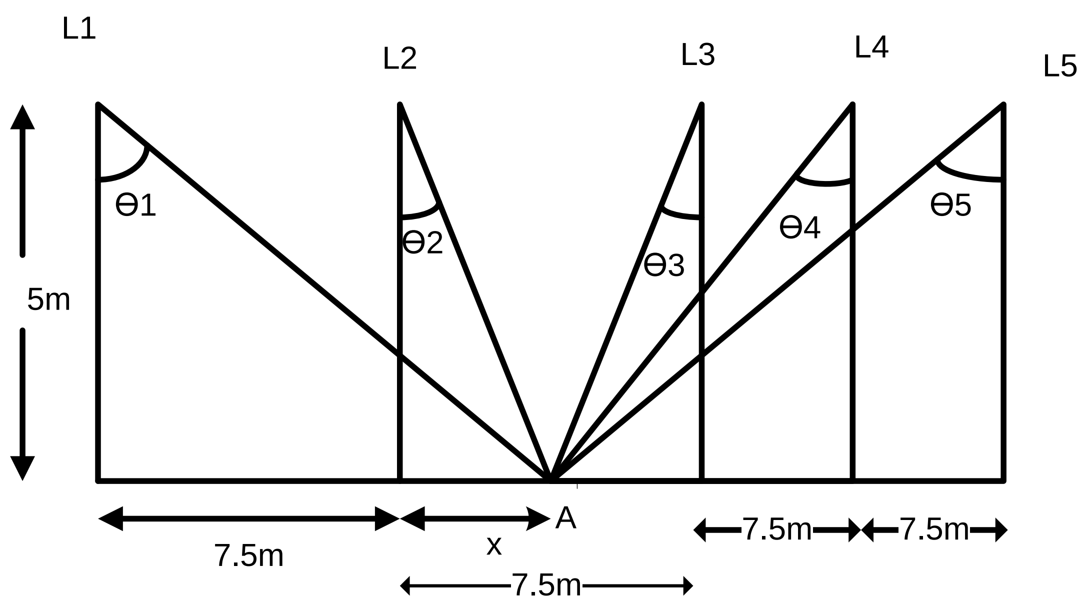


Fig 1.22

Now on any point A , which is x metres away from point lamp L_2 , the illumination due to these lamps will be given as :

Due to L_1 $= \frac{C.P}{R^2} \times Cos^3\ \boldsymbol{\Theta_1} = \frac{100}{5^2} \times Cos^3 \boldsymbol{\Theta_1}$

Due to L2 $= \frac{C.P}{R^2} \times Cos^3\ \boldsymbol{\Theta_2} = \frac{100}{5^2} \times Cos^3\ \boldsymbol{\Theta_2}$

Due to L 3 $= \frac{C.P}{R^2} \times Cos^3\ \boldsymbol{\Theta_3} = \frac{100}{5^2} \times Cos^3\ \boldsymbol{\Theta_3}$

Due to L4 $= \frac{C.P}{R^2} \times Cos^3\ \boldsymbol{\Theta_4} = \frac{100}{5^2} \times Cos^3\ \boldsymbol{\Theta_4}$

Due to L5 $= \frac{C.P}{R^2} \times Cos^3\ \boldsymbol{\Theta_5} = \frac{100}{5^2} \times Cos^3\ \boldsymbol{\Theta_5}$

Therefore the total illumination at point A

$= 4(\ Cos^3\ \boldsymbol{\Theta_1} + Cos^3\ \boldsymbol{\Theta_2} + Cos^3\ \boldsymbol{\Theta_3} + Cos^3\ \boldsymbol{\Theta_4} + Cos^3\ \boldsymbol{\Phi_5})$ (1.25)

Now tan $\boldsymbol{\Theta_1} = \frac{7.5+x}{5}$

tan $\boldsymbol{\Theta_2} = \frac{x}{5}$; tan $\boldsymbol{\Theta_3} = \frac{7.5-x}{5}$; tan $\boldsymbol{\Theta_4} = \frac{15-x}{5}$; tan $\boldsymbol{\Theta_5} = \frac{22.5-x}{5}$

$$\frac{dtan\boldsymbol{\Theta_1}}{dx} = \frac{dtan\boldsymbol{\Theta_1}}{d\boldsymbol{\Theta_1}} \times \frac{d\boldsymbol{\Theta_1}}{dx} = Sec^2\boldsymbol{\Theta_1} \times \frac{d\boldsymbol{\Theta_1}}{dx} = \frac{1}{5}$$

$$\Rightarrow \frac{d\boldsymbol{\Theta_1}}{dx} = \frac{1}{5} \times Cos^2\ \boldsymbol{\Theta_1}$$

$\frac{d\boldsymbol{\Theta_2}}{dx} = \frac{1}{5} \times Cos^2\ \boldsymbol{\Theta_2}$; $\frac{d\boldsymbol{\Theta_3}}{dx} = -\frac{1}{5} \times Cos^2\ \boldsymbol{\Theta_3}$; $\frac{d\boldsymbol{\Theta_4}}{dx} = -\frac{1}{5} \times Cos^2\boldsymbol{\Theta_4}$

$\frac{d\boldsymbol{\Theta_5}}{dx} = -\frac{1}{5} \times Cos^2\ \boldsymbol{\Theta_5}$ The illumination at any point will be maximum when $\boldsymbol{\frac{dI}{dx} = 0}$.

Therefore differentiating eqn (1.25) and equating it to be zero we get

$=4\times3(\ Cos^2\boldsymbol{\Theta_1} sin\boldsymbol{\Theta_1}\frac{d\boldsymbol{\Theta_1}}{dx} + \ Cos^2\boldsymbol{\Theta_2} sin\boldsymbol{\Theta_2}\frac{d\boldsymbol{\Theta_2}}{dx} + \ Cos^2\boldsymbol{\Theta_3} sin\boldsymbol{\Theta_3}\frac{d\boldsymbol{\Theta_3}}{dx} + Cos^2\boldsymbol{\Theta_4} sin\boldsymbol{\Theta_4}\frac{d\boldsymbol{\Theta_4}}{dx} +$

$Cos^2\boldsymbol{\Theta_5} sin\boldsymbol{\Theta_5}\frac{d\boldsymbol{\Theta_5}}{dx}\ )\quad \mathbf{= 0}$

Now when point A is midway between L_2 and L_3 then it is clear that $\boldsymbol{\Theta_1}=\boldsymbol{\Theta_4}$ and $\boldsymbol{\Theta_2}=\boldsymbol{\Theta_3}$ and so on .Therefore all the terms are cancelled out in pairs . This indicates that at this point there is either maximum or minimum illumination. But midway points between two lamps there can never be a maximum illumination, so it is the point of minimum illumination.

When the point A is directly below L_3 then $\boldsymbol{\Theta_3}=\mathbf{0}$, $\boldsymbol{\Theta_2}=\boldsymbol{\Theta_4}$ and $\boldsymbol{\Theta_1}=\boldsymbol{\Theta_5}$ **.** The term containing $\boldsymbol{\Theta_3}\ =\ \mathbf{0}$ and all other terms cancel out each other in pairs. Hence the point of maximum illumination is below lamp L_3.

Now consider this condition $\boldsymbol{\Theta_3}=\mathbf{0}$, $\boldsymbol{\Theta_2}=\boldsymbol{\Theta_4}= \tan^{-1}\frac{7.5}{5} = \tan^{-1} 1.5 = 51^o\ 20$.

$\boldsymbol{\Theta_1}=\boldsymbol{\Theta_5}= \tan^{-1}\frac{15}{5} = \tan^{-1} 3 = 71^o\, 31.$

$Cos^3\boldsymbol{\Theta_3}=\mathbf{1}$; $Cos^3\boldsymbol{\Theta_2}=\ Cos^3\boldsymbol{\Theta_4}=\ Cos^3 51.20=(0.6247)^3= 0.243$

$Cos^3\boldsymbol{\Theta_1}=\ Cos^3\boldsymbol{\Theta_5}=\ Cos^3\ 71.31= (0.3170)^3= 0.032$

∴ Maximum illumination due to 5 lamps in view of equation 1.25

$=4(\ Cos^3\ \boldsymbol{\Theta_1}+Cos^3\ \boldsymbol{\Theta_2} + Cos^3\ \boldsymbol{\Theta_3} + Cos^3\ \boldsymbol{\Phi_4}+Cos^3\ \boldsymbol{\Phi_5})$

$= 4(2\times0.243 +2 \times 0.032 + \mathbf{1})\ = 6{,}200$ m camdle

The minimum illumination due to 5 lamps is at the point midway between the lamp L_2 and L_3 and for this $\boldsymbol{\Theta_1}=\boldsymbol{\Theta_4}= \tan^{-1}\frac{11.25}{5} = 66.20^o$.

$Cos^3\boldsymbol{\Theta_1}=\ Cos^3\boldsymbol{\Theta_4}=\ Cos^3 66.20= (0.4064)^3= 0.067$

$\mathbf{\Theta_2}$=$\mathbf{\Theta_3}$= $\tan^{-1}\frac{7.5}{2\times 5}$ =$\tan^{-1}$0.75 = 36.87^o .

$Cos^3\mathbf{\Theta_{2=}}$ $Cos^3\mathbf{\Theta_{3=}}$ $Cos^3$36.87=(0.799)^3= 0.512

$\mathbf{\Theta_5}$= $\tan^{-1}\frac{18.75}{5}$ = $\tan^{-1}3.75 = 75.4$ ^{o}

$Cos^3\mathbf{\Theta_{5=}}$ $Cos^3$75.4 = (0.2577)^3= 0.017.

The minimum illumination due to 5 lamps is in view of equation (1.25) is given as

= 4(2×0.067 $+2\times 0.512+\mathbf{0.017}$) = 4.7 m camdle

At point midway between minimum and maximum illumination point in view of equation (1.25) is given as

$\mathbf{\Theta_1}$= $\tan^{-1}\frac{15.0-1.875}{5}$ = $\tan^{-1}\frac{13.125}{5}$=$\tan^{-1}\frac{13.125}{5}$=69.14 ^{o}

$Cos^3\mathbf{\Theta_{1=}}$ $Cos^3$69.14= (0.356)^3= 0.0451

$\mathbf{\Theta_2}$= $\tan^{-1}\frac{7.5-1.875}{5}$ =$\tan^{-1}\frac{5.625}{5}$ = 48.37^o .

$Cos^3\mathbf{\Theta_{2=}}$ $Cos^3$48.37=(0.664)^3= 0.2932

$\mathbf{\Theta_3}$= $\tan^{-1}\frac{1.875}{5}$ = $\tan^{-1}0.375 = 20.55$ ^{o}

$Cos^3\mathbf{\Theta_3}$ = $Cos^3$20.55 = (0.936)^3= 0.821.

$\mathbf{\Theta_4}$= $\tan^{-1}\frac{7.5+1.875}{5}$ = $\tan^{-1}\frac{9.375}{5}$ = $\tan^{-1}$1.875 = 61.93^o .

$Cos^3\mathbf{\Theta_{4=}}$ $Cos^3$61.92=(0.470)^3= 0.1042

$\mathbf{\Theta_5}$= $\tan^{-1}\frac{15.0+1.875}{5}$ = $\tan^{-1}\frac{16.875}{5}$ = $\tan^{-1}$3.375=73.49 ^{o}

$Cos^3\mathbf{\Theta_5}$ = $Cos^3$73.49 = (0.2840)^3= 0.02292

The illumination midway between minimum and maximum illumination points given as

== 4(0.0451 +0.2932 + 0.821 + 0.1042 + 0.02292) = 5,145 m camdle

The graph showing the variation of the illumination between the two lamps has been drawn as shown in fig 1.23

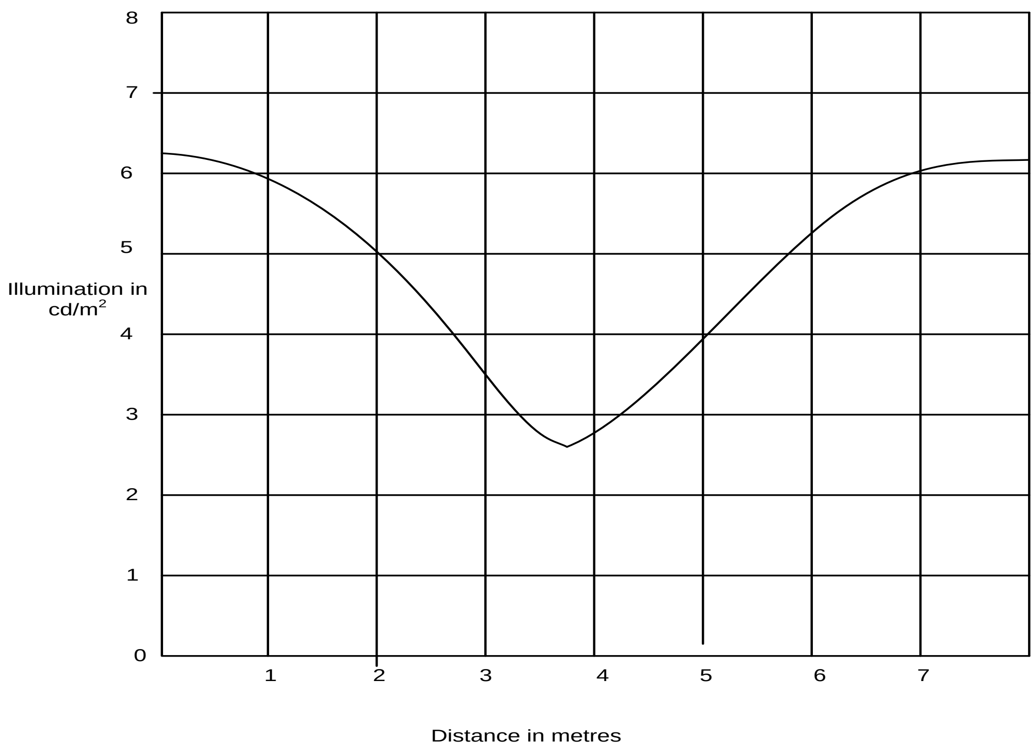


Fig 1.23

Self Assessment 2-1

1 Two lamps of 16 cd and 24 cd respectively are 2m apart. A screen is placed between them 0.8m from the 16cd. Calculate the illuminance on each side of the screen . Where must the screen be placed in order to be equally illuminated on both sides?.

2. A lamp giving 200cd in all direction below a horizontal is suspended 2m above the centre of a square table 1m side . Calculate the maximum and minimum illuminance on the side of the table.

3. Explain what is meant by luminous flux and define the units in which it is expressed.

A circular area of radius 6m is to be illuminated by a single lamp vertically above the circumference of the circle. The minimum illuminance is to be 6lx and the maximum illuminance 20lx. Find the mounting height in metres and the mean spherical luminous intensity of the lamp. Assume the luminous intensity to be uniform in all directions.

4. Four lamps are suspended 8m above the ground at the corners of a square 4m side. Each lamp gives 250cd uniformly below the horizontal plane. Calculate the luminance

a) on the ground directly under each lamp and b) at the centre of the square .

5. Two identical lamps each having luminous intensity in all directions below the horizontal are mounted at a height of 4m. Determine what the spacing of the supporters must be in order that the illuminance of the ground midway between the supporters shall be one and half of the illuminance directly beneath a lamp. (Hint: the simplest way of solving this problem is by assuming that that the illuminance directly under one lamp due to the other is negligible).

5 A 200cd lamp emits light uniformly in all direction and is suspended 5m above the centre of

of a working plane which is 7m square . Calculate the illuminance in lux, immediately below the lamp and also at each corner of the square. If the lamp is fitted with a reflector which distributes 60 percent of the light emitted uniformly over a circular area 5m in diameter, calculate the illuminance over this area.

SESSION 3-1: POLAR CURVES

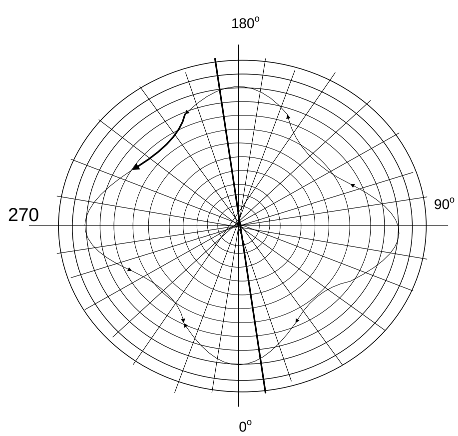
3-1.1 General

In practice and in almost every lamp or any other source of light, the luminous intensity in all the direction is not uniform. This is because of the shapes of the lamps. The luminous intensity in all directions can be represented by polar curves. A polar curve is a curve on the polar coordinates showing how the luminous intensity of a source varies with direction along the surface of a cone which has its apex at the source. The polar curves are drawn by taking the luminous intensities in various directions at an equal angular displacement in the sphere.

There are two different forms of Polar curves. These are .

3-1.2 Polar curves for horizontal plane.

It is the curve which represents the candle power of a source in horizontal plane. The candle power of the source is measured in the horizontal plane about a vertical axis for equal angular displacement and the curve obtained from the results is called polar curve for the horizontal plane.



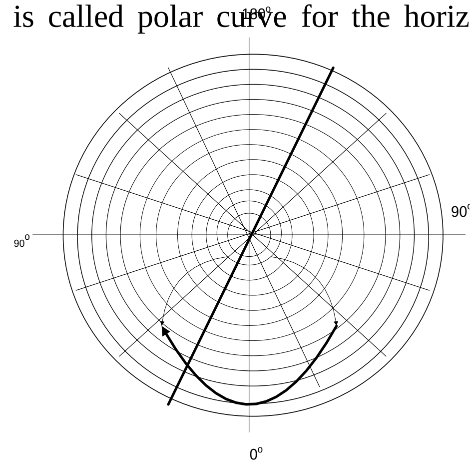


Fig 1.7 (a) Polar curve for straight type lamps in a horizontal plane

Fig 1.7(b) Polar curve for lamps with helmet type of reflectors in a horizontal plane

3-1.3 Polar curves for vertical plane.

These curves are drawn by measuring the candle powers of a source at an equal angular displacement in a vertical plane and about a vertical axis the type of such curves have been shown in fig 1.8.

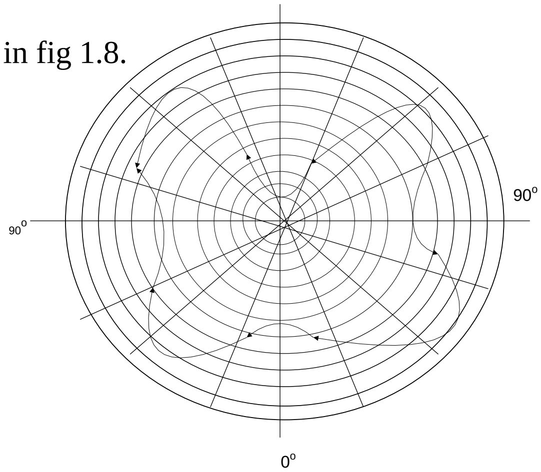


Fig 1.8(a) Polar curve in a vertical plane for tungsten lamps

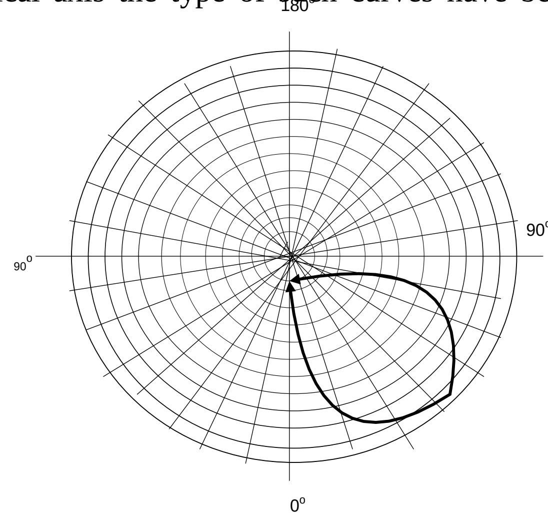


Fig 1.8 (b) Polar curve for lamps with helmet

Example 6

A streetlight is suspended at a height of 10m along the centre line at regular intervals of 24m. The polar curve of a lamp with its reflector can be obtained by the following table:

C.P	240	270	290	260	190	130	50	15
Angle to the vertical	0^o	10^o	20^o	30^o	40^o	50^o	60^o	70^o

Calculate the intensity of illumination between two lamps along the centre line and plot a graph of lux against distance in metres.

Solution 6

The polar curve is drawn as follows: with centre O, draw arcs to represent 50.100,150,200.250 and 300 C.P. From point O , draw radial lines making 0^o 10^o, 20^o, 30^o, 40^o , 50^o ,60^o and 70^o with the vertical (fig1.14). With centre O and a radius corresponding 270 C.P, draw an arc cutting 10^o line at Q . Thus Q corresponds to 10^o , 270 C.P. Similarly plot other points and draw a smooth curve through them, which will be the desired polar curve as shown in fig 1.24.

Figure 1.125 represents the two lamps with a horizontal distance between them which is divided into 8 equal parts. The illumination at point O will be due to L_1 and L_3 towards right and left of lamp L_1 . At point A, B, C, the effect of lamp L_2 has been neglected .

Illumination at point = $\frac{C.P}{d^2} \times COS\Theta$

Where d is the distance between the line of the ray and the point where illumination is to be obtained

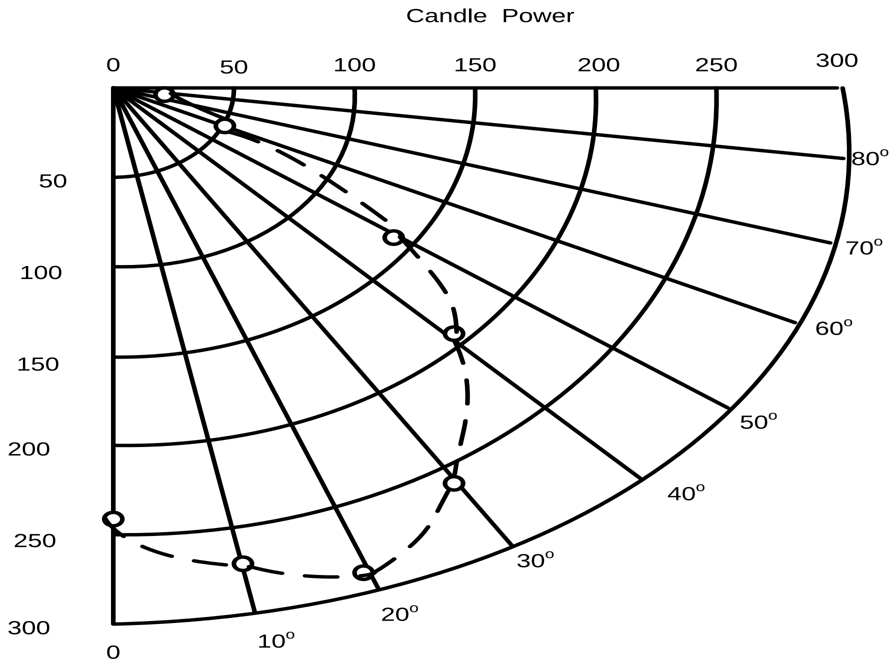


Fig 1.24 A polar curve from the given data

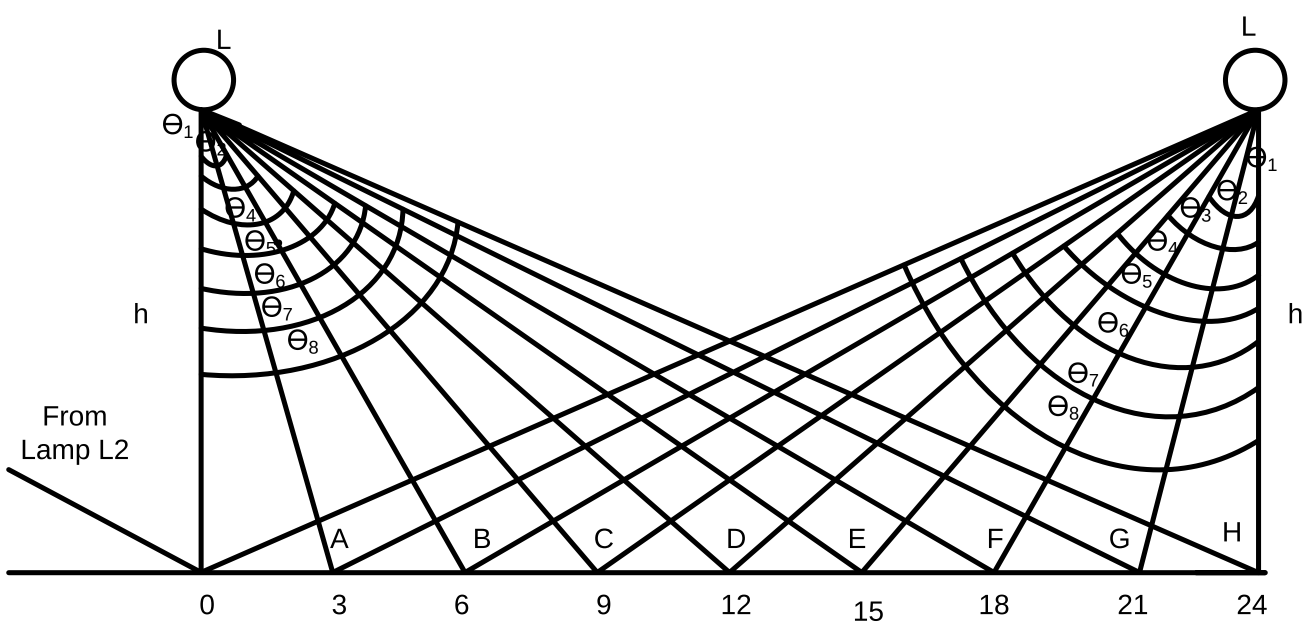


Fig 1.25

If h is the height of the lamp then

h $= d\ cos\Theta$ or d = $\frac{h}{cos\Theta}$

Illumination at a point $= \frac{C.P}{d^2} \times cos\boldsymbol{\Theta} = \frac{C.P}{h^2} \times cos^3\Theta$

The table 1.3 represent total illumination in lux at points O, A, B, C and D due to lamps L , L_1 and L_2 . The illumination a points E, F, G and J will be the same as that at points C, B, A and O.

Table 1.3

The point Under consideration	*The height of the lamp h metres*	*Lamp L*						
		Horizontal distance between the lamp and the point (H)	*tan*Θ $= \frac{H}{h}$	Θ / degrees	*C.P from curve*	cosΘ	$\cos^3\Theta$	*Illumination* $= \frac{C.P}{h^2} cos^3\Theta$ *lux*
1	2	3	4	5	6	7	8	9
O	10m	0	0	0	240	1	1	2.4

A	10m	3	0.3	16.42	274	0.7878	0.878	2.407
B	10m	6	0.6	80.58	249.5	0.8575	0.6369	1.573
C	10m	9	0.9	42	152.5	0.7431	0.4015	0.625
D	10m	12	1.2	5.12	130	0.64	0.2622	0.3408

Table 1.4

The point Under consideration	*The height of the lamp h metres*	*Lamp L_1*						
		Horizontal distance between the lamp and the point (H)	*tanϴ* $= \frac{H}{h}$	ϴ / degrees	*C.P from curve*	cosϴ	$\cos^3\Theta$	*Illumination* $= \frac{C.P}{h^2} cos^3\Theta$ *lux*
1	2	3	4	5	6	7	8	9

O	10m	24	2.4	67.24	18	0.5847	0.2	0.036
A	10m	21	2.1	64.20	30	0.636	0.255	0.07645
B	10m	18	1.8	60.57	50	0.686	0.3225	0.161
C	10m	15	1.5	56.19	65	0.744	0.4119	0.268
D	10m	12	1.2	56.12	130	0.64	0.2622	0.3408

Table 1.5

The point Under consider	*The height of the lamp h metres*	$Lamp\ L_2$

ation		*Horizontal distance between the lamp and the point (H)*	*tanϴ* $= \frac{H}{h}$	ϴ / degrees	*C.P from curve*	cosϴ	$\cos^3\Theta$	*Illumination* $= \frac{C.P}{h^2} cos^3\Theta$ *Lux*	*Sum of Column 9 in each table*
1	2	3	4	5	6	7	8	9	10
O	10m	8.4	2.4	67.24	18	0.5847	0.2	0.036	2.472
A	10m								2.4835
B	10m								1.734
C	10m								0.8934
D	10m								0.6816

Self Assessment 3-1

1. Two lamps , each of the same rating and equipped with an industrial –type reflector giving a distribution curve as shown below ,are suspended 4m apart and 2m above the horizontal working plane . Calculate the illuminance on the plane a) at the point A, vertically below one of the lamps

b) at the point B, 1m from A along the line joining A with the point vertically below one of the lamps . The polar curve for a lamp and reflector is as follows.

Angle in (degrees measured from horizontal axis	15	30	45	60	75	90
Luminous intensity (candelas)	50	125	240	190	155	140

SESSION 4-1: LIGHTING SCHEMES

4-1.1 Direct lighting

In this scheme the light falls directly on the object to be illuminated. This scheme is usually employed in industries, residential lighting, commercial lighting and special industries .When designing such schemes all the possibilities which will cause glare on eyes have to be eliminated Thus a correct size of lamp with suitable fittings is to be selected. The dirt if accumulated on the lamp shade or diffuser will decrease the luminous intensity and further it will no more be equally distributed .The fittings are required to be cleaned regularly .Working constantly under direct lighting will cause a strain on the eye.

4-1.2 Indirect lighting

It is the system which is widely employed for illuminating drawing offices ,workshops and other places where shadows are to be eliminated .However with this type of lighting ,it is found out that the requirement of light is usually more than that of the direct lighting The additional light requirement falls in the range of 50% to 100% . Due to this reason almost at all places some percentage of direct lighting is suggested .The light in this case does not fall on the objects directly . The lamps are placed on opaque type of shade and maximum light is thrown toward the ceiling from where it reaches the object by diffusion or reflection. If the fitting are not properly cleaned then the illumination will drastically be reduced .No light is directly thrown downwards. At least 80% of the total light is diverted upwards .

4-1.3 Semi direct lighting

This system is efficient and reduces the chances of glare to the eye to a considerable extent.

The shades used are of such a type that about 60% of light is directed downwards and about 40% is projected upwards. The most important characteristic of such scheme is that it provides a uniform distribution which increases be efficiency of the system

4-1.4 Semi -indirect system

In this system the light received by any object is due to a) diffused refraction b) directly thrown

The system does not possess the defect of indirect system. About 10- 40% of light from the source is thrown downwards and about 20 to 80 % is projected upwards which is received by the object

.

SESSION 5-1: LIGHTING SOURCES

5-1.1 Incandescent lamp

They consist of a thin filament of tungsten inside a glass bulb. When a current is passed through the filament, heat is produced and the temperature of the filament rises. The filament is designed so that it reaches a temperature at which it generates light energy as well as heat, which means that the filament glows or is incandescent and hence the lamp is called an incandescent lamp. The higher the temperature of the filament, the more efficient is the conversion of electrical energy into light energy, but if the temperature becomes too high the filament melts and breaks. Tungsten has a melting point of 3382°C, and most modern lamps have filaments running at about 2800°C, although some special lamps may run at 3220°C.

The characteristics of incandescent lamps are shown in Figure 1.9. The graph shows how very sensitive the life is to change of voltage. For example an increase of 2½ per cent above normal voltage increases the efficiency by 2½ per cent and the light output by 7 per cent but reduces the life by 20 per cent. The graph also shows that for voltages below normal the light output falls more rapidly than the voltage, which is something to be borne in mind when one considers the voltage drop that can be accepted in the circuit wiring to the lamps.

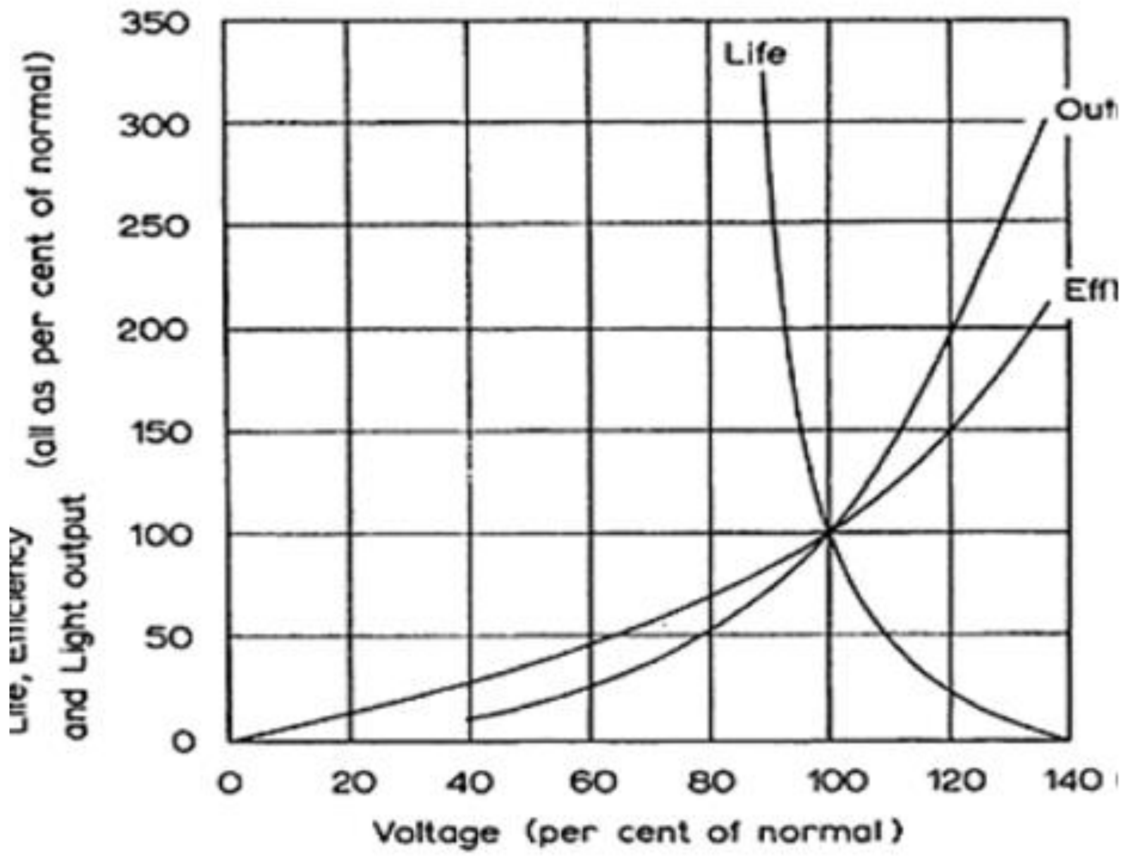


Fig 1.9 Characteristics of Incandescent lamp

5-1.2 Tungsten halogen lamps

In a conventional incandescent lamp the filament loses material by evaporation. The inert gas inside the bulb reduces the rate of evaporation but cannot prevent it completely. A further improvement can be obtained by adding a halogen to the gas, which gives rise to a reversible chemical reaction..

For a given power a tungsten halogen lamp has a longer life and a higher light output than an ordinary tungsten lamp. The high temperature makes it of limited use in domestic or commercial lighting but it finds application in floodlighting and the lighting of film and television studios. It is probably most widely known for its use in automobile headlamps.

5-1.3 Fluorescent lamps

The action of a fluorescent lamp depends on the discharge of a current through a gas or a vapour at a low pressure. If a tube containing a vapour has an electrode at each end, a current will flow through the vapour provided electrons are emitted by one electrode (the cathode) and collected by the other (the anode). Electrons will be emitted if the potential gradient from anode to cathode is great enough. After the discharge has started a voltage is still needed between the electrodes to maintain the discharge, but the maintaining voltage is less than the striking voltage. A current flowing through a gas or vapour at low pressure causes the gas or vapour to emit radiation at wavelengths which depend both on the nature of the vapour and on its pressure. A fluorescent lamp consists of a long glass tube containing a mixture of mercury vapour and argon gas at a pressure of 2 to 5mm mercury. When the lamp is cold, the mercury is in the form of small globules on the tube surface, and the argon is needed to start the discharge. As soon as the discharge starts the temperature rises sufficiently to vaporise the mercury which then takes over the conduction of practically the whole current.. The inside of the tube is coated with a fluorescent powder.. Thus in the fluorescent lamp the radiation emitted by the current discharge through the mercury vapour is absorbed by the fluorescent coating which then emits a different radiation. The circuit needed to operate such a lamp is shown in Figure 1.10.

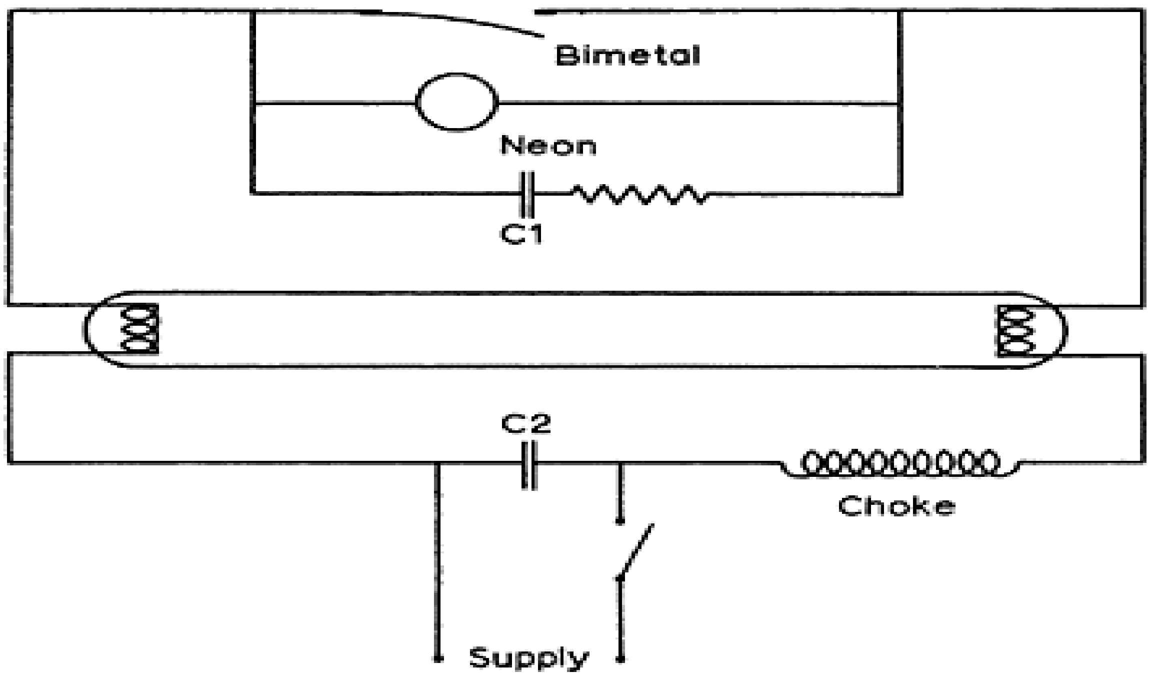


Fig 1.10 Fluorescent light circuit -start circuits,

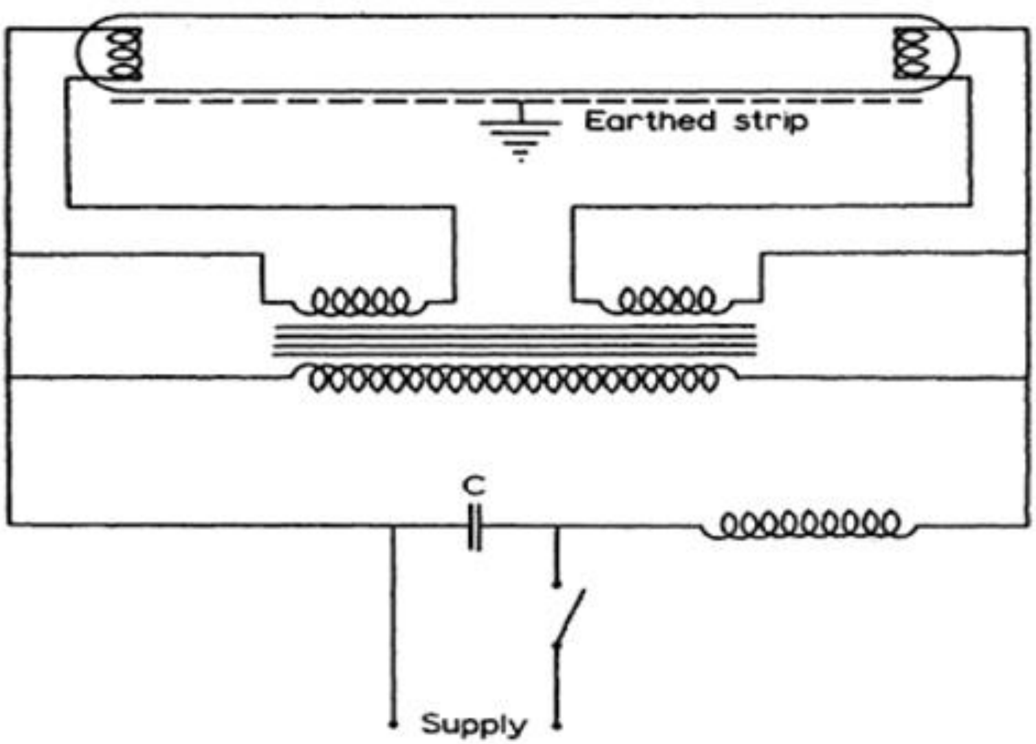


Figure 1.11 *Quick*-start circuits

.Figure 1.10 shows a small capacitor across the switch contacts. The capacitor is inserted to suppress radio interference. Figures 1.10 and 1.11 both show a larger capacitor across the entire circuit. This one is included to correct the power factor, which would otherwise be unacceptably low because of the inductive choke.

Most modern switches are capable of breaking an inductive current of the value at which the switch is rated, but the older switches designed only for incandescent lights had to be de-rated when they were used on circuits serving fluorescent lights. Thus a 5A switch controlling a fluorescent circuit is considered as a 2.5A switch and therefore can only control a number of fluorescent fittings whose total current will not exceed 2.5A.

Fluorescent lamps have a lower surface brightness than incandescent ones and have a higher efficiency in terms of light energy given out per unit of electrical energy consumed.

5-1.4 Compact Fluorescent lamps

Compact fluorescent lamps (CFLs) are intended to replace standard incandescent lamps where longer life, lower power consumption, and lower heat dissipation justify their higher cost. They are available in many different shapes, but are generally about the same size as conventional incandescent lamps. The 13-W spiral lamp *is* said to be the equivalent of a 60-W incandescent lamp., . Regardless of bulb shape, all CFLs operate the same way as standard fluorescent lamps, and they all require ballasts that add to their weight and cost. Promoted as energy-savings alternatives to incandescent lamps, CFLs offer a range of illumination characteristics. Another important feature of CFLs is their long life, typically 10 times that of the nearest equivalent incandescent lamps. They have continuous rated lives of 6000 to 10,000 hrs (10,000 hrs is longer than 1 year). These compare with 750- to 1000-hr ratings for typical incandescent lamps. The characteristics of CFLs match those of conventional fluorescent tubes and also depend on the phosphor coating inside each lamp. They also convert about 90 percent of their energy into light, with the remaining 10 percent dissipated as heat (infrared) radiation. Consequently, they also run cooler than incandescent lamps. CFLs with electronic ballasts are less top-heavy than those with magnetic ballasts, making them more suitable for use in table and floor lamps. However, some CFLs have magnetic ballasts as separate units that plug directly into wall outlets and permit the CFL to be lighter, shorter, and more stable. These CFLs can fit table lamps with shorter shade-supporting harps that cannot accept the taller integral-ballast CFLs . The principal benefits of CFLs are energy conservation and heat-load reduction in a room. As a result, the cost of lighting and perhaps air conditioning can be reduced. approximately 90-cent retail price for a typical incandescent bulb. CFLs are most cost effective and efficient when they illuminate rooms or spaces where lights remain on for long periods of time, so if CFLs are switched on and off frequently or stay on for only a few minutes, such as in closets, payback or cost justification will be slower. Moreover, frequent on/off switching of CFLs can decrease their lives. Because CFLs have long lives, they are ideal for hard-to-reach sockets in rooms with high ceilings.

5-1.5 Mercury lamps

Mercury lamps are discharge lamps which operate on the same principle as fluorescent lamps.

At sufficiently high pressure the radiation emitted by the mercury is in the visible spectrum so that such a lamp can be used without a fluorescent coating.. The basic mercury lamp consists of an arc tube with an electrode at each end and a starting electrode near one of the main electrodes, the electrodes themselves being similar to those in the fluorescent lamp. The starting electrode is connected to the opposite main electrode through a high resistance. The arc tube is fitted inside an outer glass envelope.

The main types of mercury lamps of are designated MBF. The construction of an ordinary MBF lamp is shown in Figure 1.12. The two main electrodes are sealed inside the arc tube with a starting electrode near the lower one connected to the upper one through a high resistance outside the tube. The arc tube is made of fused silica and the operating pressure inside it is between two and ten atmospheres The radiation from the arc tube is greenish-white in the visible spectrum with some ultraviolet. The latter is converted into a visible red by a fluorescent coating on the inside of the outer envelope and the combined light from the arc tube and the coating has a colour which is considered acceptable for street lighting and for some factory and warehouse applications. When the lamp is switched off, it will not restart until it has cooled and the pressure has dropped again. This takes two to three minutes, but the lamp will not come to any harm if it is left switched on while cooling down. In other words, if the lamp is switched off and switched on again immediately, it will not re-light immediately but will not be damaged.

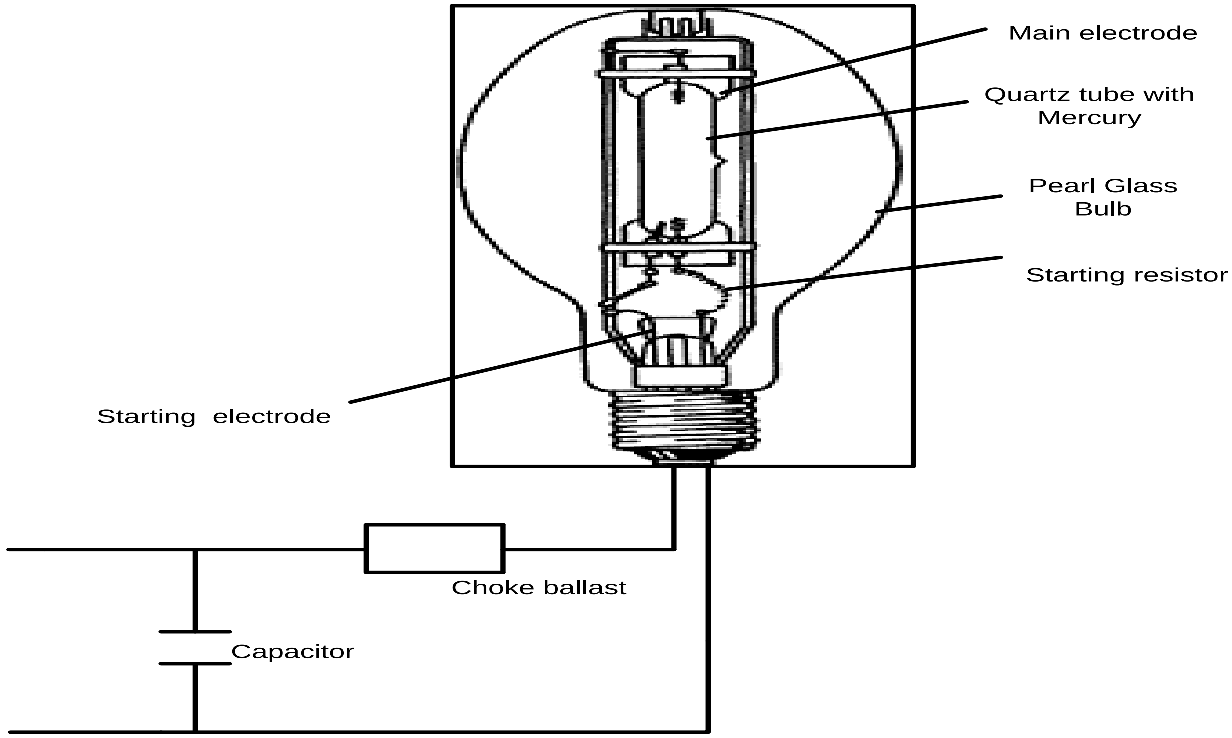


Fig1.12 Mercury Lamp

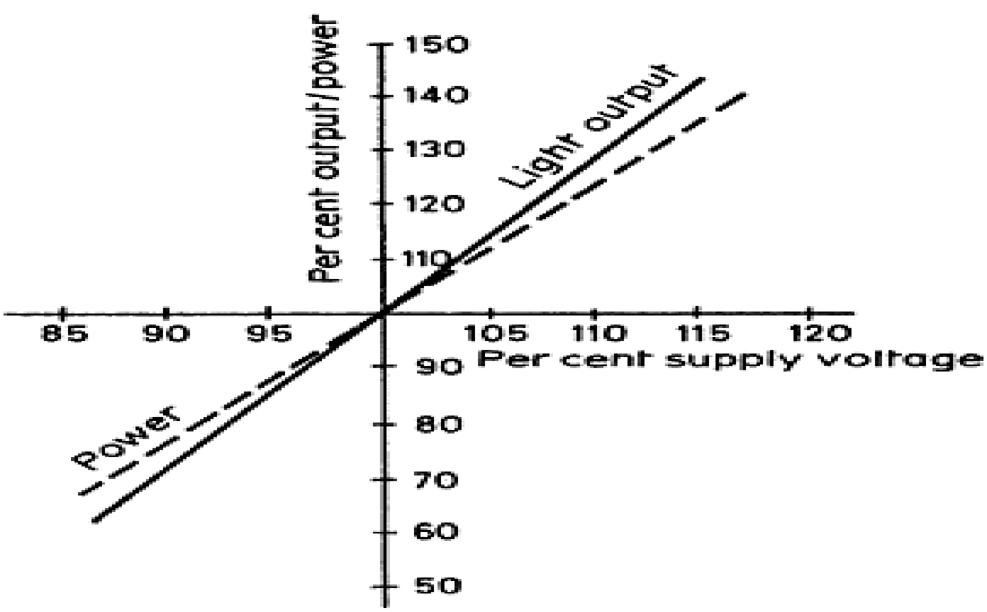


Fig1.13 Characteristics of a mercury lamp

. Both the light output and the power consumed increase linearly with an increase of supply voltage. The relationship is shown in Figure 1.13.

5-1.6 Sodium discharge lamps

Sodium discharge lamps have a similar action to mercury lamps, but the filling used is sodium instead of mercury. Lamps designated SOX and SLI work at low pressure and their luminance is low. They therefore have to be very long to give a good light output; in order to reduce the overall length the tube of an SOX lamp is bent into the shape of a U and the resulting construction is shown in Figure 1.14. The operating pressure is very low, being in the region of 1mm mercury, although the vapour pressure of the sodium alone is of the order of 0.001mm mercury, the rest being due to the neon. To start an arc through the neon when the lamp is cold requires a voltage higher than normal mains voltage (about 450V). The necessary striking voltage is obtained from an autotransformer which is specially designed to have poor regulation.. The transformer thus performs the functions of the ballast and no separate choke is required. A capacitor for power factor correction is, however, needed. The discharge which starts in the neon is of a red colour.

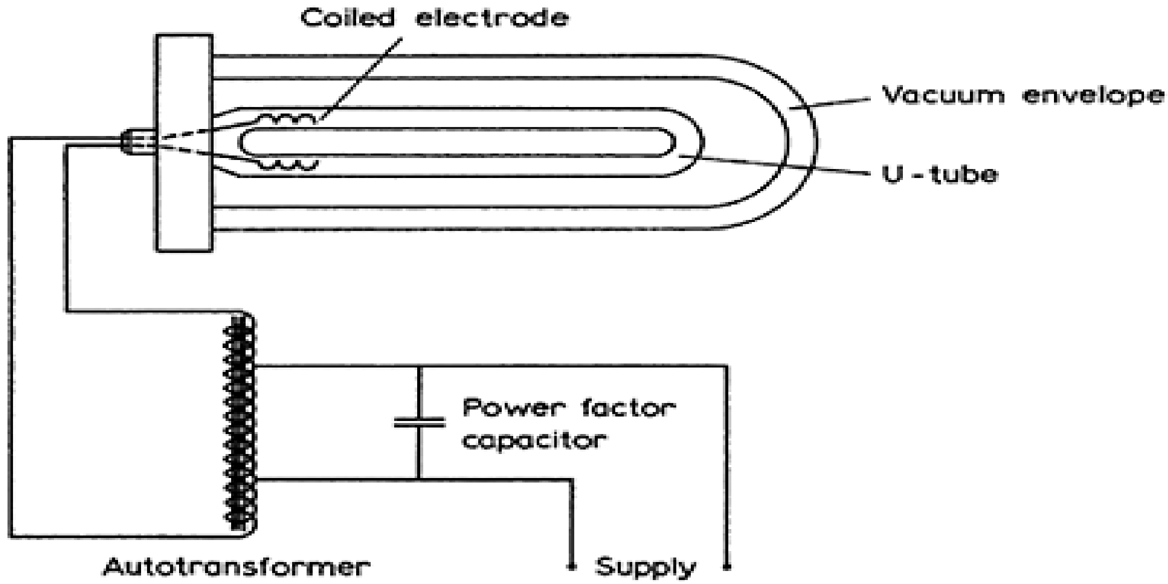


Figure 1.14 Sodium discharge lamp

Consequently, as soon as the discharge starts the voltage drops to that required to keep the discharge going.. A capacitor for power factor correction is, however, needed. The discharge which starts in the neon is of a red colour. This warms the tube and gradually vaporizes the sodium. After about twenty minutes, the sodium is fully vaporized and gives its characteristic yellow colour. The sodium discharge lamp is the most efficient means so far known of converting electrical into light energy, but because of its peculiar colour the low pressure sodium lamp is limited to street lighting and similar applications.. High-pressure sodium lamps give a rather sunny yellow light.. They are suitable for factories and warehouses and are now also widely used for street lighting and floodlighting. The pressure within the arc tube when the lamp is fully warmed up is between 30 and 60kPa. The lamp runs at a temperature of 1300°C.. A typical circuit is shown in Figure 1.15. The circuit comprises a thyristor starting circuit, which pulses a high voltage across the lamp, once the lamp

.

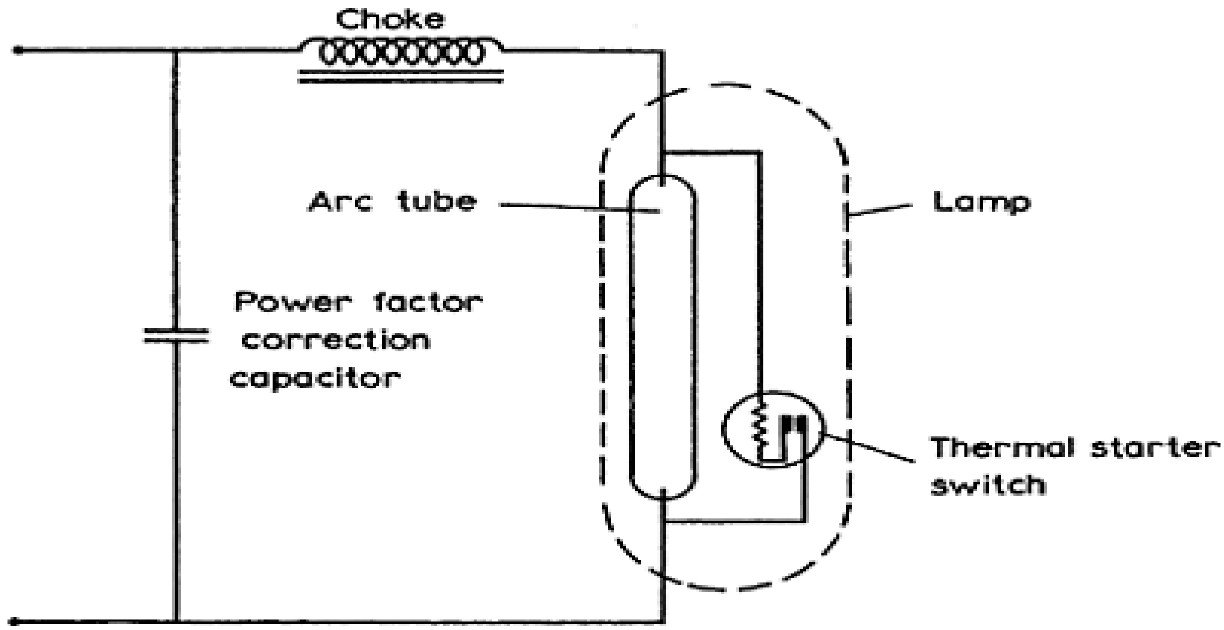


Figure 1.15 Typical solar colour lamp circuit

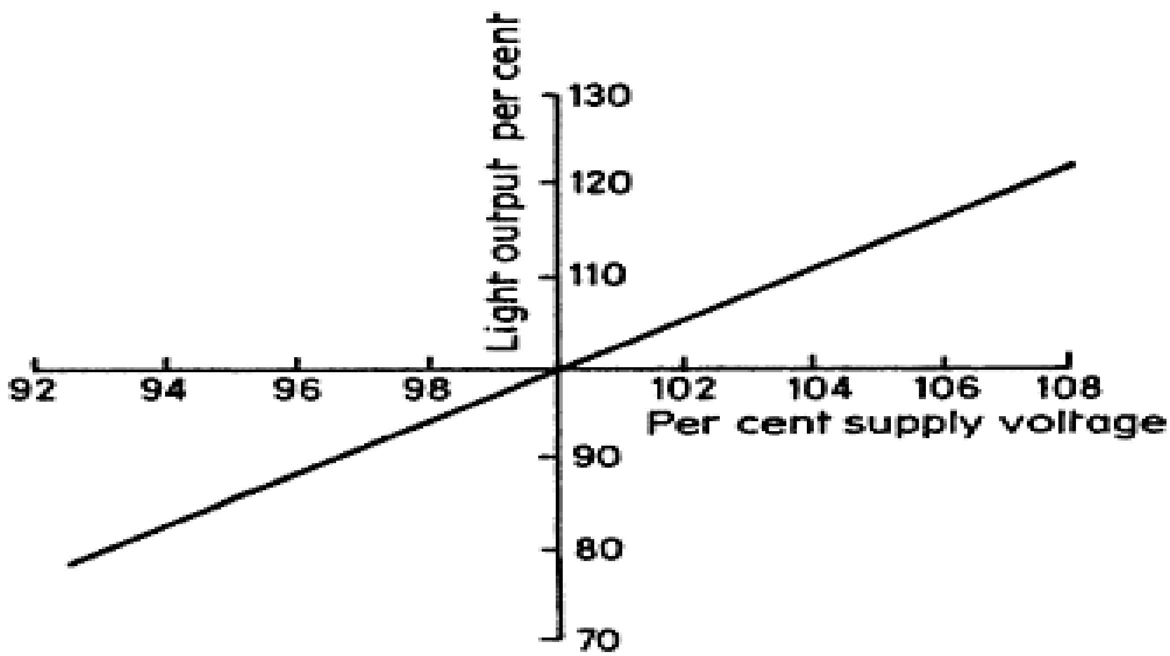


Figure 1.16 Performance of SON lamp

strikes the pulse generator is shut down and the current through the lamp is restricted by the ballast High pressure sodium lamps can work either vertically or horizontally. High pressure sodium lamps have a very high efficiency and a long life. Most high pressure sodium lamps have rated lives of more than 24,000 hours. Both light output and the power consumed increase very rapidly with an increase in the supply voltage and the design of the ballast has to be such as to limit variation in the applied voltage in order to preserve lamp life. Figure 1.16 shows the variation of light output with voltage.

5-1.7 Metal halide lamps

The colour rendering of a mercury lamp can be improved by the addition of another metal. It is, however, necessary that the metal used should have a sufficiently low vapour pressure at the operating temperature of the lamp, and that it should not react with the material of the arc tube. This can be achieved by using the metal in the form of its halide salt. The general design of metal halide lamps is similar to that of mercury lamps. When one of these lamps is first ignited the output is due to the mercury. As the temperature rises the metal halide, which is initially solid, melts and vaporizes. The high temperature causes it to dissociate into metal and halogen, and emission of light commences. The tube walls are cooler than the interior of the tube and the metal and halogen recombine on the surface of the walls; this has an important effect in preventing chemical attack on the silica walls. The metal halide lamp with a clear glass outer envelope is designated MBI. When the outer envelope has a fluorescent coating the designation becomes MBIF. A linear version for use in floodlighting and in television studios are designated MBIL. These lamps have a better colour rendering than MBF or incandescent lamps. They also have better colour rendering than SON lamps but are not so efficient and therefore SON lamps are still preferred where colour rendering is not so important. Metal halide lamps are finding use in offices, supermarkets and large stores. They can also be used for high bay warehouse lighting and floodlighting, but it is in these applications that the higher efficiency of the high-pressure sodium lamp is generally thought to be more important than the colour rendering.

5-1.8 Cold cathode lamps

These include both neon advertising lights and lamps for illumination used in large stores, cinemas and similar areas. If a sufficiently large potential difference is applied between the electrodes of a discharge tube, the arc can be struck and maintained without any heating of the cathode. With a hot cathode, the volt drop across the electrode is small, but with a cold cathode, it is higher. A long tube helps to keep a larger part of the total applied voltage drop across the arc and a smaller part across the electrode, and cold cathode lamps are, therefore, made longer than the hot cathode lamps described previously. The greater length, in fact, increases the efficiency and hence also the light output. It is because of this that they are used in stores and cinemas and under the projecting canopies which are now so popular at the entrances to commercial buildings, including hotels. The high voltage required is provided by transformers, and in order to keep the amount of high voltage wiring to a minimum the lights are supplied with transformers in self-contained units suitable for direct connection to the mains. A common arrangement has three 2.75m-long tubes physically parallel to each other, but electrically connected in series. The circuit diagram of such a luminaire is shown in Figure 1.17. The two transformers and all the high voltage wiring are sealed within the luminaire and are not accessible. The two primaries are in parallel across the mains supply, and each has a power factor correcting capacitor. The high-voltage windings each have one end connected to earth and are so arranged that the voltage between their two other ends is double the maximum voltage to earth. The transformers give a voltage high enough to strike the arc. As in the case of the transformers used with the hot cathode sodium lamps, they are designed to have poor regulation so that once the arc has been struck, the voltage drops to that required to maintain the arc. For a typical three-tube luminaire the striking voltage is 3600V and the running voltage 2000V. The great advantage of the cold cathode tube is its very long life, which is in the region of 15000 hours as against about 5000 hours for an ordinary fluorescent tube. It also maintains its output better throughout its life, and starts instantly. Its life is not

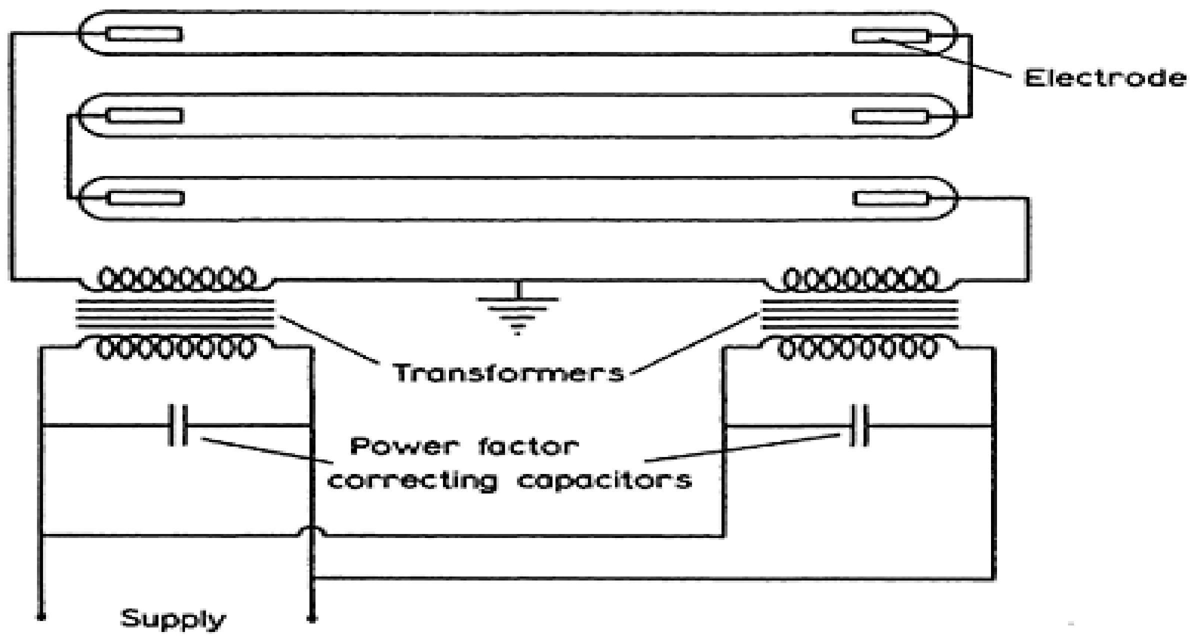


Figure 1.17 Cold cathode lamps

reduced by frequent switching. When the tube is used for lighting it is filled with mercury vapour and has a suitable fluorescent coating on its inside surface. As with ordinary fluorescent tubes a variety of colours is available. The length of cold cathode tubes makes them suitable for bending into special shapes. This makes them useful where special decorative effects are wanted and also, of course, for advertising purposes. For advertising use many different colours can be obtained by the use of different types of glass, which may be coloured or have fluorescent coatings. The earliest gas used was neon, and 'neon light' has stuck as the popular generic name for all advertising lights of this type.

5-1.9 Comparison between different light sources

Incandescent lamps –They have instantaneous start and momentarily goes off when the supply goes off . The colour of their light is near the natural light. Their initial cost of installation is minimum but their running cost is maximum . They work both well on a.c and d.c supply and frequent switching does not affect their life of operation .Change in supply voltage affect their efficiency, output and life span in a significant way . They have an average life span of 1000 hours and luminious efficacy of 12lm per W. Since their light has no stroboscopic effect ,the incandescent lamp is suitable for domestic ,industrial street lighting and floodlighting etc.

The are available in a wide range of voltage rating and are used in automobiles ,trains emergency light ,trains ,aeroplanes and signal for railways etc.

Fluorescent lamp - They have a reaction time of one second or a little more at start

They go off and restart when the supply is restored , The colour of their light varies with phosphor coating .Their initial cost of installation is maximum but running cost is minimum .Since stroboscopic effect is present they are suitable for semi direct lighting ,domestic, industrial commercial road etc. Changes in voltage affect their starting although light output is not affected as incandescent lamp .Colour of their light varies with different phosphor coating in the inner side of the tube Frequent switching affects the life period of the fluorescent lamp.

They have quite utility but their voltage rating is limited .Hence their use is limited to the mains voltage or complicated inverter which inverts 12Vdc to high voltage d.c .They have average life span of 4000 hours and luminious efficacy of 40lm/W

Mercury Vapour lamp – They have a starting time of 5 to 6 minutes . They go off and cannot be restarted after the recovery of the voltage till the pressure falls to normal. They suffer from high colour distortion .Their initial cost of installation is high but lesser than fluorescent lamp. Their running cost is lesser than the incandescent but higher than the fluorescent tubes for the same level of illumination .Stroboscopic effect is present in their light .They are suitable for open space like yard, parks and highway lightings. Change in voltage affect their starting time and colour of their radiation emitted by them. Switching does not affect their life period. They have a utility that too depends on the main voltage .They are suitable for vertical position of working .They have an average working life of 3000 hours and efficacy of 40lm per watt.

Sodium vapour lamps - They have a starting time of 5 to 6 minutes. They go off and cannot be restarted after the recovery of the voltage till its pressure value falls to normal. The colour of its light is yellowish and produces distortion Their initial cost of installation is maximum although their running cost is less than the filament lamp but more than the fluorescent tubes. They have stroboscopic effect and are suitable for open space like highway lightings and street lighting etc Change in voltage affect their starting time and colour of their radiation .They work on a.c and frequent switching affect their life. They are suitable for local lighting and the colour of their light can not be changed. They are very suitable for street lighting purpose. Their position of working is horizontal . They have a working life of 3000 hours and efficacy of 60-0 lm per watt.

5-1.10 Determination of the operating cost of a light source

Because lamps are consumable devices, both the initial lamping and lamp replacement cost should be treated as running cost instead of being considered as an overhead capital charges . The total annual operating cost of lighting installation includes the energy cost ,lamp replacement , lamp cleaning and labour for replacing lamps . For comparative purposes , cost are calculated on lumen –hour basis :.

$$C = \frac{1000}{F} \left(\frac{C_i}{h} + (C_c \times P) \right) \qquad (1.25)$$

where C = total running cost in pesewa per million lumen-hour ;

C_i = total cost of all lamps in pesewas;

Cc = cost of current in pesewas per unit (kWh) ;

F = total lumen output of all lamps;

h = lamp life in thousands of hours

P= total lighting wattage

When calculating Cc, allowance must be made for any kilowatt of maximum demand charges ,divided by the estimated annual burning hours.

Although under running a filament lamp results in an increased life span of the lamp, it is observed ,however that the efficiency is reduced. Therefore when under running a lamp it is necessary to compare the savings on the lamp cost against electricity costs. The method of comparing lamps and electricity costs is in terms of equal lumen output over equal periods of time. The basis for comparison is cost per 1000 lumens per 1000 hours.

WORKED EXAMPLE 5-1

Example 1

Compare the cost of operating filament A and B on a 200V supply

Given data

Electricity cost per unit Z cedis

	Lamp A	Lamp B
Rated voltage	250V	200V
Rated Power	200W	100W
Rated lamp life	1000hrs	1000hrs
Rated lamp lumens	2880 lm	1230 lm
Cost of lamp	X_1 cedis	X_2 cedis
Lamp replacement labour cost	Y_1 cedis	Y_2 cedis

Solution 1

% of rated lamp voltage	80%	100%
From graph at fig 1.9		
% of rated lamp life	1700%	100%
% of rated lamp lumens	50%	100%
% of rated lamp Watts	69%	100%

Calculation

Actual lamp life	17000hrs	1000hrs
Actual lamp lumens	1440 lumens	1230 lumens
Actual lamp watts	138W	100W
Total cost per lamp	$X_1 + Y_1$	$X_2 + Y_2$

Lamp and labour cost per lamp per 1000hrs used	$(X_1 + Y_1)\times \frac{1000}{17000}$	$X_2 + Y_2)\times \frac{1000}{1000}$
Lamp cost per 1000hrs per 1000 lumens	$(X_1 + Y_1)\times \frac{1000}{17000})\times \frac{1000}{1440}$	$X_2 + Y_2)\times \frac{1000}{1000})\times \frac{1000}{1230}$
Total kilowatt –hours per 1000 hrs use	138kWh	100kWh
Electricity cost	138 Z	100 Z
Electricity cost per 1000hrs per 1000 lumens	$138\ Z\times \frac{1000}{1440}$	$100\ Z\times \frac{1000}{1230}$

Total cost per million lumen hours of lamp A = $(138\ Z\times \frac{1000}{1440}) + (X_1 + Y_1)\times \frac{1000}{17000})\times \frac{1000}{1440}$

Total cost per million lumen hours of lamp B = $(100\ Z\times \frac{1000}{1230}) + (X_2 + Y_2)\times \frac{1000}{1000})\times \frac{1000}{1230}$

Self Assessment 5-1

1. A filament lamp is enclosed in a fitting that absorbs 25 percent of the light flux from the lamp and distribute the remainder uniformly over the lower hemisphere. The lamps may be assumed to have luminous efficacy of 12 lm / W. The fitting is suspended 2m above the centre of a horizontal surface 3m square. Determine the necessary rating (in watts) of the lamp if no point on the horizontal surface is to have an illuminance less than 18 lux .Reflected light from other surfaces may be neglected.

.

Unit 2

LIGHTING INSTALLATION

Introduction

Good lighting helps to increase production in industry, reduces accidents in factories and on roads, and makes buildings in general safe and pleasant places to work or undertake other activities. Enough light at working places can be achieved by using applying the appropriate lighting schemes and arranging the luminaires to provide uniform illumination on the work plane.. The type of luminaires that will be used also affect the illumination levels on the workplane.

Learning Objectives

After reading this unit you should be able to:

1. Discuss the various factors that need to be considered in lighting design
2. Design interior lighting (residential and industrial) exterior lighting (Flood and

street lighting)

3. Use room index and zonal cavity methods to determine Utilisation and Depreciation factors to be used for calculating the number of luminaries required for a given dimension of a building plan.
4. Represent the required electrical services equipment and devices by standard electrical symbols on a given a architectural plan
5. Determine the maximum number of a given type of lamps that can be connected in a circuit , and also maximum number of a given type of lamps that can be controlled by a switch

Unit content

Session 1-2: Design of lighting Schemes

1-2.1 General consideration of factors affecting the design of a lighting scheme.
1-2.2 Design of Interior lighting scheme
1-2.3 Design of flood lighting scheme
1-2.4 Design of street lighting scheme
1-2.5 Determination of Utilisation and depreciation factors using room index and zonal cavity methods

Session 2-2: Representation of electrical services equipment and devices by standard electrical symbols on a given a architectural plan

2-2.1 Standard electrical symbols used for electrical services equipment and devices

2-2.2 Determination and representation of maximum number of a given type of lamps that can be connected in a circuit on an architectural plan

2-2.3 Determination and representation of maximum number of a given type of lamps that can be controlled by a switch

2-2.4 Representation of One and multi positional control of lamps schematically and on the architectural plan

2-2.5 Switching and connection circuits of lamps .

2-2.6 Ring and Radial connection of socket outlets .

SESSION 1-2: DESIGN OF LIGHTING SCHEMES

1-2.1 General consideration of factors affecting the design of lighting schemes (Design of an interior lighting scheme (Residential ,Commercial Lighting)

Lighting design is a component of installation design in which light sources and luminaries are selected and arranged in such a way that certain requirements of illumination are satisfied. While aesthetic and decor are important features of the selection and arrangement process, it is cost that often plays the deciding role.

The lighting arrangement should be such as a) to provide sufficient illumination (or illuminance).

b) to prevent excessive variation of illumination over the working plane .

The minimum illuminance at any point on the working plane should not be less 70% of the maximum .The working plane is usually assumed to be horizontal and 0.85m above the floor.

c) to provide shadow (except in drawing offices) –not the kind that makes for danger but that helps to give shape to solid objects and make them recognized.

d) to make the principal object the brightest thing in the field of vision , immediate back ground a little less bright and the general surroundings (walls) still less bright .

An illuminance ratio of 10: 3: 1 has been suggested as the best for task , background and surrounding respectively .

***Illumination level*:** For each type of work there is range of brightness which causes minimum fatigue and give maximum output in terms of quantity and quality .Degree of illumination to give necessary brightness to the object depends upon the size of the object – the smaller the size of the object ,the greater will be the illumination required to distinguish the object properly .Objects which are seen for longer duration of time require more illumination than those for casual work . Similarly, moving objects more illumination than those for stationary object.

Table 2.1 shows the recommended standard service values of illumination for different classes of visual tasks

Class of visual task	Examples	Standard service levels of illuminations (lux)
Casual seeing	Locker room	150
Rough task with large details	Heavy, machinery ,assembly, stores	300
Ordinary task with small details	Food can inspection, clothing and sewing business , machines drawing offices	750
Severe prolonged task with very small details	Fine assembly and machinery ,hand tailoring ,weaving silk or synthetic fibres	1000
Very severe prolonged task with very small details	Gauging very small parts, gem cutting	1500
Exceptionally severe tasks severe prolonged task with minute details	Watch making, inspection of very small instrument	3000

Illumination requirement of various parts of a building is as shown below in table 2.2

Location	Illumination level in lux
Entrance ,hallway	100
Living room	300
Dining room	150
Bed room general	300
Dressing table	230
Table games	300
Games or recreation rooms	100
Kitchen	200
Bathroom	100
Bathroom mirror	300
Garage	70
study	300
Stairs	100

Table 2.3

Purpose and places	Illumination (lux)
Precision work ,displays, task requiring rapid discrimination	Above 500
Extra fine machine work around needle of sewing machine ,fine engraving, inspection of fine details having low contrast	200-500
Proof reading ,drawing sustained reading, fined assembling ,skilled bench work	100-200
Drawing offices, art exhibition and usual reading	60-100
In museum drill halls , for work of simple nature not involving close attention to fine details	40-60
Usual observation as in bed rooms waiting rooms ,auditoriums and in general lighting in factory	20-60
Hospital ward , yards, railways platforms and corridors	5-10

Space to height ratio

It is defined as the ratio of horizontal distance between the lamps and mounting height of the lamps or

$$\text{Space to height ratio} = \frac{The\ horizontal\ distance\ between\ lamps}{Mounting\ height\ of\ the\ lamps}. \qquad (2.1)$$

It depends on the nature of the polar curves of a lamp when used with its reflectors. A reflector has a tremendous influence on the polar curve of a lamp and hence the value of space to height ratio, in fact it depends entirely on the type of reflector used.

In order to have a uniform illumination on the working plane which can be only with reflection, it is necessary that the value of this should be properly chosen . When reflectors are used the value of this ratio is given as 1 and 2.

Utilization Factor (. Coefficient of utilization)

The total light radiated out by a light source is not utilised on the working plane. The ratio of the lumens which ultimately reach the work plane for use to the total lumens generated by the a source of light (lamp) is referred to as Utilization factor (UF) .

$$\text{Utilization Factor}=\frac{Total\ lumens\ utilised\ on\ the\ working\ plane}{The\ total\ lumen\ generated\ or\ radiated\ by\ the\ source\ of\ light}. \quad (2.2)$$

The value of this utilisation factor depends on the following:

i) The area to be illuminated

ii) Height at which the lamps are fitted

iii) The colour of surrounding walls, ceiling, fittings etc.

iv) The type lighting scheme -direct or indirect

The value of utilisation factor for direct lighting varies from 0.2 to 0.5 while that of indirect lighting varies from 0.1 to 0.3

Maintenance or Depreciation factor

When the lamps are covered with dust and, dirt and smoke they do not radiate out the same amount of flux as they do they do at the time fitting. Similarly, after some time the walls and the surroundings at which lamps are fitted are covered with dirt and dust ,so they do not reflect the same amount of light as compared to the initial conditions. The maintenance factor takes into account all such losses of flux.

$$\text{Maintenance Factor} = \frac{Illumination\ under\ normal\ working\ conditions}{Illumination\ when\ every\ thing\ is\ clean} \qquad (2.3)$$

Its average factor is 0.8

The maintenance factor can also be defined as

$$\text{Maintenance Factor} = \frac{Illumination\ when\ everything\ is\ clean}{Illumination\ umder\ normal\ working} \qquad (2.4)$$

In this case the value of the maintenance factor is more than 1

Waste light factor

A surface when illuminated by a number of lamps, there is a certain amount of wastage due to overlapping of light waves. Its values for rectangular and irregular areas are 1.2 and 1.5 respectively.

The total lumens required

The gross lumens Φ

$$= \frac{Area\ (m^2) \times llumination\ (m.Candle\ ) \times Waste\ light\ factor}{Utilization\ factoe \times Maintenance\ factor\ (\ for\ values\ less\ than\ 1)} \qquad (2.5)$$

Or

The gross lumens Φ

$$= \frac{Area\ (m^2) \times Ilumination\ (m.Candle\ ) \times Waste\ light\ factor \times Maintenance\ factor}{Utilization\ factor}$$

(2.6)

The size of lamp depends on the number of fitting ,which if uniformly distributed should not be far apart . The actual spacing and arrangement is governed by space to height values and by the layout of ceiling beams and columns depending on the requirement, the lighting scheme can be any of the following: Direct lighting Indirect lighting, Semi direct lighting and Semi -indirect system

1-2.2 Design of an interior lighting scheme (Factory Lighting)

The factory lighting should be such as to provide sufficient light without glare to the work men . If an adequate light is provided, it will increase production, improve the quantity of the products and reduce the chance of accident .

It should be remembered that, it is economical to have white walls, as the reflection of white colour is more than that of any other colour. The lighting scheme should be that such in addition to providing requisite lumens, there should be an equal distribution .The fittings employed should be clean and in any case they should not produce a glare . There is a chance that the glare might exist due to reflection of light from any object other than reflectors and every care should be taken to eliminate such chances. The lamps should be mounted at sufficient height to provide even luminous intensity. In case, there are travelling crane in the factory then the lamps should be kept above the crane . Under these conditions ,suspended lamps either do not provide sufficient light or the distribution of light may not be even . So it becomes necessary to supplement the suspended lamps with side lights which will increase the illumination in the vertical plane .

In an industry where certain works require high illumination, adjustable portable lights with deep reflectors are provided on the machines. It is safer to use lamps of lower voltage for portable lamps .The portable or local light should not be provided alone .As the dark patches between the two local lights will be straining to the workmen’s eyes.

Reflectors which are employed for industrial lighting are

i) Standard reflectors ii) Diffusion fittings iii) concentrating reflectors and angular reflectors.

The light fittings must be cleaned periodically to have sufficient light .Filament lamps and fluorescent tubes are usually employed. Fluorescent tubes are recommended for general purpose industrial lighting and filament for local lighting.

1-2.3 Design of an exterior lighting scheme (Flood lighting)

It means flooding any open large surfaces with the help of light from powerful projectors . Usually flood light projectors having suitable reflectors fitted with standard 250,500 or 1000W gas filled tungsten or discharge lamps are employed. Floodlight is used for the following purpose: 1) For aesthetic purposes as for enhancing the beauty of building by night ie

Flood lighting of ancient monument ,religious building on important festive occasion

2) For an advertisement ie huge hoarding house and commercial building

3) For industrial and commercial purposes as in the case of illuminating sports stadium, quarries railway yards , etc.

The projectors used for flood light are water tight. fitted with reflectors . The light emitted by the lamp is projected in a narrow beam.

The projector is kept 15m to 20m away from the surface to be floodlighted and provides parallel beam or approximately parallel beam having beam spread of 25 ^{o} to 30 ^{o} .The total luminous flux required to flood light a building can be found from the relation

The gross lumens Φ

$$= \frac{Area\ (m^2) \times llumination\ (m.Candle\ ) \times Waste\ light\ factor \times Maintenance\ factor}{Utilization\ factor}$$

(2.7)

The waste factor features prominently here because when several projectors are used there is bound to be overlap and also because the light will fall beyond the area that they are bound to illuminate.

1-2.4 Design of an exterior lighting scheme (Street Lighting)

Street lighting installation is designed to provide the visual conditions needed for safe ,quick and comfortable movement of road users.

The most important criteria of street lighting from the point of view of both visual performance and visual comfort are :

1) Luminance level

2) Luminance uniformity

3) Degree of glare limitation

4) Lamp spectra

5) Effectiveness of the visual guidance

Luminance level

The luminance of a road surface influences the contrast sensitivity of driver eye and the contrast of obstacles on the road relative to their background; it therefore has a direct influence on visual performance on the drivers. An important criterion for the required luminance level is the brightness of the surrounding. This is because the light from the surrounding interfers with the normal adaptation state of the eye..

Luminance uniformity

Adequate uniformity of the luminance pattern on the road is important for both the visual performance and the visual comfort of a road user. The criterion of uniformity from the point of view of visual performance is the ratio L_{min} / L_{av} called the overall uniformity ratio U_o which should nowhere be below 0.4.

Glare limitation

There are two criteria used in connection with glare. These are physiological or disability glare is judged in terms of visual performance, while psychological or discomfort glare is judged in terms of visual discomfort.

Lamp spectra

The spectra composition of the light emitted by a lamp determines in the first place the colour appearance of the lamp and the way that lamp will render the colours of objects it illuminates. Although these lamp characteristics are of very little importance for the majority of road lighting application ,the spectra composition of the light also has a noticeable influence on the criteria used in road lighting to assess the visual performance and visual comfort of road users.

Visual guidance

Visual guidance facilities cover the whole complex of measures taken to give the road users an immediate recognizable picture of the course of the road ahead over a distance according to a maximum permitted speed for the stretch of road in question '

Table 2.5 Road categories as defined by CIE

Category of road	Type and density of traffic	Type of road	Example
A	Heavy and high speed motor and traffic	Road with separate carriage ways completely free of crossing at grade access control	Motorway Expressway
B	Heavy and high speed motor and traffic	Important traffic road for motorized traffic only ,possibly separate carriageways for slow traffic	Trunk road Major road
C	Heavy and moderate speed motorized traffic or Heavy mixed traffic of moderate speed	Important all purpose rural and urban road	Ring road Radial road
D	Fairly Heavy mixed traffic of which a major part may be slow be or pedestrians .	Roads in cities or shopping centres,approach roads to official buildings and areas where motorized traffic meet heavy slow traffic or pedestrians	Trunk road Commercial road

			Shopping streets
E	Mixed traffic of limited speed and moderate density . .	Collector roads between residential areas (residential streets and A to D type roads.	Collector road Local street etc

Table 2.6 Recommended maintained values of Road lighting parameters

Category	Surrounds	Luminance level	Uniformity ratios		Glare restriction	
		Average road surface luminance L av (cd /metre ^{2}) ≥	Overall Uniformity Ratio Uo ≥ MIN / AVERAGE	Lengthwise Uniformity U1 ≥ MIN/MAX	Glare Control Mark ≥	Threshold increment T / % ≥
A	Any	2			6	10
	1 Bright	2		0.7	5	10
B	2 Dark	1			6	10

C	1 Bright	2	0.4		5	20
	2 Dark	1			6	10
D	1 Bright	2		0.5	4	20
E	1 Bright	1			4	20
	2 Dark	0.5			5	20

Table 2.7 Recommended quality criteria for public lighting in Ghana

QUALITY CRITERIA FOR PUBLIC LIGHTING IN GHANA					
ROAD CLASS	NAME OF ROAD CLASS	MINIMUM ROAD ILLUMINANCE CD / METRES ^{2}	MINIMUM UNIFORMITY RATIOS		GLARE RESTRICTION
			OVERALL UNIFORMITY MIN / AVERAGE	LENGTHWISE UNIFORMITY MIN /MAX MINIMUM	THRESHOLD INCREMENT %
A	MOTORWAY	2	0.4	0.7	10%
B	MAJOR TRAFFIC ROUTES	1.5	0.4	0.7	20%
C	MINOR TRAFFIC ROUTES	1	0.4	0.5	20%
D	LOCAL ROADS	0.1	0.4	0.4	20%

E	MINOR LOCAL ROADS	THE USE OF THESE CRITERIA IS NOT APLICABLE (SPECIAL REQUIREMENT)

Calculations of illuminance on a road surface

Illuminance at a point: The value of horizontal illuminance at a point on the road consists of the sum of the partial illuminance by the all the luminaries (neglecting contribution from other light sources) . The total illuminance at a point P is given is given by

$$\sum_{1}^{n} \frac{I_{\gamma}}{h^2} Cos^{3} \gamma \qquad (2.8)$$

where I_{γ} - luminous intensity of a luminairies in the direction of point P

n - number of luminaires taken into consideration.

With this formula it is possible to calculate the value of the illuminance at various points on the surface of the road and the points having equal values of illuminance are connected, the result is

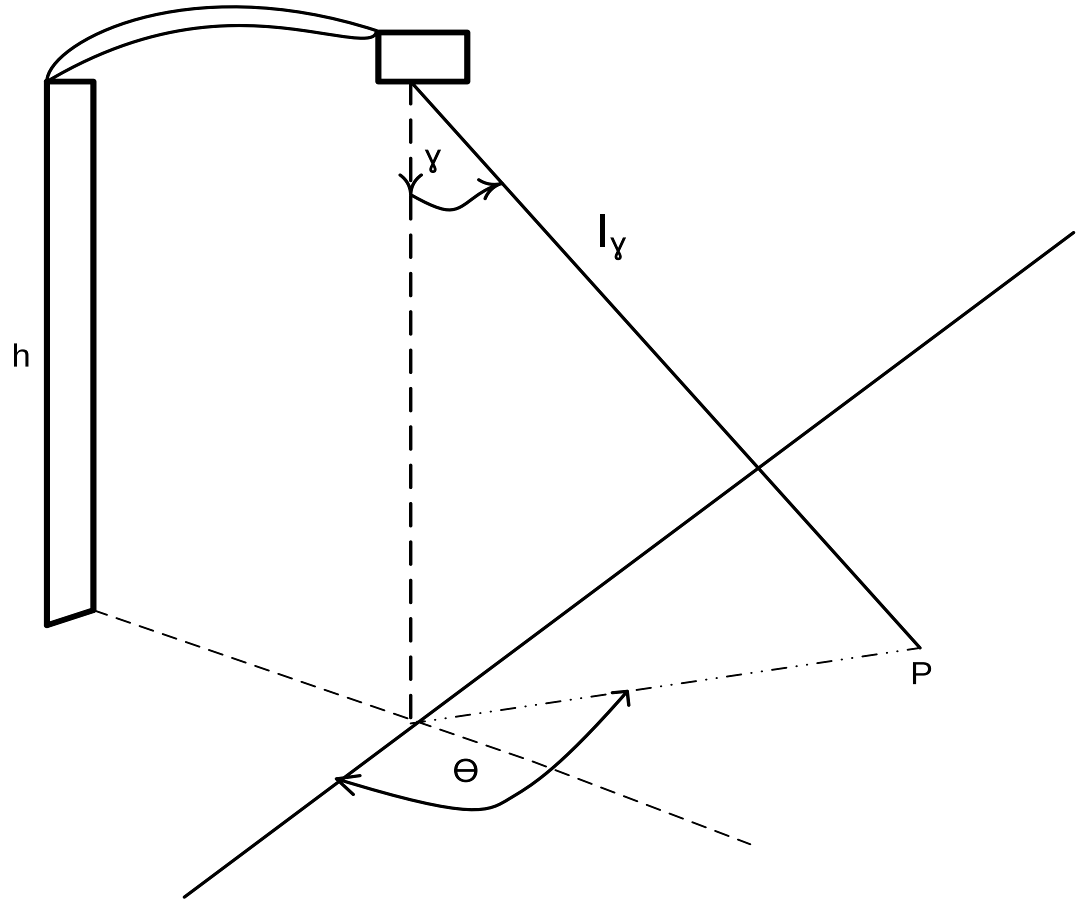


Fig 2.1 illuminance on the road at point P

what is called ***isolux diagram.*** The illuminance at any point can be read from the diagram. A computer generated isolux is shown in fig 1.20

As can be seen from fig 1.20, the grid on which the curves are drawn is dimensioned in terms of the mounting height h, of the luminaires .The relative illuminance at any point is read directly from the diagram . The absolute value of the illuminance at the point is then found from the relationship

$$E_p = E_\gamma \times \frac{an\Phi_L}{h^2} \qquad (2.9)$$

where E_γ - relative illuminance at a point ; a - a factor for a particular luminaire in use and given at the bottom of the isolux diagram ; Φ_L= luminous flux of the lamp ; n - number of lamps in luminaire ; h- mounting height of the luminaires

By repeating this procedure for each of the number of luminaires ,it is possible to arrive at the total illuminance at the point for any street light arrangement .

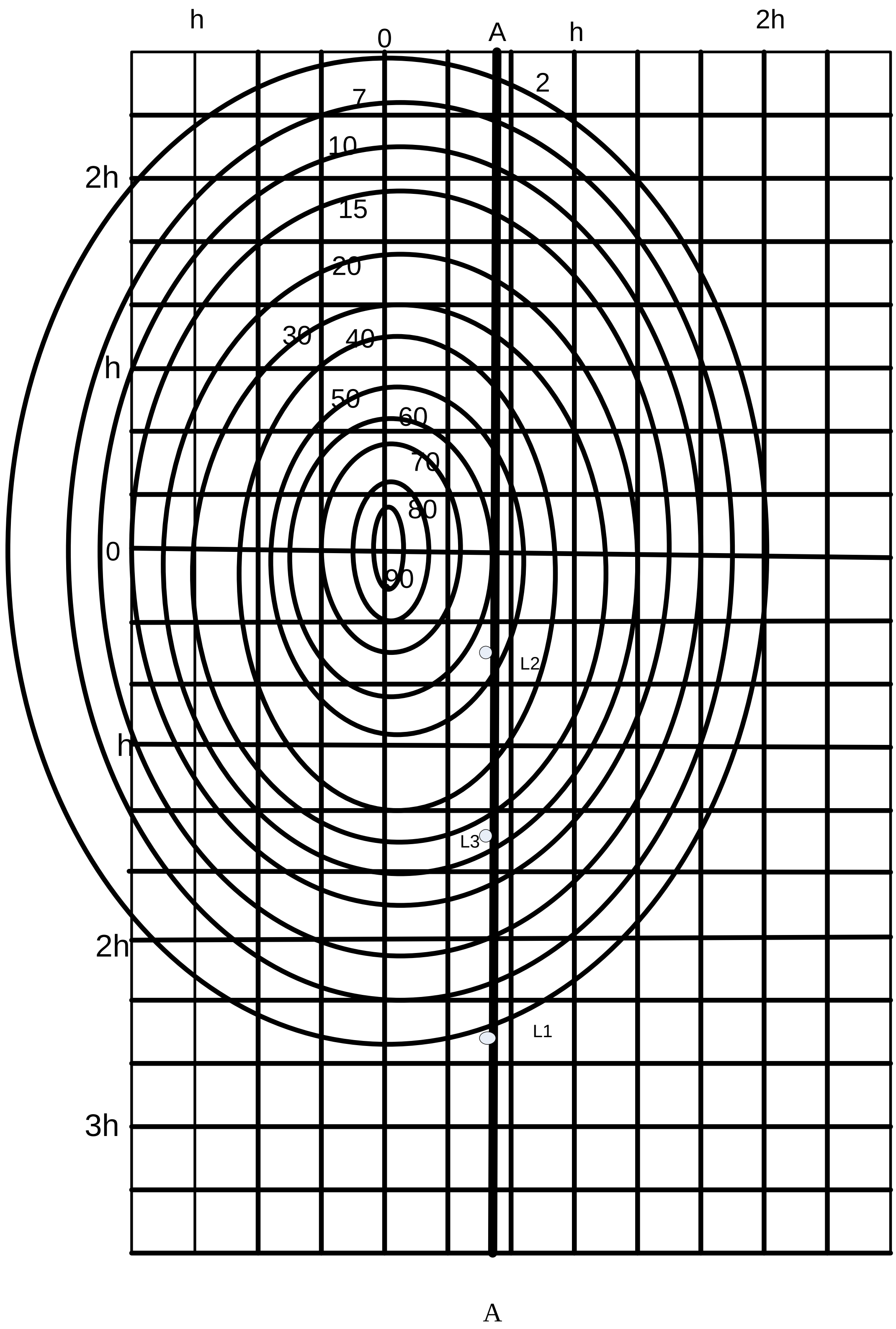


Fig 2.2 A typical isolux diagram to be illuminated with $E_{max} = a\Phi/h^2 = 0.187\ \Phi/h^2$

Calculation of Average illuminance

The average illuminance is calculated as a numerical value . When the illuminance values over a part of a road have been calculated ,the average illuminance over the area may be found from

$$E_{av}= \frac{\sum E_p}{n} \quad (2.10)$$

where E_p = Illuminance at each point in a regular pattern

n- total number of points considered

The greater the number of points considered the greater will be the accuracy of the calculated average value.

Average illuminance calculated using the utilisation factor curves - The easiest and quickest way of calculating the average illuminance of a straight road of infinite length is by using the utilisation factor curves given in a photometric data sheet in conjunction with the following formula

$$E_{av} = \frac{\eta n \Phi_L}{ws} \quad (2.11)$$

Φ_L= luminous flux of the lamp; n - number of lamps in luminaire; w- width of the road

S – Spacing between luminaires (columns) ; η - Utilisation factor - that fraction of the luminous flux coming from a luminaire that actually reaches the road .

A utilisation factor curves given in two forms are as shown in fig 2.3

From figure 2.3, the total utilisation factor with reference to the kerbside distance and the road side distance is η = 0.075 + 0.310 = 0.385.

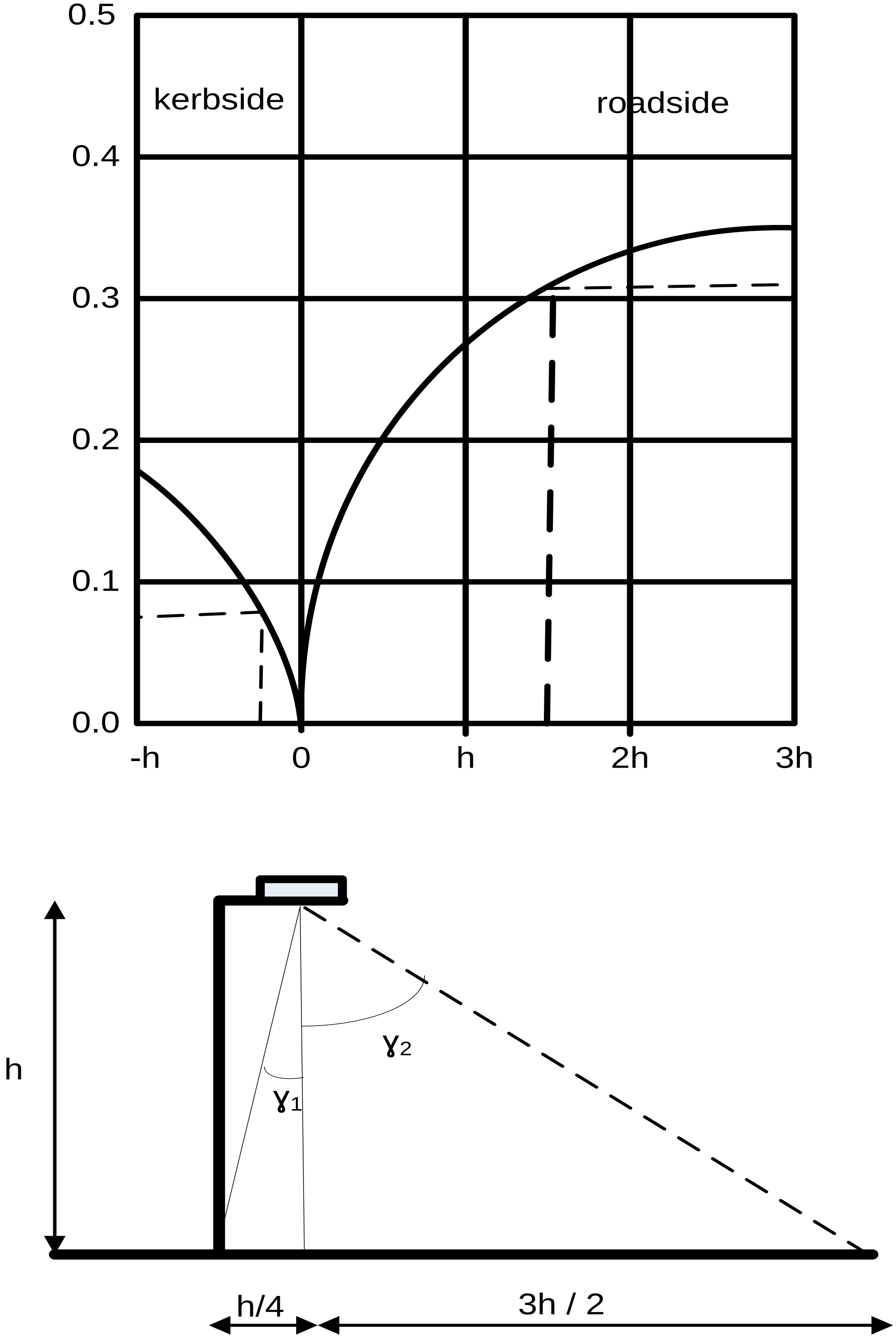


Fig 2.3 To illustrate the use of utilisation curve

1-2.5 Determination of Utilisations and Depreciation factors using room index and zonal cavity methods

One important factor in determining the number of luminaries required for a particular purpose is the utilisation factor. Tables are available for selecting the utilisation factor under new conditions of installations. The determination of this factor is not straight forward, however as it depends on a number of factors. One of these factors is the reflection factor namely the ceiling reflectance (ρ_c) , the wall reflectance (ρ_w) and the floor reflectance (ρ_f) . Several methods are available to determine the utilization factor. One method requires a value of the index of the premises (Room Index). The other method is using what is called zonal cavity method (mostly used method).

Room Index Method

$$\text{Room index (k)} = \frac{2\,L + 8W}{10H} \tag{2.12}$$

where L = Length of the room ; W = Width of room ; H = Height of the fitting above the work plane with L less than 5 m . Equation (2.1) is an empirical formula from experience and experiment. However for a predominantly direct and uniform illumination, the following expression is normally used

$$\text{Room index (k)} = \frac{L \times W}{H\,(L+W)} \tag{2.13}$$

Another factor, already discussed is the maintenance factor whose value can also be obtained from the tables.

Table 2.8

Type of lamp		*Utilisation factor* *New condition*			*Maintenace Factor*		
		$\rho_{c} = 0.7$	$\rho_{c}=0.5$	$\rho_{c}=0.3$	*once*	*every*	*every*
Type of illumination	*Room index*	$\rho_{w}=0.5, 0.3, 0.1$	$\rho_{w}=0.50.3\ 0.1$	$\rho_{w}=0.5,$ $0.3\ 0.1$	*A year*	*2 years*	*3years*
	1	*.27 21 .17*	*26 21 .17*	*26 21 .17*	*Soiling rate normal*		
e.g direct	*2*	*.46 .40 .36*	*.45 .40 .36*	*.44 .39 .36*	*1.35*	*1.55*	-
	4	*.61. 56 .53*	*.60. 56 .53*	*.60. 55 .53*			
	6	*.67 .63 .61*	*.66 .63 .60*	*.66 .62 .60*	*Soiling rate high*		
	10	*.72 .70 .68*	*.71 .69 .67*	*.71 .69 .67*	*1.65*	*2.15*	

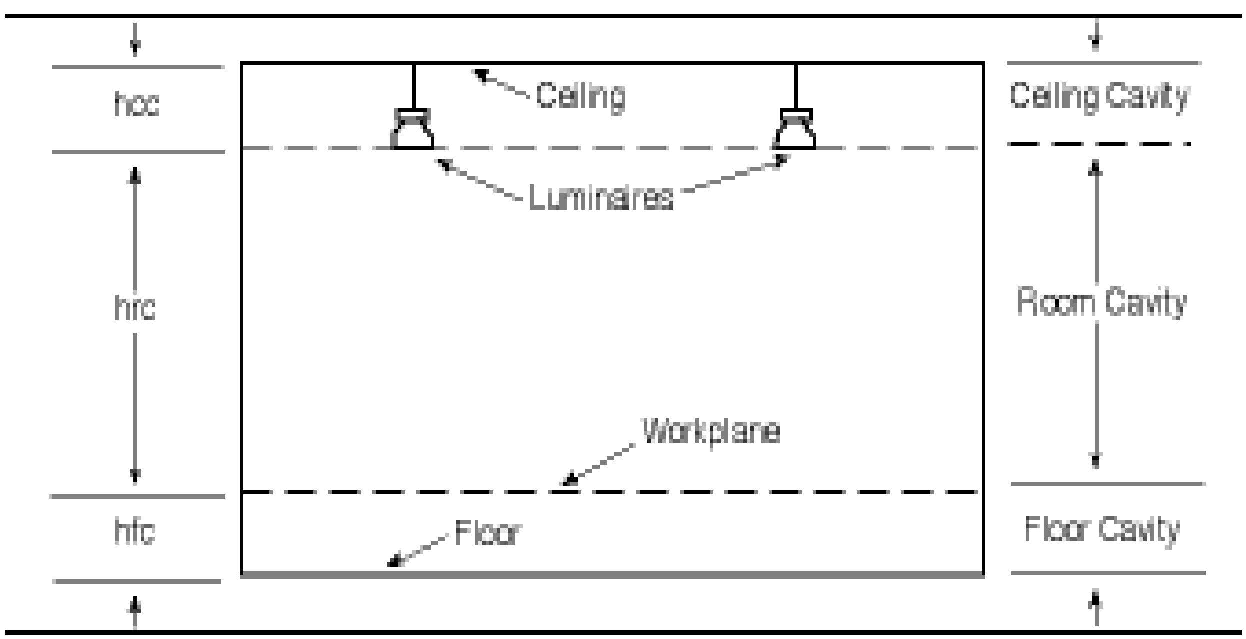
A typical table from which the utilisation factor and maintenance factor are found is in Table 2.8 where reflection factors of ceiling and wall are assigned values as

0.7(70%) for white and very light colours, 0.5 (50%) for light colours; 0.3 (30%) for medium hues and 0.1 (10%) for dark colours

Zonal Cavity Method

The zonal cavity method is the currently accepted method for calculating average illuminance levels for indoor areas unless the light distribution is radically asymmetric. It is an accurate hand method for indoor applications because it takes into consideration the effect that inter-reflectance has on the level of illuminance. Although it takes into account several variables, the basic premise that foot candles are equal to flux over an area is not violated.

The basis of the zonal cavity method is that a room is made up of three spaces or cavities. The space between the ceiling and the fixtures, if they are suspended, is defined as the "ceiling cavity"; the space between the work plane and the floor, the "floor cavity"; and the space between the fixtures and the work plane, the "room cavity".



. Fig 2.9

Once the concept of these cavities is understood, it is possible to calculate numerical relationships called "cavity ratios", which can be used to determine effective reflectance of the ceiling and floor and then to find the coefficient of utilization.

There are four basic steps in any calculation of illuminance level:

1. Determine cavity ratios 2. Determine effective cavity reflectances

3. Select coefficient of utilization 4. Compute average illuminance level

Step 1: Cavity ratios may be determined using the following formulas:

$$\text{Ceiling Cavity Ratio (CCR)} = \frac{5 \times h_{cc} \times (L+W)}{L \times W} \tag{2.13}$$

$$\text{Room Cavity Ratio (RCR)} = \frac{5 \times h_{rc} \times (L+W)}{L \times W} \tag{2.14}$$

$$\text{Floor Cavity Ratio (FCR)} = \frac{5 \times h_{fc} \times (L+W)}{L \times W} \tag{2.15}$$

Where:

h_{cc} = distance in metres from luminaries to ceiling

h_{rc} = distance in metres from luminaries to work plane

h_{fc}= distance in metres from work plane to floor

L = length in metres of room; W= width in metres of room

An alternate formula for calculating any cavity ratio is:

$$\text{Cavity Ratio} = \frac{2.5 \times height\ of\ Cavity\ \times Cavity\ Perimeter}{Area\ of\ Cavity\ base} \tag{2.16}$$

especially for irregular shapes.

Step 2: Effective cavity reflectance must be determined for the ceiling cavity and the floor cavities. These are located in Table 2,10 under the applicable combination of cavity ratio and actual reflectance of ceiling, walls and floor. Note that if the luminaries' is recessed or surface mounted, or if the floor is the work plane, the CCR or FCR will be 0 and then the actual reflectance of the ceiling or floor will also be the effective reflectance. The effective reflectance values found will then be ρ_{cc} (effective ceiling cavity reflectance) and ρ_{fc} (effective floor cavity reflectance) .

Step 3: With these values of $\rho_{cc,}$ ρ_{fc} and ρ_{W} (wall reflectance), and knowing the room cavity ratio (RCR) previously calculated, find the utilization factor or coefficient of utilization in the luminaries Utilisation factor table. Note that since the table is linear, linear interpolations can be made for exact cavity ratios or reflectance combinations. The utilization factor found will be for a 20% effective floor cavity reflectance, thus, it will be necessary to correct for the previously determined ρ_{fc}. This is done by multiplying the previously determined CU by a factor.

Utilisation Factor (final) = Utilisation Factor (20% floor Cavity reflectance) x Multiplier for actual ρ_{fc}. If it is other than 10% or 30% then interpolate or extrapolate and multiply by this factor

Table 2.10 Percentage effective ceiling or floor cavity reflectance (ρ_{CC}, ρ_{fc}) for various reflectance combinations

ρ_{cc}, ρ_{fc}	80				30				10		
ρ_w	80	70	50	30	65	50	30	10	50	30	10
CCR or FCR											
0	80	80	80	80	30	30	30	30	10	10	10
0.2	79	78	77	76	30	30	30	30	10	10	10
0.4	78	76	74	72	30	29	27	26	11	10	9
0.6	77	75	71	68	29	28	26	25	11	10	9
0.8	75	73	69	65	29	27	25	23	11	10	8
1.0	74	71	66	61	29	27	24	22	11	9	8
1.2	73	70	64	58	29	26	23	20	12	9	7
1.4	72	68	62	55	28	26	22	19	12	9	7
1.6	71	67	60	53	28	25	21	18	12	9	7
1.8	70	65	58	50	28	25	21	17	12	9	6
2.0	69	64	56	48	28	24	20	16	12	9	6
2.2	68	63	54	45	28	24	19	15	13	9	6
2.4	67	61	52	43	28	24	19	14	13	9	6

.

Step 4: Computation of the illuminance level is performed using the standard lumen method formula.

Table 2.11 Utilisation factor of a typical luminaire

Typical luminaire	ρ_{cc}	80			70		
	ρ_w	50	30	10	50	30	10
	RCR	Coefficients of utilization for 20% effective floor reflectance ρ_{fc} = 20					
two-lamp fluorescent strip unit	0	1.01	1.01	1.01	.96	.96	.96
	1	.85	.81	.77	.81	.77	.73
	2	.73	.66	.61	.69	.63	.58
	3	.63	.56	.50	.60	.53	.48
	4	.56	.47	.41	.53	.46	.40
	5	.49	.40	.34	.46	.39	.33
	6	.43	.35	.29	.41	.34	.28
	7	.39	.31	.25	.37	.29	.24
	8	.34	.27	.21	.33	.26	.21
	9	.31	.23	.18	.30	.23	.18
	10	.28	.21	.16	.27	.20	.16

Table 2.12

Multiplying factors for effective floor reflectance other than 20 percent : (30%)

	ρ_{cc}	80			70		
	ρ_w	50	30	10	50	30	10
	RCR	For 30 percent effective floor Cavity reflectance (20% =1.00					
	1	1.082	1.082	1.064	1.070	1.064	1.059

	2	1.066	1.066	1.047	1.057	1.048	1.039
	3	1.054	1.054	1.033	1.048	1.037	1.024
	4	1.045	1.045	1.024	1.040	1.029	1.021
	5	1.034	1.034	1.018	1.034	1.024	1.015
	6	1.033	1.033	1.014	1.030	1.020	1.012
	7	1.029	1.029	1.011	1.026	1.017	1.009
	8	1.026	1.026	1.009	1.024	1.015	1.007
	9	1.024	1.024	1.007	1.022	1.014	1.006
	10	1.022	1.022	1.006	1.020	1.012	1.005

Table 2.13 Multiplying factors for effective floor reflectance other than 20 percent effective floor reflectance: (10%)

	ρ_{cc}	80			70		
	ρ_{w}	50	30	10	50	30	10
	RCR	For 10 percent effective floor Cavity reflectance (20% =1.00					
	1	0.929	0.935	0.940	0.939	0.945	0.948
	2	0.942	0.950	0.958	0.949	0.957	0.963
	3	0.951	0.961	0.969	0.957	0.966	0.973
	4	0.958	0.969	0.978	0.963	0.973	0.980
	5	0.964	0.976	0.985	0.968	0.974	0.985
	6	0.969	0.980	0.986	0.972	0.982	0.989

	7	0.973	0.983	0.991	0.973	0.985	0.991
	8	0.976	0.986	0.993	0.977	0.987	0.993
	9	0.978	0.987	0.994	0.979	0.989	0.994
	10	0.980	0.990	0.995	0.981	0.990	0.995

WORKED EXAMPLES 1-2

Example 1.

A room 20m× 10m is to be illuminated eight lamps and the average illumination is to be 50 lumens /m^2 .The utilization factor is 0.48 and the maintenance factor is 1,2 ,calculate the mean spherical power per lamp.

Solution 1:

The area to be illuminated A = 20× 10 = 200 m^2 .

The total luminious flux required = 200× 50=10000 lumens.

The total lumens to be given out by the lamps =

$$= \frac{Total\ luminous\ flux \times Maintenance\ factor}{Utilization\ factor}$$

$$= \frac{10000 \times 1.2}{0.48} = 25000 \quad lumens$$

.: The mean spherical power (M.S.C.P) per lamp =

$$\frac{Total\ luminous\ flux}{4\pi} = \frac{25000}{4\pi \times 8} = 248.68$$

Example 2

A room 17m$\times$ 6m is illuminated by twenty 200 watts. lamps. The M.S.C.P of each lamp is 250. Assuming a depreciation factor of 1.2 and utilisation factor of 0.6, find the average illumination produced on the floor .

Solution 2:

The area of room illuminated A = 17$\times$ 6 = 102 m^2 .

M.S.C.P of each lamp = 250

Total number of lumens (Φ) given by each lamp = 250$\times$ 4π = 3140 lumens

= 200$\times$ 50=10000 lumens.

Total number of lumens (Φ) given out by all 20 lamps = 3140 $\times$ 20 =62800 lumens

Taking into consideration the utilization and maintenance factors

The lumens utilised for the room =

$$= \frac{Total\ luminous\ flux \times Utilization\ factor}{Maintenance\ factor}$$

$$= \frac{62800 \times 0.6}{1.2} = 31400 \quad lumens$$

The average illumination of the floor =

$$: \ = \frac{Total\ lumens\ utitilised}{Area\ \ of\ floor} = \frac{31400}{102} = 308\ lux$$

Example 3

It is required to provide an illumination of 100 m. Candle in a factory hall 40m $\times$ 10m . Assume that the depreciation factor is 0,8, the utilisation factor is 0.4 and efficiuency of the lamp is 14 lumens per unit . Calculate the number of lamps and their disposition .

Solution 3

Area of the room = 40m$\times$ 10m = $400m^2$.

Total lumens required = 400 $\times$ 100 = 40000 lumens

Gross lumens output of the lamps= $\frac{40000}{0.4\times0.8}$= 125000 lumens

;. Total wattage required = $\frac{125000}{14}$ = 8900 W

Suppose 300-W lamps are to be used, then the number of lamps required = 29.67 ≅ 30

If the lamps are arranged ,say 3 along the width ,it will not give quite uniforms uniform illumination since for 10m length and for 40m length the lamps are 10.

If we use 4 lamps along the width and 8 lamps along the length for symmetry sake , the total number of lamps required is 4 $\times$ 8=32 .

The dispositions of the lamps are as shown in fig2.4

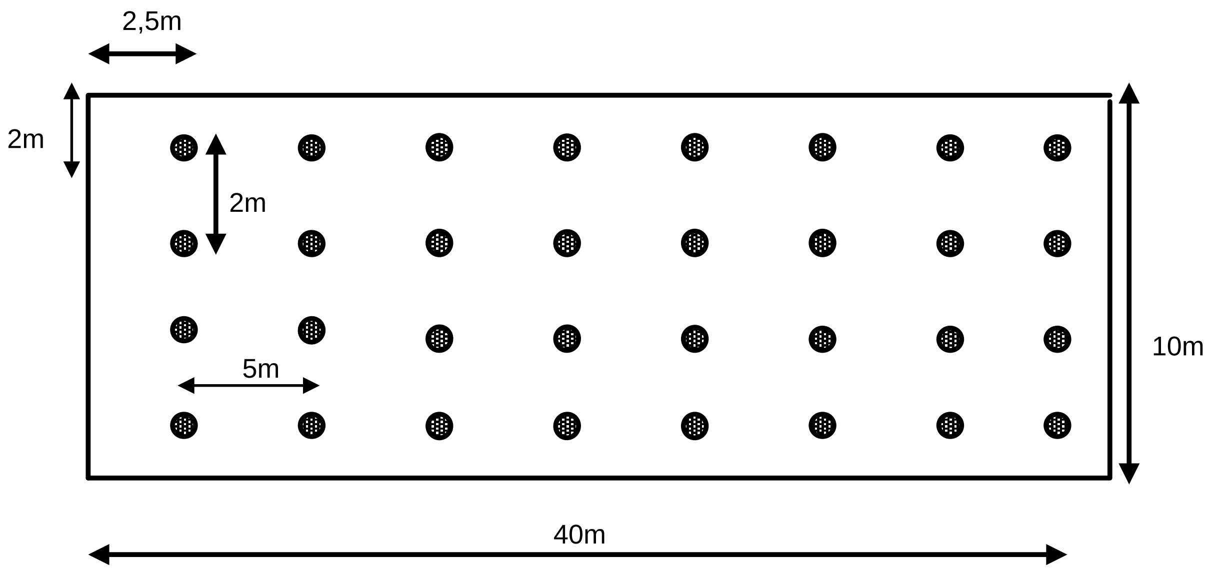


Fig 2.4

Example 4

A hall 30m long and 12 m wide is to illuminated and the illumination required is 50 m .candle . Calculate the number , voltage of each unit and the location and mounting height of the taking a maintenance factor of 1.3 and the utilisation factor of 0.5 given that the outputs of the different types of lamps are as below

Watt	100	200	300	500	1000
Lumens	1615	3650	4700	9950	21300

Solution 4.

The area to be illuminated = $30 \times 12 = 360m^2$.

Total lumens required = 360×50 = 18000 lumens

Gross lumens to be required from lamps $= \frac{18000 \times 1.3}{0.5}$ = 46800 lumens

Suppose a 200-W lamps are to be used, then the number of lamps required

$= \frac{Gross\ lumens\ required\ by\ the\ lamps}{lumens\ reqired\ by\ a\ 20W\ lamps} = \frac{46800}{3650} = 12.82 \cong 13$

This number of the 200W lamp will not give a suitable disposition of the lamps .

If 100W lamps are used,

The number of lamps required in this instance $= \frac{Gross\ lumens\ required\ by\ the\ lamps}{lumens\ reqired\ by\ a\ 10W\ lamps}$

$= \frac{46800}{1615} = 28.9 \cong 28$ lamps (for a uniform disposition)

Let 4 lamps be used along the width side and 7 lamps along the length side . Fig 2.5 shows the disposition of the lamps.

If the lamps are used at a height of 3m from floor level then

i) Space height ratio of lamps along the length = $\frac{4}{3}$ =1.333

ii) Space height ratio of lamps along the width = $\frac{3}{3}$ =1.0

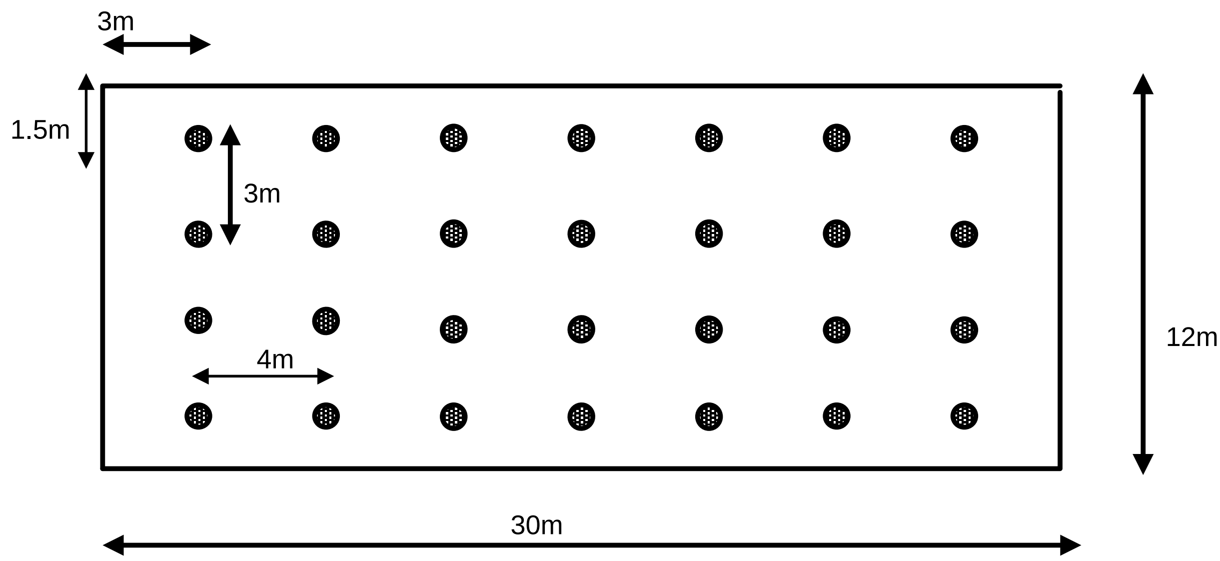


Fig 2.5

Example 5 A drawing hall 30 metres by 15 metres with ceiling height of 5 metres is to be provided with a general illumination of 120 lux. Taking a utilization factor of 0.5 and maintenance factor 1.4, determine the number of fluorescent tubes required, their space to height ratio, and total ratio. Take luminous efficiency of the fluorescent tube as 40 lumens per watt.

Solution 5:

The area to be illuminated A = 30$\times$ 15 = 450 m^2 .

The gross lumens Φ

$$= \frac{Area\ (m^2)\times llumination\ (m.Candle\ )\times Waste\ light\ factor\times Maintenance\ factor}{Utilization\ factor}$$

$$=\frac{450\times120\times1.4}{0.50} = 151200 \quad lumens$$

.: Total wattage required with 80 Watt tube = $\frac{151200}{40}$ =3780 Watts

Number of 80 watt tube required $=\frac{3780}{80}=$ 47.25 or 48

48 tubes can be arranged in 24 sets with each set containing 2 tubes. These 24 sets can be arranged as shown in fig 2.6.

Assuming the mounting height is 3 metres,

The space to height ratio of the lamp along the length= $\frac{4.0}{3.0}$=1.34

The space to height ratio of the lamp along the width = $\frac{5,0}{3.0}$ = 1.67

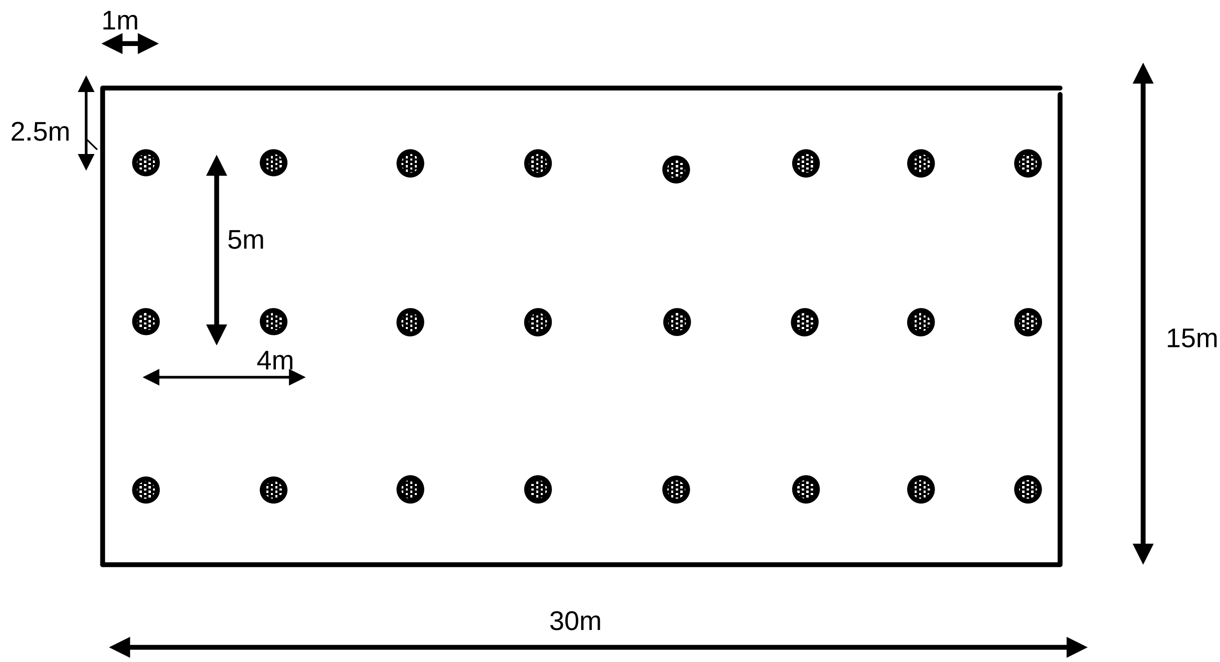


Fig 2.6

Example 6 . Find the illuminance on the surface of the road at the point P (fig 2.7) ,given that the mounting height of the luminaires is 10metres and that each lamp has a luminous flux of 40000 lumens .

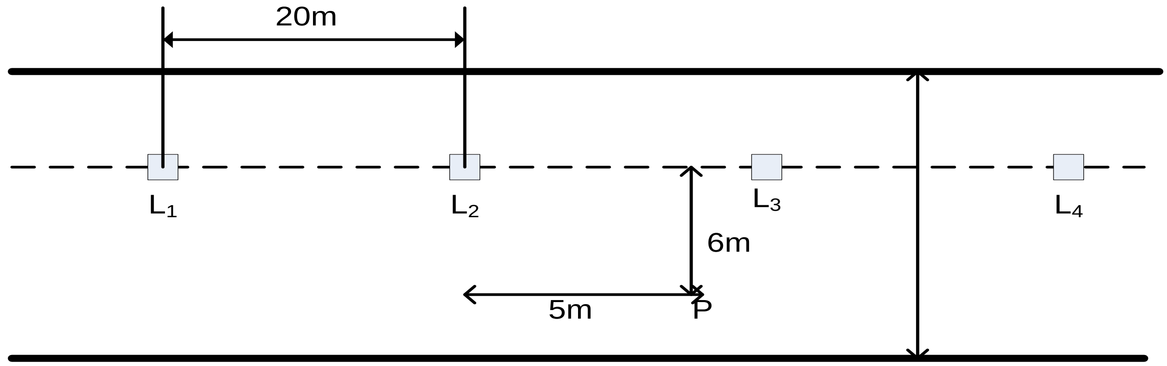


Fig 2.7 . To find the illuminance at point P

Solution 6

1. Determine the distance from the row of luminaires to the point P in terms of the mounting height ,h, . Draw on the isolux diagram this same distance from and parallel to the row of luminaires –line A –A (fig 2.7)

2. Determine the distance between the longitudinal axis of each luminaire and the point P in terms of h . Thus from fig 2.7

L_1 to P = 25m = 2.5 h

L_2 to P = 5m= 0.5 h

L_3 to P = 15m = 1.5m

Mark these distances off the line A-A in fig 2.2

3. Read –off the relative illuminance at each of the these points and calculate the total illuminance at point P , thus

E_{L1}= 3% of E_{max}

E_{L2}=53% of E_{max}

E_{L3}=23% of E_{max}

Total = 79% of E_{max} .

Now from the bottom of fig 1.20 , E_{max} =0.187 Φ/h^2

Hence $E_{max} = 0.187 \times \frac{40000}{h^2} = 74.8$ lux

The illuminance at point p is therefore 79 % of 74.8 = 59.1 lux

Example 7

Find the average illuminance on the right –hand traffic lane with a left hand single sided arrangement (fig2.8) given that the mounting height of the luminaires is 10 metres and that each has luminous flux of 40000 lumens

Solution 7

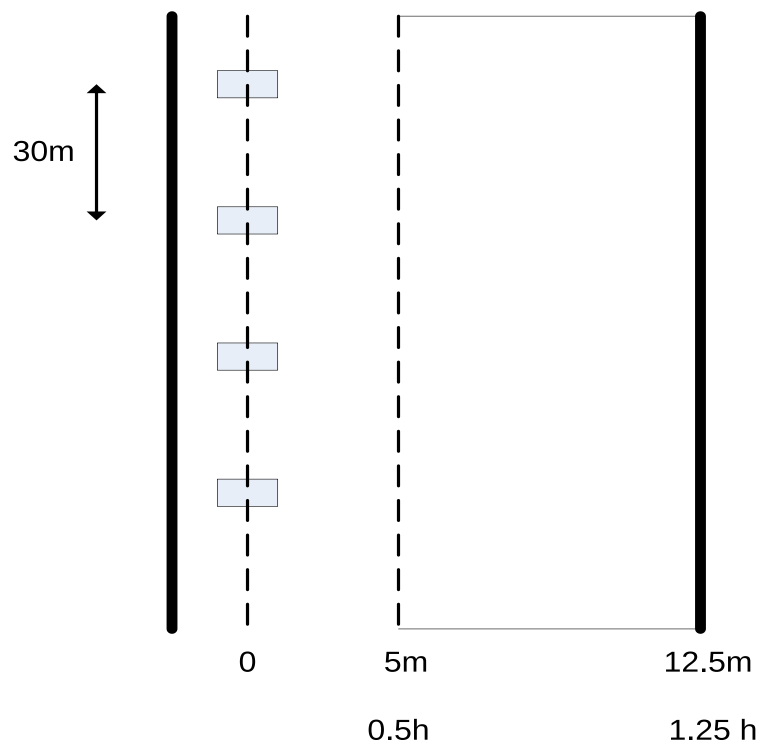


Fig 2.8

1. Determine the utilisation factor for the right handed traffic lane from fig 2.3

$\eta_{0-1.25h} = 0.28$

$\eta_{0-0.5h} = 0.19$

Thus $\eta_{0-0.5-1.25h}$=0.09

2. Substitute this value of η into the equation $E_{av}= \frac{\eta n \Phi_L}{ws}$.

Thus $E_{av}= \frac{0.09 \times 40000}{7.5 \times 30} = 16$

Example 8

A 10m by 25m hall is lit by fluorescent lamps. The height of the ceiling is 4m. The width of the hall is 10m. The ceiling is painted white and the wall is painted medium hue..Assuming the cleaning of the ceiling, the walls and the luminaries is done every two years and the soiling rate is normal. Under this condition determine the number of 40 W fluorescent lamps required for the hall. Assume that the luminaries hang 20 cm below the ceiling and the working plane 80cm above the floor. From luminaires data, the selected lamp produces a luminous flux 2300 lumens and the illumination level requirement for the hall is 250 lux .(Use room Index method)

Solution 8.

The number of fluorescent tubes required for the hall can be determined from the formula

$$N = \frac{illumination\ level\ \times Area \times maintenace\ factor}{Utilisation\ factor \times lumens\ per\ lamp}$$

But to use this formula we need the values of maintenance and utilisation factors from a table. For this we calculate the room index as follows:

Room index (k) = $\frac{2\,L + 8W}{10H} = \frac{2 \times 25 + 8 \times 10}{10 \times 3} = 4.33$

Also Room index (k) = $\frac{L \times W}{H\ (L+W)} = \frac{25 \times 10}{3 \times (25+10)}$ =2.38

The average Room index (k_{av}) = $\frac{4.33+2.38}{2}$ = 3.36

From table E with $\rho_{C} = 0.7$ $\rho_{w} = 0.3$ we find by interpolation as follows :

Let x be equal to the utilization factor corresponding to a room index of 3.36.

Table 2.9 To clarify the determination of utilisation factor

ρ_c	0.7			0,5		
ρ_w	0,5	0.3	0.10	0.5	0.3	0.10
Room Index k	Coefficients of utilization for 20% effective floor reflectance ρ_{fc} = 20					
2.0		.40				
3.36		X				
4.0		.56				

From table 2.9

$$\frac{4.0-2.0}{0.56-.40} = \frac{3.36-2.0}{X-0.40} \Rightarrow (2.0) \times (X - 0.40) = (1.36) \times (0.16)$$

=> 2.0 x - 0.80 = 0.2176 =>2.0X=0.80 + 0.2176 => 2.0X =1.0176 => X =0.509

Also from the table 2.9 , the maintenance factor is 1.55 corresponding to normal soil rating and cleaning once every two years.

With these values ,we have

$$N = \frac{illumination\ level\ \times Area \times maintenace\ factor}{Utilisation\ factor \times lumens\ per\ lamp} = = \frac{250 \times 10 \times 25 \times 1.55}{0.509 \times 2300} = 82.8$$

lamps. Using twin fittings of a fluorescent tube we get 41.4 lamps. But for convenience we use 40 lamps ie 4 rows of 10 lamps.

Example: 9

A typical lecture hall is 40 metres long and 20 metres wide with a ceiling height. of 4 metres above the work plane which in turn is 0.86 metre above the floor level . The ceiling reflectance is 80%, walls reflectance is 30%, and floor reflectance is 20%. Determine the number of 40W fluorescent fixtures required for the effective illumination of the hall .Assume a the average luminous flux of a fluorescent is 2300 lumens and illumination requirement of the hall is 250 lux and maintenance factor of 1.55 .(Use zonal cavity method)

Solutions 9:

(l) Calculate cavity ratios as follows:

h_{cc} = 0 for fluorescent tubes fixed close to the ceiling

h_{fc}= 0.86m ; h_{rc}= 4 m ; L = 40 metres ; W = 20metres

Ceiling Cavity Ratio (CCR) = $\frac{5\times hcc \times(L+W)}{L\times W} = \frac{5\times 0 \times(40+20)}{40\times 20} = 0$

Room Cavity Ratio (RCR) = $\frac{5\times hrc \times(L+W)}{L\times W} = \frac{5\times 4 \times(40+20)}{40\times 20} = 1.5$

Floor Cavity Ratio (FCR) = $\frac{5\times hfc \times(L+W)}{L\times W} = \frac{5\times 0.86 \times(40+20)}{40\times 20} = 0.3325$

(2) In Table 2.10, the effective cavity reflectance for the ceiling and floor cavities,

ρ_{cc} and ρ_{fc} respectively are determined. For the Ceiling Cavity Ratio (CCR) =0 and the ceiling reflectance of 80% and walls reflectance of 30%, the effective cavity reflectance for the ceiling , ρ_{cc} =80% .

(3) From the same table 2.10 and with Floor Cavity Ratio (FCR) =0.3325 and the floor reflectance of 20% and walls reflectance of 30%, the effective cavity reflectance for the floor, ρ_{fc} can be obtained by interpolation .

Table 2.14 To clarify the determination of the effective cavity reflectance for the floor

FCR ratio	ρ_w = 30 %		
	Cavity reflectance for the floor ρ_f		
	30	20	10
0.2	30		10
0.3325	a	x	b
0.4	27		10

Since the floor reflectance is 20% which should lie between 30 % and 10 % on the table while 0.3325 lies between 0.2 and 0.4 then a series of manipulations must be made in order to determine the effective cavity reflectance for the floor .

First, let the value of the effective cavity reflectance for the floor be equal to a when

ρ_w =30, ρ_f =30 and FCR =0.3325 then from table 2.14

$$\frac{0.4-0.20}{27-30} = \frac{0.3325-0.2}{a-30} \Rightarrow (0.20) \times (a-30) = (0.1325) \times (-3)$$

$\Rightarrow 0.2a - 6.0 = -0.4056 \quad \Rightarrow 0.2\,a = 5.5944 \Rightarrow a = 28.0$ (refer To Table 2.14)

Also let the value of the effective cavity reflectance for the floor be equal to b when $\rho_w = 30$, $\rho_f = 10$ and FCR =0.3325 then from the Table 2.14.

$$\frac{0.4-0.20}{10-10} = \frac{0.3325-0,2}{b-10} \Rightarrow (0.20) \times (b-10) = (0.1325) \times (0)$$

$\Rightarrow 0.20b - 2.0 = 0 \quad \Rightarrow b = 10$

b=10 (In this case we can get this same value by inspection, since the , ρ_{fc} values for 0.2 and 0.4 are the same)

Now let the value of the effective cavity reflectance for the floor be equal to x when $\rho_{f\,2} = 20$

$\rho_w = 30$, $\rho_{f\,1} = 30$, $\rho_{f\,3} = 10$ and FCR =0.3325 then from table 2.14

$$\frac{30-10}{28-10} = \frac{20-10}{x-10} \Rightarrow (20) \times (x-10) = (10) \times (18), \Rightarrow 20x - 200 = 180$$

$\Rightarrow 20x = 380 \Rightarrow x = 19$

(3) Knowing the room cavity ratio (RCR), it is now possible to find the coefficient of Utilization for the fluorescent tubes in a room having an RCR of 1.5 and Effective reflectances as follows:

$\rho_{cc} = 80\%$; $\rho_W = 30\%$; $\rho_{fc} = 19\%$.

Table 2.15 To clarify the determination of Utilisation factor

ρ_{cc}	80			70		
ρ_{w}	50	30	10	50	30	10
RCR	Coefficients of utilization for 20% effective floor reflectance ρ_{fc} = 20					
1.0		.81				
1.5		X				
2.0		.66				

Let the value of the utilization factor be equal to X when ρ_{w} =30 , ρ_{fc} =20 and RCR =1.5 then from the Table 2.15.

$$\frac{2.0-1.0}{0.66-0.81} = \frac{1.5-1.0}{X-0.81} \Rightarrow (1.0) \times (X - 0.81) = (0.50) \times (-0.15)$$

=>1.0 X - 0.81 = -0.0750 => X = 0.81- 0.0750 =0.735

This value of the utilization factor corresponds to a effective floor reflectance ρ_{fc} of 20%, but the effective floor reflectance of our lecture hall is 19%. As a result, a table of multiplying factors for reflectances other than 20% will be consulted.

In our case, ρ_{cc} = 80%; ρ_{w} = 30%; ρ_{fc} = 19%. and therefore the multiplying factor is calculated as follows as shown in table 2.16

Table 2.16

	ρ_{cc}	80			70		
	ρ_w	50	30	10	50	30	10
	RCR	Coefficients of utilization for 30% and 10% effective floor reflectances					
		30	19	10			
	1.0	1.082		0.935			
	1.5	X	y	Z			
	2.0	1.066		0.950			

From table 2.16

$\frac{2.0-1.0}{1.066-1.082} = \frac{1.5-1.0}{X-1.082}$ => $(1.0) \times (X - 1.082) = (0.50) \times (-0.016)$

=> 1.0 X – 1.082 = -0.008 => X = 1.074

$\frac{2.0-1.0}{0.950-0.935} = \frac{1.5-1.0}{Z-0.935}$ => $(1.0) \times (Z - 0.935) = (0.015) \times (0.50)$

=>1.0 Z - 0.935 =0.0075 => Z = 0.935 + 0.0075 =0.9425

Table 2.17

	ρ_{cc}	80			70		
	ρ_w	30	19	10	50	30	10

	RCR	Coefficients of utilization for 20% effective floor reflectance ρ_{fc} = 20					
	1.0	1.082		0.935			
	1.5	1.0735	y	0.942			
	2.0	1.066		0.950			

From table 2.17

$$\frac{30-10}{1.0735-0.942} = \frac{19-10}{y-0.942} \Rightarrow (20) \times (y - 0.942) = (9) \times (0.1315),$$

$\Rightarrow 20\,y - 20 \times 0.942 = 1.1835 \Rightarrow 20\,y = 20.0235 \Rightarrow y = 1.0$

The multiplying factor is therefore 1.0

The final value of utilisation factor corresponding to effective floor reflectance of $\rho_{fc} = 19\%$

$\rho_{cc} = 80\%$ and $\rho_{w} = 30\%$ can be expressed as

$$UF_{19\%} = UF_{20\%} \times Multiplying\ factor = 0.735 \times 1.0$$

The number of fluorescent fixtures required is

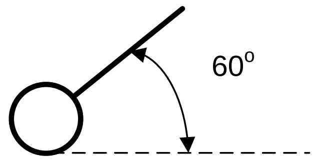
$$N = \frac{illumination\ level \times Area \times maintenace\ factor}{Utilisation\ factor \times lumens\ per\ lamp} = \frac{250 \times 20 \times 40 \times 1.55}{0.735 \times 2300} = 183.4$$

Using twin fittings of a fluorescent tube we get 92 lamps. But for convenience we use 91 lamps ie 7 rows of 13 lamps

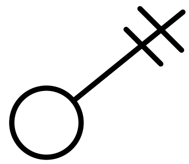
SESSION 2-2: REPRESENTATION OF ELECTRICAL SERVICES EQUIPMENT AND DEVICES BY STANDARD ELECTRICAL SYMBOLS

2-2.1 Standard electrical symbols used for electrical services equipment and devices

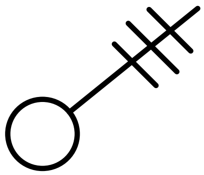
Switches



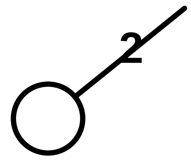
5A Single pole flush switch



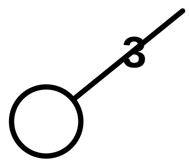
5A Single pole two gang flush switch



5A Single pole three gang flush switch

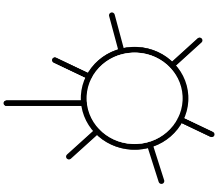


5A Single pole two way flush switch

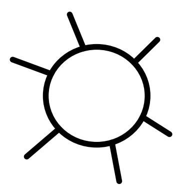


5A Single pole two way with intermediate flush switch

Lighting outlet

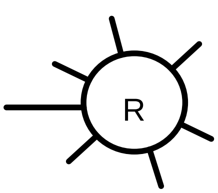


Wall

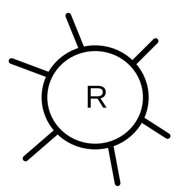


Ceiling

Surface or pendant incandescent, mercury vapour or similar lamp outlet

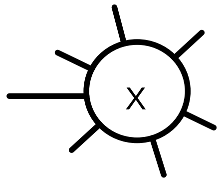


Wall

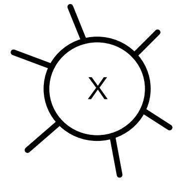


Ceiling

Recessed incandescent, mercury vapour or similar lamp outlet

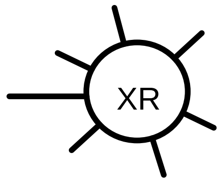


Wall

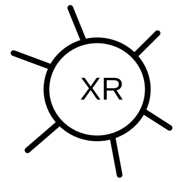


Ceiling

Surface or pendant exit fixture of incandescent, mercury vapour or similar lamp outlet

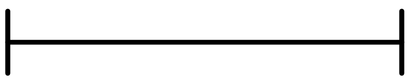


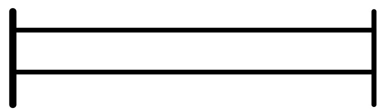
Wall

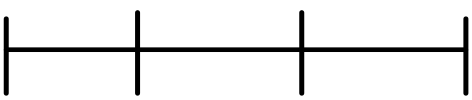


Ceiling

Recessed exit fixture of incandescent, mercury vapour or similar lamp outlet


Bare fluorescent fixture outlet


Twin Bare fluorescent fixture outlet

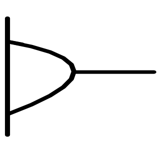

Surface or pendant continuous row of Bare fluorescent fixture outlet

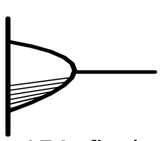

Surface or pendant continuous row of fluorescent fixture outlet

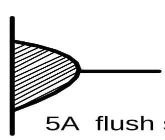

Surface or pendant individual fluorescent fixture outlet

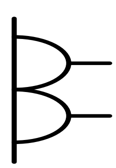
Recessed continuous row fluorescent fixture outlet

Socket outlets

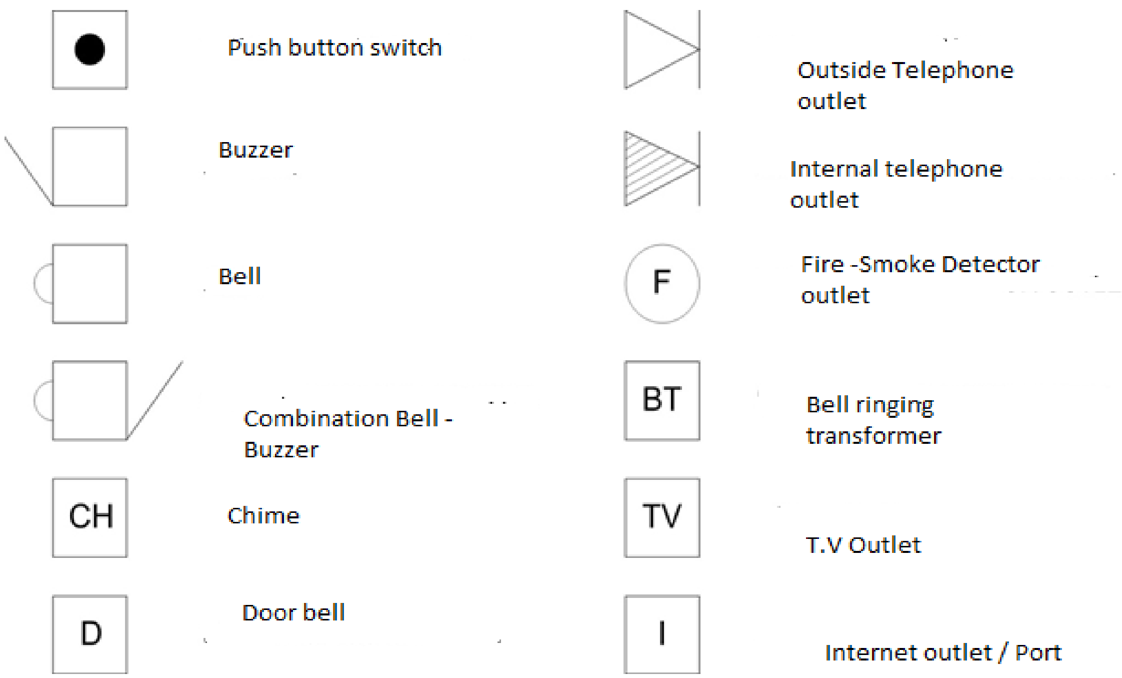

13A flush socket outlet


15A flush socket outlet

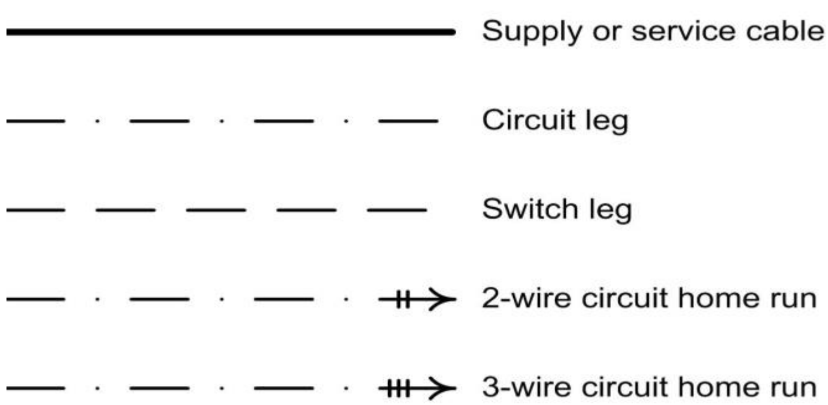

5A flush socket outlet


13A two gang flush socket outlet

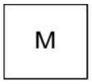
Signalling system outlet



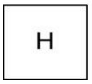
Circuiting



Underground distribution

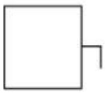


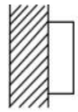
Manhole

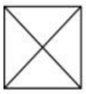


Handhole

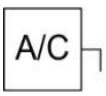
Panel board, Switch Board and related equipment


Externally operated disconnection switch

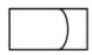

Surface mounted consumer unit


Cooker control


Ceiling fan outlet



Air conditioner outlet


Ceiling fan regulator


Flush consumer unit

Table 2.18 Recommended lighting ratings for lighting medium sized homes

Location	Watts
Living room	150-200
Passages	60
Stairs	60
Landing	60
Writing table	100
Sewing table	150
Dining room	150
Kitchen	200

Bedrooms	100-150
Mirror	2×60
Bathroom	100
Garage	150

The above power values refer to tungsten filament lamps. If fluorescent lamps are to be used, multiply the above power values by factors from $1/_3$ to $1/_2$.

To prevent the risk of under designing, use the upper limit i.e. $1/_2$ of the above powers.

Table 2.19 Minimum number of socket outlets allowable for various rooms in a building

Room	Number of outlets
Kitchen	3
Living room	4
Dining room	2
Double/Master bedroom	3
Single bedroom	2
Study bedroom	2
Study	2
Garage	1
Store	1

2-2.2 Determination of maximum number of a given type of lamps that can be connected in a circuit and the representation of the lamps on an architectural plan

If the circuit supplies current using equipment, wiring from one fuse or CB is known as the final circuit, and all the outlets fed from the same fuse or CB are on the same final circuit. The fuse or CB must be large enough to carry the largest steady current ever taken at any one instant by the

A final circuit for lighting is usually supplied by a fuse or MCB rated 5A and it may feed an unlimited number of points provided that the total current demand does not exceed 5A. For example, if it is required that a number of 100W incandescent lamps be supplied by a 240V circuit which is protected by 5A fuse then the maximum number of such 100W lamps can be determined as follows

1) Determine the current requirement, $I_{l,}$ of the 100W incandescent lamp

   ie $I_l = \frac{P}{V} = \frac{100}{240} = 0.42\text{A}$

But the rating of the protective fuse (the maximum permissible current) of the circuit is 5A

∴ The maximum number of incandescent lamps required $N_l = \frac{5}{0.42} = 12$

However, in order to minimize the pressure on the protective device should any instability occur in the system, IEE regulation stipulates that we load the circuit to about 80% of its rated value .

Hence the actual number of lamps required is $12 \times 0.8 = 9.6$

In design, it is better to round down the figure to 9 lamps especially when power consumption and cost of material are involved.

The arrangement of the lamps in a circuit when at least one lamp is controlled by one switch is shown in fig 2.10

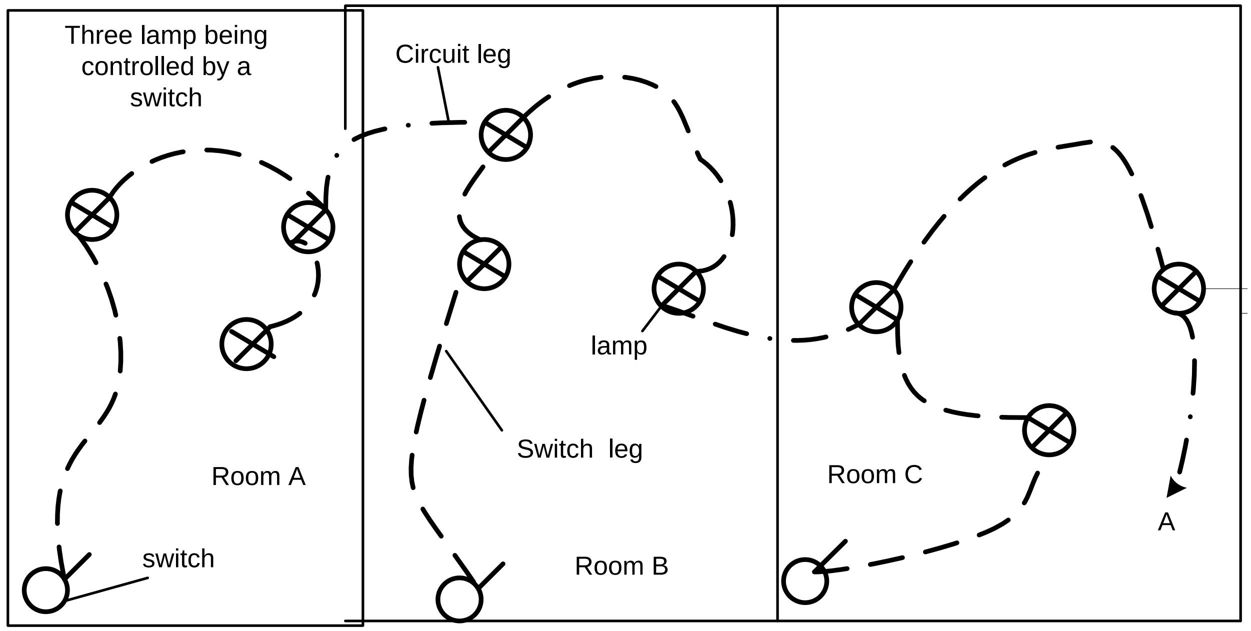


fig 2.10

Now if the lamps were to be fluorescent tubes , the procedure will be almost the same except that the circuit in this case is feeding fluorescent lamps (discharge lamps). The consideration of the rating of the discharge lamps outlets, has a different meaning from the one used for incandescent lighting points. The reason is that owing to the losses in the lamp control gear (ballast) plus low power factor, it is necessary to multiply the rated lamp watt by a factor 1.8 and divide the product by the lamps rated voltage to obtain the actual current flowing in the circuit. This factor also takes into consideration harmonic current in the circuit

Suppose the rating of the fluorescent lamp is 40W, then from the above consideration the current requirement per a fluorescent tube is $I_F = \frac{1.8 \times 40}{240}$ = 0.3 A

The maximum number of fluorescent lamps required $N_F = \frac{5}{0.30}$ = 16.7

By applying a factor of 0.8 , the actual number of fluorescent tubes required will be

16.6 × 0.8 =13.3 =13

The arrangement of the fluorescent tube is as shown in fig 2.11.

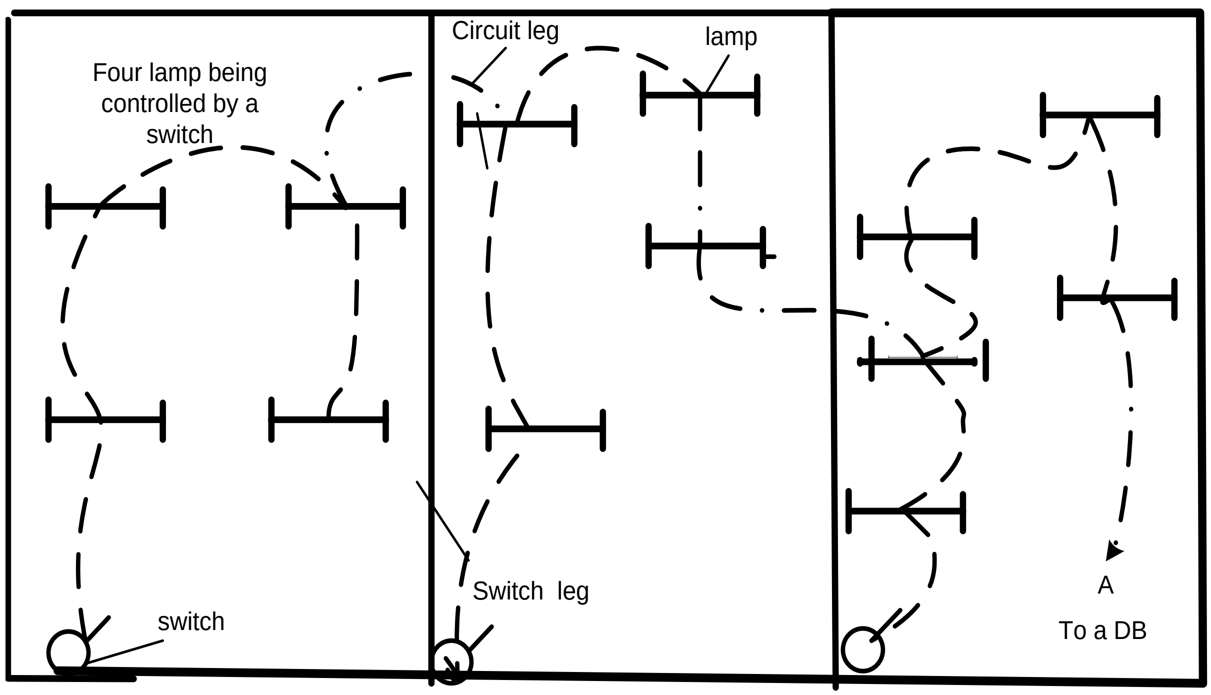


Fig 2.11

2-2.3 Determination of maximum number of a given type of lamps that can be controlled by a switch and the representation of the lamps and the switch on an architectural plan

Although commercial and industrial lighting may require the use of 15A switches, interior lighting are mostly controlled by switches rated 5A.. If it is required that a number of certain types of lamps be controlled by one 5A switch, 240V single phase , then the procedure may be as follows

1. Determine the current requirement, $I_{l,}$ of the lamp ,say, one 100W incandescent lamp

ie $I_l = \frac{P}{V} = \frac{100}{240}$ = 0.42A

But the rating of the controlling switch is 5A , (the maximum permissible current is 5A)

∴ The maximum number of 100W incandescent lamps that can be controlled by one 5A switch is

$N_l = \frac{5}{0.42} = 12$.

Thus one 5A switch can control not more than 12 lamps at the same time.

The arrangement of one 5A switch controlling say 12 incandescent lamps are as shown below in fig 2.12.

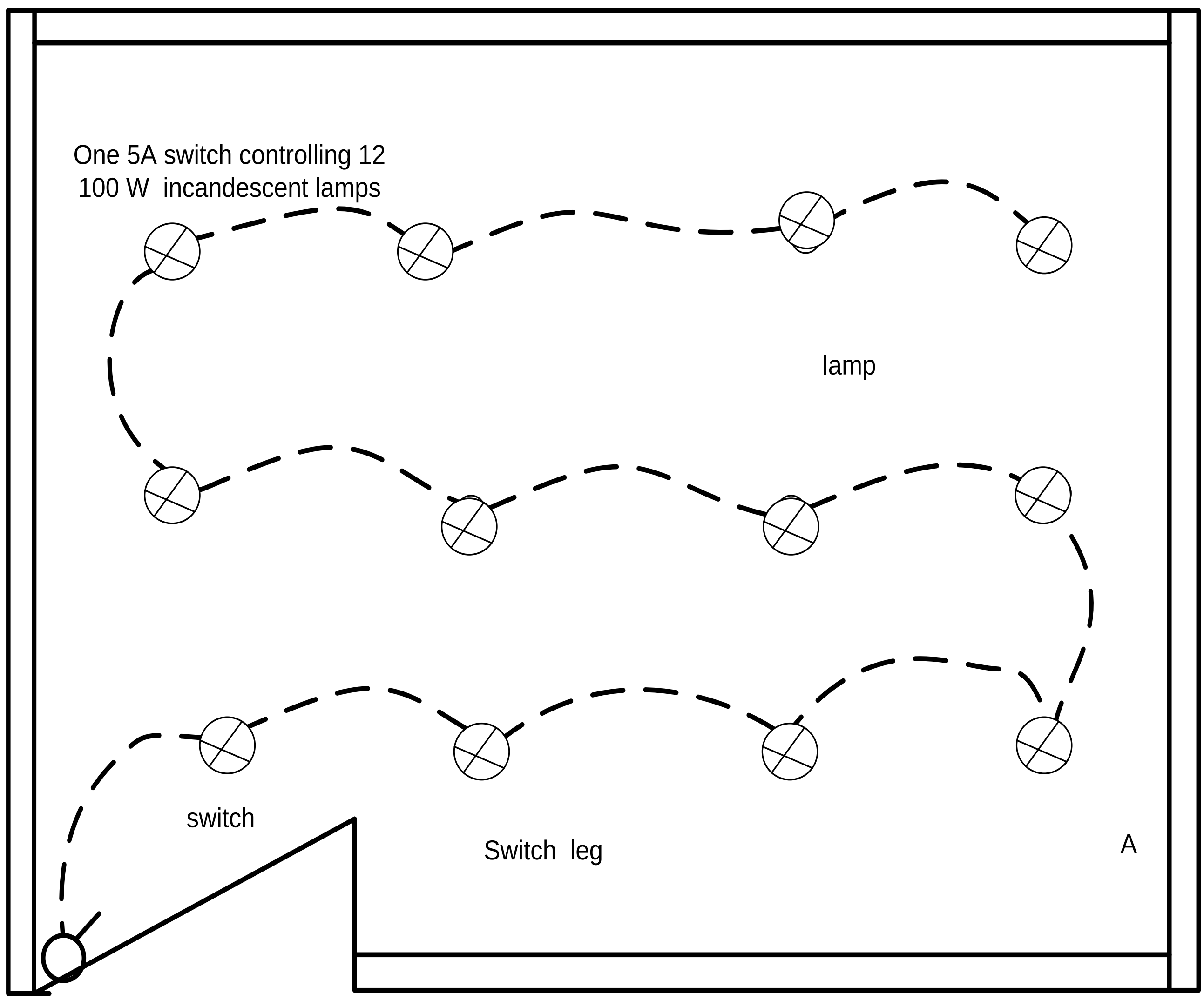


Fig 2.12 A number of incandescent lamps being controlled by one switch.

However, if the lamps are discharge lamps ,say, fluorescent lamps , then because of the high inductiveness associated with discharge lamps , it is necessary to derate the 5A or 15A switch that is to be used to control the discharge lamp ie to assume that the .

rating of the 5A or 15A switch is say 2.5A for the 5A switch or 7.5A for 15A switch. Then proceed to determine the number of, say, 40W fluorescent lamps as follows:

1. Multiply the rating of the lamp by 1.8 (owing to the losses in the lamp control gear (ballast) plus low power factor), and divide the product by the lamps rated voltage to obtain the actual current flowing in the circuit.

The current requirement of one fluorescent tube $I_F = \frac{1.8 \times 40}{240} = 0.3$ A.

Now using 2.5A as the rating of the 5A switch,

The maximum number of fluorescent lamps required $N_F = \frac{2.5}{0.30} = 8.33 = 8$.

Thus one switch can control not more than eight 40 W fluorescent tubes at the same time..

The same principle can be applied to a 15A switch.

2-2.4 Representation of One and multi positional control of lamps schematically and on the Architectural plan

Depending on the size of a room and the requirement of a client, the number of lamps in a given room can be controlled from one or more positions .Usually for small sized room, the lamps are controlled from one position as shown in figure 2.13

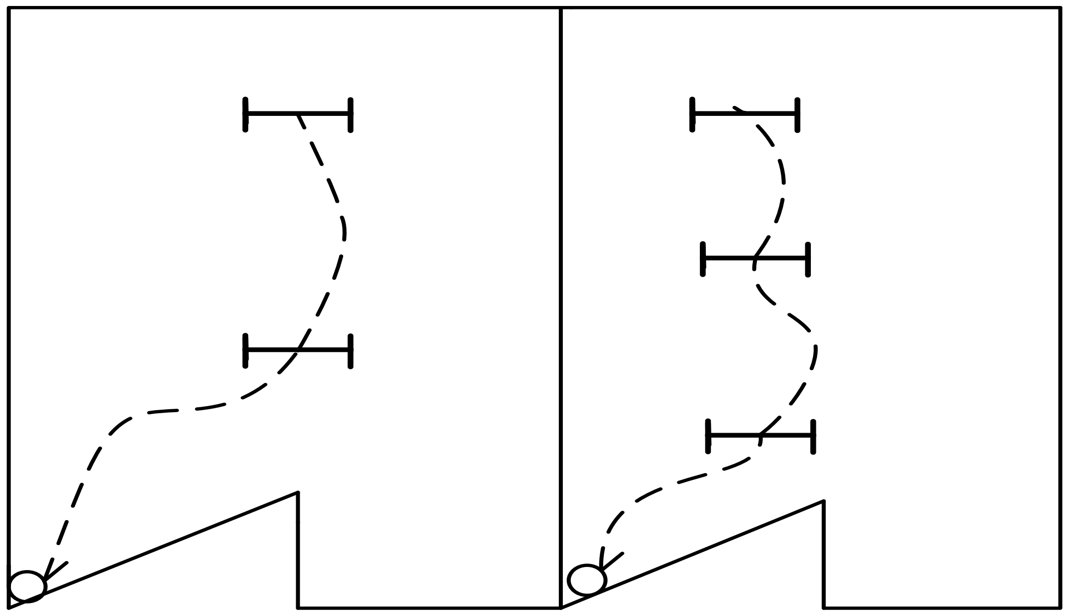
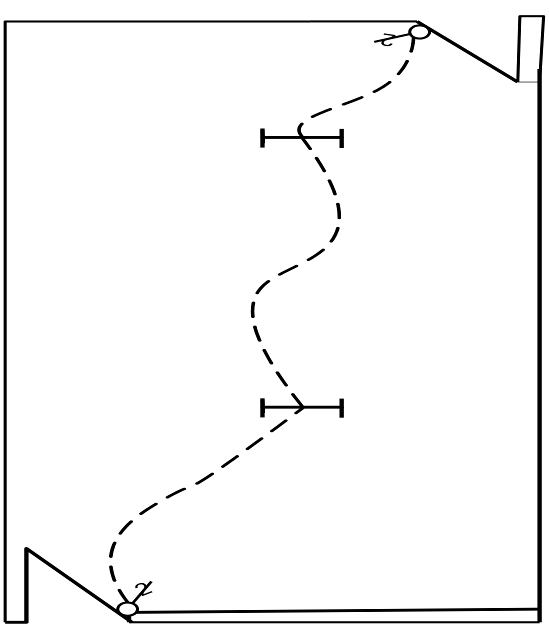


Fig 2.13   Control of lights from one position

However, for long hall especially the one with two or more entrances or exits, the normal practice is to control the lights from more than one position. The switches that are employed to control the lights in such long halls may be either two-way or two-way and intermediate switches. Figure 2.14 shows the control of fluorescent tubes from two and three points respectively.



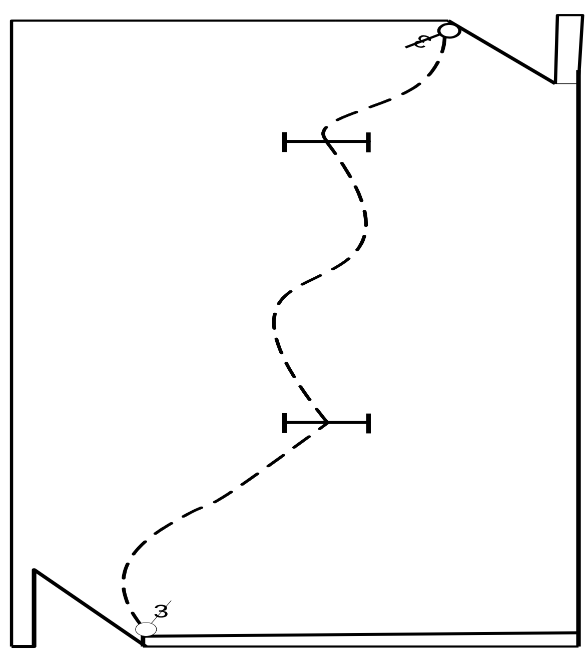


Fig 2.14 Control of lamps from multi-positions (two-way and intermediate)

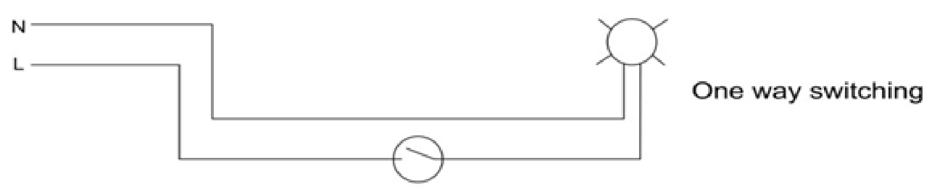
2-2.4 Switching and connecting circuits of lamps

The Figures 2.14 show how multi positional controls of lamps are represented on an architectural plan. The corresponding schematic diagrams for the switching and circuit connections of the lamps can be represented as shown in figure 2.15.

With one way switching the lamps can be switched on and off only from one position.

With two way switches the lamps are controlled from two positions such that when the lamp is switched on from one end of a room and then the original position of the switch at the other end of the room is changed, the lamps will go off. The lamps can be switched on again by bringing either the latter switch or the first switch to its original position..

The same switching principle can be applied to a two way and intermediate switches, except that in this case the lamps can be controlled from three positions in the same way as was explained for the two way switches .



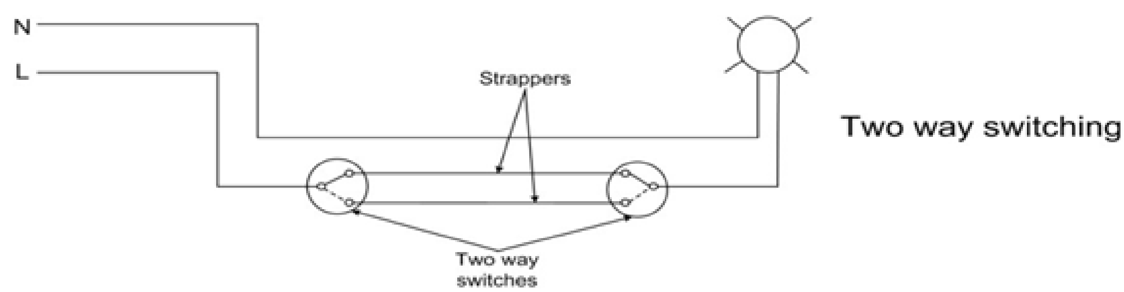


Fig 2.15

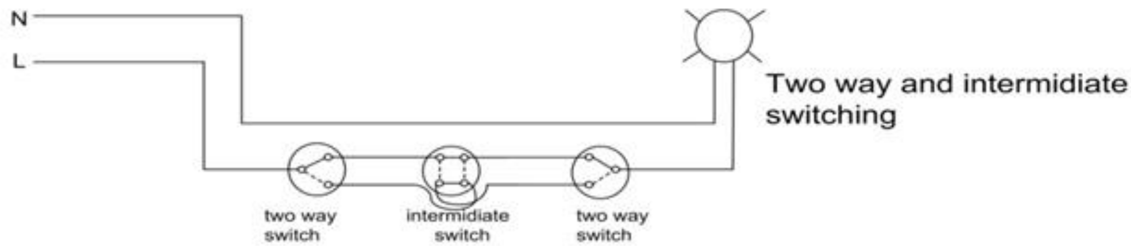


Fig 2.15 (cont'd)

2-2.5 Ring **and Radial connection of socket outlets.**

Ring connection of socket outlets .

As its name implies, a ring connection of socket outlets is one which forms a closed ring; it starts at one of the ways of a distribution board, runs to a number of socket outlets one after another, and returns to the distribution board it started from. This is illustrated in Figure 2.16.

The advantage of this arrangement is that current can flow from the fuse way to the socket outlets along both halves of the ring, so that at any one point the cable carries only part of the total current being taken by the whole circuit.

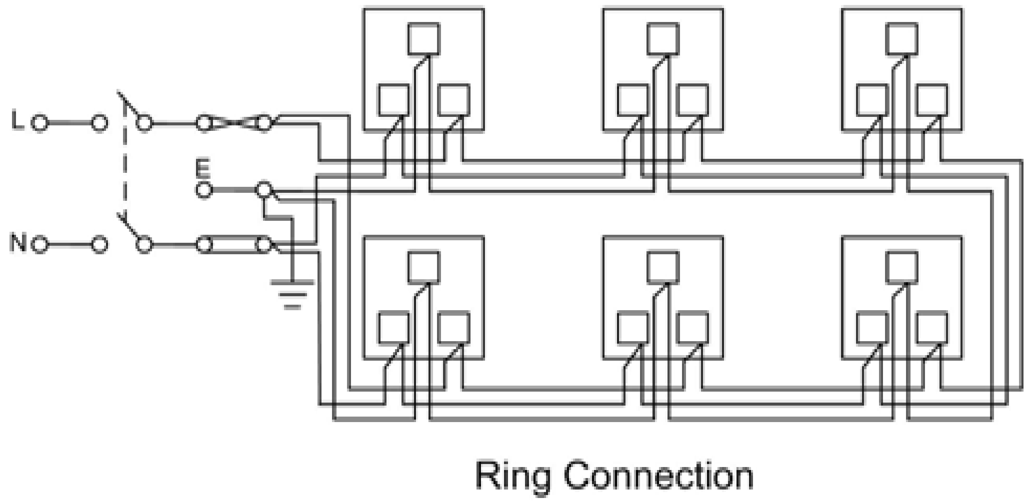


Fig 2.16 Ring and Radial connections of socket outlets.

It is this feature which makes it possible for the fuse rating to be greater than the cable current rating. The fuse carries the sum of the currents in the two halves of the ring and will blow when the current in one part of the ring is about half the fusing current of the fuse. A ring circuit with socket outlets for 13A fused plugs cabled in 2.5mm^2 PVC cable and protected by a fuse or circuit breaker rated at 30A or 32A can serve any number of outlets but the floor area covered must not be more than 100m^2

Radial connection of socket outlets

A circuit which runs only from the fuse way to the outlets it serves without returning to the fuse is called a radial circuit. A radial circuit for this type of outlet can serve a floor area of 50m^2 if it is cabled in 4mm^2 cables and protected by a 30 / 32A HRC fuse or circuit breaker. If it is cabled in 2.5mm^2 cable and protected by any type of fuse or circuit breaker rated at 20A, it is restricted to a floor area of 20m^2. In either case there can be any number of outlets within this area

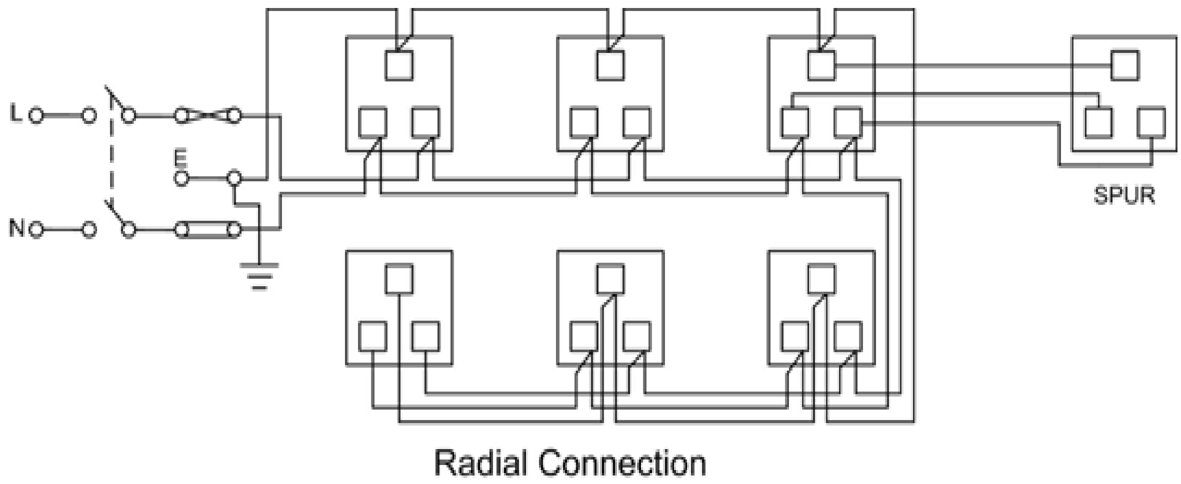


Fig 2.17 Ring and Radial connections of socket outlets

Bathroom requirement for socket outlets and lamp switches

The human body when shoeless wet and covered in moisture from condensing bath water is most vulnerable to electric shock. In those instances the body resistance is greatly reduced. Bathrooms containing a bath and / or shower shall not have any main socket or make provision for main portable equipment. However, it is permissible to install in bathroom a shaver supply unit and or a shaver light unit and totally enclosed luminaries and to have normal access to the insulated cord of a cord switch all within a reach of a person using a bath or shower. All other mains switches, controls or equipment are out of normal reach. Metal work and other conductive parts in bathroom must be bonded to prevent dangerous fault voltage existing during earth fault.

Unit 3

LOAD ESTIMATION AND SELECTION ELECTRICAL SERVICE EQUIPMENT AND DEVICES

Introduction

An important part of any electrical design is the determination of the size of cables. The size of cable to be used in a given circuit is governed by the current which the circuit has to carry, so the design problem is to decide the size of a cable needed to carry a known current. A conductor carrying a current is bound to have some losses due to its own resistance. These losses appear as heat and will raise the temperature of the insulation. The current the cable can carry is limited by the temperature to which it is safe to raise the insulation.

Learning Objectives

After reading this unit you should be able to:

1. Apply the concept of diversity factor and maximum demand and diversity after maximum demand in electrical services design work.
2. Determine the load in a given circuit and use it to select sizes of cables to be used for the circuit under various load demands and operating conditions.
3. Design a lighting arrestor for a given installation.

Unit content

Session 1-3: Concepts of Diversity factor and Maximum demand
1-3.1Diversity factor
1-3.2 Maximum demand
Session 2-3: Cable ratings
2-3.1 Selection of cable sizes under various operating conditions
Session 3-3: Design of a lightning protection system
3-3.1 Design of a lightning arrestor
]

SESSION 1-3: CONCEPTS MAXIMUM DEMAND AND DIVERSITY

1-3.1 Maximum Demand and Diversity

Maximum demand (often referred to as MD) is the largest current normally carried by circuits, switches and protective devices; it does not include the levels of current flowing under overload or short circuit conditions, Assessment of maximum demand is sometimes straightforward. For example, the maximum demand of a 240 V single-phase 8 kW shower heater can be calculated by dividing the power (8 kW) by the voltage (240 V) to give a current of 33.3 A. This calculation assumes a power factor of unity, which is a reasonable assumption for such a purely resistive load.

There are times, however, when assessment of maximum demand is less obvious. For example, if a ring circuit feeds fifteen 13 A sockets, the maximum demand clearly should not be 15 x 13 = 195 A, this is because the circuit protection will not be rated at more than 32 A. Some 13 A sockets may feed table lamps fitted with 60 W lamps , whilst others may feed 3 kW washing machines; others again may not be loaded at all.

Lighting circuits pose a special problem when determining MD. Each lamp-holder must be assumed to carry the current required by the connected load, subject to a minimum loading of 100 W per lampholder (a demand of 0.42 A per lampholder at 240 V). Discharge lamps are particularly difficult to assess, and current cannot be calculated simply by dividing lamp power by supply voltage. The reasons for this are:

i)control gear losses result in additional current ii) the power factor is usually less than unity so current is greater, and iii) chokes and other control gear usually distort the waveform of the current so that it contains harmonics which are additional to the fundamental supply current.

So long as the power factor of a discharge lighting circuit is not less than 0.85, the current demand for the circuit can be calculated from:

Current (A) = $\frac{Total\ Lamp\ wattage \times 1.8}{240}$

For example, the steady state current demand of a 240 V circuit supplying ten 65 W fluorescent lamps would be:

I = $\frac{10 \times 65 \times 1.8}{240}$ = 4.88 A

Switches for circuits feeding discharge lamps must be rated at twice the current they are required to carry, unless they have been specially constructed to withstand the severe arcing resulting from the switching of such inductive and capacitive loads.

When assessing maximum demand, account must be taken of the possible growth in demand during the life of the installation.

Suppose the various items connected to a small installation take their loads as shown on table 3.1 by the shaded patches .The total connected load is 12.9 kVA. However, the highest total load demand by the items within a period of 24 hours is 10.4 kVA. This value is termed as the maximum demand on the installation. This value is less than the installed load demand of the connected items because all the connected items do not take their loads at the same time ie diversity exists among the load demands of the connected items.

Table 3.1 To illustrate the meaning of maximum demand and diversity for various items of installed load in a small installation

	kVA	DAY											
		6AM	7AM	8AM	9AM	10AM	11AM	12AM	13PM	14PM	15PM	16PM	17PM
CENTRAL HEATING	0.2												
APPLIANCES	0.5												
	0.7												
POWER	2.5												
WATER HEATER	3.0												
OVEN	6.0												
INSTALLED LOAD	12.9												
DEMAND	kVA	0.9	6.9	6.2	3.2	0.2	0.2	3.0	6.0	0.5	0.5	6.0	9.9

Table 3.1 (cont'd) To illustrate the meaning of maximum demand and diversity for various items of installed load in a small installation.

	kVA	NIGHT											
		18PM	19PM	20PM	21PM	22PM	23PM	24PM	1AM	2AM	3AM	4AM	5AM
CENTRAL HEATING	0.2												
APPLIANCES	0.5												
	0.7												
POWER	2.5												
WATER HEATER	3.0												
OVEN	6.0												
INSTALLED LOAD	12.9												
DEMAND	kVA	10.4	1.4	1.4	3.9	4.2	3.7						

The maximum demand of a simple final circuit with commonly used equipment is calculated from the values given in table 3.2, but the values given may need to be varied by the installation engineer with a suitable degree of knowledge and experience of the diversity applicable to a particular installation. Table 3.3 contains some useful information which will provide guidance on diversity allowances. This information can be used for circuits feeding a number of final circuits or the total current of the separate final circuits may be added together and a diversity allowances applied to this total by a responsible designer.. Other methods used by a qualified electrical engineer are permitted. It should be noted that no diversity is permissible for thermostatically controlled water heaters, floor warming installations or thermal storage space heating installation.

Table 3.2 Current demand of points other than standard circuit arrangements and an example of use

Outlet point or equipment	Assumed load	**Simple example**				
		No of Outlets	**Total load (kW)**	**Assumed current (A)**	**Diversity factor**	**Design current (A)**
Socket outlets 2A	0.5 A	12	_	6.0	25%	1.5
Other socket outlets	Rated current	4 x 15A	_	60.0	50%	30.0
Light outlets per lamp holder	100W	10	1.0	4.2	50%	2.1
Domestic cooker	10A +30% of remainder+5A if auxiliary socket	1	10.7	44.0	-	25.4

	fitted		
Other stationary equipment	BS current rating or normal current		
		Total load current and rating of over current device	**59**

Diversity

A domestic ring circuit typically feeds a large number of 13 A sockets but is usually protected by a fuse or circuit breaker rated at 30 A or 32 A. This means that if sockets were feeding 13 A loads, more than two of them in use at the same time would overload the circuit and it would be disconnected by its protective device.

In practice, the chance of all domestic ring sockets feeding loads taking 13 A is small. Whilst there maybe a 3 kW washing machine in the kitchen, a 3 kW heater in the living room and another in the bedroom, the chance of all three being in use at the same time is remote. If they are all connected at the same time, this could be seen as a failure of the designer when assessing the installation requirements; the installation should have two ring circuits to feed the parts of the house in question.

Most sockets, then, will feed smaller loads such as table lamps, vacuum cleaner, television or audio machines and so on. The chances of all the sockets being used simultaneously is remote in the extreme provided that the number of sockets (and ring circuits) installed is large enough. The condition that only a few sockets will be in use at the same time, and that the loads they feed will be small is called diversity.

By making allowance for reasonable diversity, the number of circuits and their rating can be reduced, with a consequent financial saving, but without reducing the effectiveness of the installation. However, if diversity is over-estimated, the normal current demands will exceed the ratings of the protective devices, which will disconnect the circuits - not a welcome prospect for the user of the installation! Overheating may also result from overloading which exceeds the rating of the protective device, but does not reach its operating current in a reasonably short time. The Regulations require that circuit design should prevent the occurrence of small overloads of long duration.

The sensible application of diversity to the design of an installation calls for experience and a detailed knowledge of the intended use of the installation. Future possible increase in load should also be taken into account. Diversity relies on a number of factors which can only be properly assessed in the light of detailed knowledge of the type of installation, the industrial process concerned where this applies, and the habits and practices of the users.

1-3.2 Diversity factor

Diversity factor is an important element in the design of an installation and its final costing. It is a factor that is applied to sub- mains and mains cables and their associated switch gear to reduce the cross sectional area of the cable conductors and the capacity of the switch gear. The factor is based on the assumption not the whole of the connected load will not be on the same time . According to IEE regulation, factor of diversity should not be allowed when calculating the size of circuit conductors and switch gear of final circuit, other than specified circuits such as cooker circuits. The provision of an allowance for diversity is a matter that calls for special knowledge and experience. The application of diversity is generally decided by the engineer responsible for designing a particular installation. In the table of diversity factor in the IEE regulation ,it is stressed that the figures given are to be taken as a guide only . The actual amount by which they are increased or reduced for each installation is a matter for the installation engineer to decide. Table recognizes ten types of final circuits which diversity applies: lighting ,heating ,cooking appliances which are permanently connected ,motors ,instantaneous type water heater ,floor -warming installations, thermal storage space heating installations ,13A fused socket outlets and appliances fed from these ,and other socket outlets such as those rated 15A . Three general installation premises are also recognized

1. Individual domestics installations including individual flats of blocks
2. Hostels ,boarding houses ,lodging houses and similar premises
3. Shops stores, offices and business premises other than factories

In case of lighting for each type of installation it will be noticed that that the more the total lighting load is likely to be switched on over a definite period the smaller is the allowance made for diversity . In a domestic installation it is estimated that some two-thirds of lighting will be on at any one time. In hotel, the figure is 75 percent. And in a shop, where virtually all the lights are on for most of the time the shop is open ,the figure is 90 percent .It should be noted that no diversity is allowed on the relevant wiring supplying certain loads.

Table 3.3. Allowance for diversity factor for single house or flat

Purpose	Initial allowance	remainder
Lighting	none	66% of total
Heating and power (other than items below)	Total up to 10A	+50%
Cookers	10A	+30% +5A if auxillary socket included
Motors	–	–
Water heaters (Instant type)	Full load of largest and second largest heater	+25%
Standard socket outlets and cooker circuits	Full load of largest circuit	+ 40%
Other socket outlets and fixed equipment	Full load of largest point	+40%

Table 3.4. Allowance for diversity factor for small shops, offices and other business premises

Purpose	Initial allowance	remainder

Lighting	none	90% of total
Heating and power (other than items below)	Full load largest appliance	+75%
Cookers	Full load largest appliance +80% of second largest	+60%
Motors (not lift)	Full load largest motors +80% of second largest	+60%
Water heaters (Instant type)	Full load of largest and second largest heater	+25%
Standard socket outlets and cooker circuits	Full load of largest circuit	+ 50%
Other socket outlets and fixed equipment	Full load of largest point	+75%

Table 3.5. Allowance for diversity factor for Small Hotels, Boarding and Shops, Offices and Guest House

Purpose	Initial allowance	remainder
Lighting	none	75% of total
Heating and power including cookers but other than items below	Full load largest appliance +80% of second largest	+60%
Motors (not lift)	Full load largest motor	+50%
Water heaters (Instant type)	Full load of largest and second largest heaters	+25%
Standard socket outlets and cooker circuits	Full load of largest circuit	+ 50%
Other socket outlets and fixed equipment	Full load of largest point +75% of every point in dining room and other main rooms.	+40%

Worked Example 1-3
A shop has the following single-phase loads, which are balanced as evenly as possible across the 415 V three-phase supply.

2 x 6 kW and 7 x 3kW thermostatically controlled water heaters
2 x 3 kW instantaneous water heaters
2 x 6 kW and 1 x 4 kW cookers
12 kW of discharge lighting (Sum of tube ratings)
8 x 30 A ring circuits feeding 13 A sockets.

We calculate the total demand of the system, assuming that diversity can be applied. Calculations will be based on {Table 3.4}.

The single-phase voltage for a 415V- three-phase system is $\frac{415}{\sqrt{3}}$ = 240V

All loads with the exception of the discharge lighting can be assumed to be at unity power factor, so current may be calculated from

$I = \frac{P}{V}$

Thus the current per kilowatt will be $\frac{1000}{240}$ = 4.17 A

Water heaters (thermostatic)

No diversity is allowable, so the total load will be:
(2 x 6) + (7 x 3) kW = 12 + 21kW = 33kW
This gives a total single-phase current of I = 33 x 4.17 = 137.6 A

Water heaters (instantaneous)

100% of largest plus 100% of next means that in effect there is no allowable diversity.
Single-phase current thus = 2 x 3 x 4.17 = 25.0 A

Cookers

100% of largest	= 6 x 4.17A =	25.0 A
80% of second	$= \frac{80}{100}$ x 6 x 4.17A =	20.0 A
60% of remainder	$= \frac{60}{100}$ x 4 x 4.17 A =	10.0 A
Total for cookers		= 55.0 A

Discharge lighting

90% of total which must be increased to allow for power factor and control gear losses.

Lighting current $= \frac{12 \times 4.17 \times 1.8 \times 90}{100} =$ 81.1 A

Ring circuits

First circuit 100%, current is 30 A

75% of remainder $= \frac{7 \times 30 \times 75}{100} =$ 157.5 A

Total current demand for ring circuits = 187.5 A

Total single phase current demand = 486.2 A

Since a perfect balance is assumed, three phase line current = $\frac{486.2}{3}$ A

= 162 A

SESSION 2-3: CABLE RATINGS

2-3.1 Selection of cable sizes

A current flows through a conductor , resistance of the conductor causes a drop of voltage along its length. Because of this drop, the voltage at the receiving end is less than that at the sending end. Since all electrical equipment used in a building is designed to work on the nominal voltage of the supply in the building, it is necessary to limit the amount by which the voltage drops between the point of entry into the building and the outlet serving an appliance. In other words, the voltage drop in the wiring must be kept reasonably low. BS 7671 require that the voltage drop in the wiring should not exceed a value appropriate to the safe functioning of the equipment. BS 7671 limits the volts drop to 4 per cent of the nominal voltage.
The assumed ambient temperature is 30°C. The maximum conductor operating temperature is 70°C. Therefore it can be assumed that the currents in the conductors will raise the temperature of the cable by 40°C.

It is normal practice to run more than one circuit in an enclosure or to bunch multicore (more than one core) together. If the circuits were grouped with other circuits or if multicore cables were bunched with other multicores, the heat dissipation properties of the circuits or cables would be reduced; the more cables there are in the group the dissipation properties of the cable is reduced. Then if the cables were loaded to their ungrouped level when they are grouped they would overheat. The number of grouped circuits must therefore be taken into account. Table 3.7 gives correction factors to apply for grouping C_g. If an enclosed circuit as in method 3 or 4 is taken, or it is bunched and clipped direct to a non-metallic surface multicore (method 1) for two circuits or two multicore cables, the correction factor is 0.80 (refer to Table 3.7). This means that for two circuits, only 80 per cent of the single circuit current is allowed. For three circuits, the factor is 0.70 (refer to Table 3.7). This means that for three circuits, only 70 per cent of the single circuit or multicore current is allowed.

Consider one single-phase thermoplastic 70°C circuit enclosed in conduit and installed as reference method 3; the minimum fuse size chosen from the range of fuses is 50A. For the fuse to protect the cable against overload, the minimum cable rating, I_z, is 50A. Also, the minimum tabulated rating, I_t, for the cable is also 50A. However, if the cable is grouped with three other circuits (four in total), the correction factor is 0.65. (refer to Table 3.7). The correction factor is applied as a divisor to the protective device rating.

Therefore the minimum rating I_z, or the minimum tabulated rating I_t of the cable will be

$$I_t = \frac{I_n}{C_g} = \frac{50}{0.65} = 76.92\text{A} \qquad (3.1)$$

In other words a cable which will carry 76.92A is acceptable, ie if the cable is derated by a factor of 0.65: $76.92 \times 0.65 = 50A$

Therefore, in these conditions, the cable is rated at 50A. We are selecting a larger size of cable because of the reduction in current carrying capacity due to grouping. If the cable is installed in an ambient temperature of 30°C and loaded with the maximum rated current, the final temperature will be 70°C. Then, if the cable is installed at a temperature above 30°C, the starting temperature of the cable will be higher, and the running temperature will also be higher. Therefore, to prevent the cable from overheating, we must make adjustments to the current carrying capacity of the cable, if it is installed in an ambient temperature above 30°C. Table 3.6 relates to correction factors (C_a) for ambient temperature. For general purpose PVC at 35°C the correction factor is 0.94(refer to Table 3.6) . This means that the cable may only be loaded to 94 per cent of its 30°C capacity. Table 3.6 is for all protective devices other than rewireable fuses.

If the above circuit is run with three other circuits (four in total), there are two correction factors to apply, one for grouping and one for ambient temperature above 30°C. The minimum rating of the cable will be

$$I_z = \frac{I_n}{C_a \times C_g} = \frac{50}{0.65 \times 0.94} = 81.34\text{A} \qquad (5.2)$$

One must also consider if the cable is run in heat-insulating material, whether its ability to dissipate heat will be impaired. To take this into consideration a correction factor is applied when a cable is enclosed in thermal insulation.

The correction factor C_i is applied to the length of the cable. The formula is now amended to

$$I_z\text{, or minimum } I_t = \frac{I_n}{C_a \times C_g \times C_i} \qquad (3.3)$$

When considering overload protection earlier, it was mentioned that when a rewireable fuse was used, a factor of 0.725 is used. The formula is now amended to minimum

$$I_t = \frac{I_n}{C_a \times C_g \times C_i \times 0.725} \qquad (3.4.)$$

If any of the factors are not applicable, ignore them or replace with a 1.

In summary, the procedures involved in working out the correct size of a cable, and final volt drops are as follows:

1. First find the load current of the circuit, I_b

2. Determine the correct factor for the ambient temperature, C_a in which the cable is to be installed (the highest temperature is always taken

3. Determine the correction factor for grouping(C_g) , the cable is run with others

4. Determine the correction factor, C_i if the cable is in contact with or surrounded by, thermal insulation material . if only one side is in contact with the material a factor (cable clipped to a joint) 0.75 is used and 0.5 if the material completely surrounds the cable .

5. Select the rating of the overcurrent device. If this offers what is called closed protection e.g by a MCB , the factor is 1.0 . If however, the device is semi-enclosed fuse ,the factor is reduced to 0.725. In any case, the rating of the device must equal the circuit load current .

5. Determine the size of the circuit conductor, by calculating the desired current rating obtained from the required table

6. Check that the voltage drop does not exceed the maximum permissible value allowed by the IEE regulation.

If I_z represents the current of the conductor, and I_n the rating of the protective device, then

$$I_z = \frac{I_n}{C_a \times C_g \times C_i \times C_p} \tag{3.5}$$

where C_g is the correction for grouping ; C_a is the correction for ambient temperature ; C_i is the correction for factor thermal insulation , if applicable ; C_p is the correction for the overcurrent protective device.

Table 3.6 Ambient temperature correction factors

Ambient temperature	25^0C	30^0C	35^0C	40^0C	45^0C	50^0C	55^0C	60^0C	65^0C	70^0C	75^0C
PVC insulated	1.06	1.00	0.94	0.87	0.79	0.71	0.61	0.50	0.35	-	-
Rubber insulated	1.02	1.00	0.97	0.94	0.92	0.89	0.85	0.77	0.68	0.59	0.47

Table 3.7 Grouping factors of cables

	Number of Circuits						
	1	2	3	4	5	6	7
Direct on walls	1.0	0.8	0.7	0.65	0.6	0.57	0.54
Closed together	1.0	0.85	0.79	0.75	0.73	0.72	0.72

Table 3.8 Current carrying capacities and associated voltage drops for twin and multicore p.v.c insulated cables non armoured (copper conductors)

Conductor cross sectional area	Installation method A to C			
	One twin cable with or without protective conductor Single phase a.c or d.c		One three core cable with or without protective conductor Three phase a.c or d.c	
1	Current carrying capacity 2	Volt drop per ampere per metre 3	Current carrying capacity 4	Volt drop per ampere per metre 5
mm^2		mV	A	mV
1.0	14	42	12	37
1.5	18	28	16	24
2.5	24	17	21	15

4.0	32	11	29	9.2
6.0	40	7.1	36	6.2
10.0	53	4.2	49	3.7
16.0	70	2.7	62	2.3
25.0	79	1.8	70	1.6
35.0	98	1.3	86	1.1
50.0	-	-	-	-
70.0	-	-	-	-
95.0	-	-	-	-
120.0	-	-	-	-
150.0	-	-	-	-
185.0	-	-	-	-
240.0	-	-	-	-
300.0	-	-	-	-
400.0	-	-	-	-

Table 3.8 (contd) Current carrying capacities and associated voltage drops for twin and multicore p.v.c insulated cables non armoured (copper conductors)

	Installation method E to H	Installation method K

Conductor cross sectional area	(Clipped direct)				(Defined conditions)			
	One twin cable with or without protective conductor Single phase a.c or d.c		One three core cable with or without protective conductor Single phase a.c or d.c		One twin cable with or without protective conductor Single phase a.c or d.c		One three core cable with or without protective conductor three phase a.c or d.c	
	Current carrying capacity	Volt drop per ampere per metre	Current carrying capacity	Volt drop per ampere per metre	Current carrying capacity	Volt drop per ampere per metre	Current carrying capacity	Volt drop per ampere per metre
1	2	3	4	5	6	7	8	9
mm^2	A	mV	A	mV	A	mV	A	mV
1.0	16	42	13	37	-	-	-	-
1.5	20	28	17	24	-	-	-	-
2.5	28	17	24	15	-	-	-	-
4.0	36	11	32	9.3	-	-	-	-
6.0	46	7.1	40	6.2	-	-	-	-
10.0	64	4.2	54	3.7	-	-	-	-
16.0	85	2.7	71	2.3	-	-	-	-
25.0	108	1.8	90	1.6	114	1.8	95	1.6
35.0	132	1.3	115	1.1	139	1.3	132	1.1

50.0	163	0.92		140	0.81	172	0.92		148	0.81
70.0	207	0.65	0.64	176	0.57	218	0.65	0.64	186	0.57
95.0	251	0.48	0.46	215	0.42	265	0.48	0.46	227	0.42
120.0	290	0.40	0.36	251	0.34	306	0.40	0.36	265	0.34
150.0	330	0.32	0.25	287	0.29	348	0.32	0.25	302	0.29
185.0	380	0.29	0.23	330	0.24	400	0.29	0.23	348	0.24
240.0	450	0.25	0.18	392	0.20	474	0.25	0.18	413	0.20
300.0	520	0.23	0.14	450	0.18	548	0.23	0.14	476	0.18
400.0	600	0.22	0.11	520	0.17	632	0.22	0.11	548	0.17

Table 3.9 Fuse ratings

45 AMP	For circuits of more than 13kW (13000 W)
30 AMP	For socket ring mains, some cooker and shower circuits up to 7kw (7000 w)
20 AMP	For storage and water heater circuits
15 AMP	For single appliance circuits up to 3kw (3000 w)
13 AMP	For appliances between 700 and 3000w (3kw)
5 AMP	For lighting circuits. The maximum permissible load of a lighting circuit is 1200w or 12* 100 watt lamps
3 AMP	For appliances up to 700 watts, such as table lamps and alarm clocks

Worked Examples 2-3

Example 1

A single-phase 240V, 36A loads are to be supplied by means of 70°C thermoplastic PVC twin and earth cables having copper conductors, 25m in length, in an area having an ambient temperature of 35°C The cables are touching another two – single layer cables and they are clipped to a non-metallic surface . The overcurrent device at the origin of the installation is a type-B MCB Calculate the minimum permissible cable size.

Solution1

The cables are clipped to a non-metallic surface so they belong to the Reference method 1

The design current I_b= 36A. Nominal rating of the protective device I_n= 40A (considering the current I_b= 36A.

There are three circuits grouped together so from Table 3.7, C_g= 0.79, From Table 3.6 the correction factor for ambient temperature of 35°C , C_a= 0.94 . The combined factor to be applied, C= $C_a \times C_g$ = 0.79×0.94 = 0.7426

The minimum tabulated rating $I_t = \frac{I_n}{C_a \times C_g} = \frac{40}{0.7426}$ = 53.86 A

Consulting table 3.8, the appropriate I_t= 64A. Therefore, the minimum size with respect to current carrying capacity is 10mm^2.

Regulation group 525–01, states that the voltage at the terminals of a piece of equipment should be appropriate for the standard to which the equipment was manufactured. If no value is stated, the voltage should be such that the equipment operates safely. The safety aspect is satisfied if the volt drop between the terminals of the incoming supply and the terminals of the equipment, if directly connected to the mains, or the socket outlet, does not exceed 2.5 per cent of the nominal voltage of the mains. ie Allowable Voltage drop = $\frac{2.5\ 240}{100} = 6$V

We now need to check that the voltage drop in the 10mm^2 cable is within the permissible value. Table 3.8 gives voltage drop in millivolts per ampere per metre (($VD/A/_m$). To calculate the voltage drop, use the relation

The total volt drop is $\frac{(VD/A/_m)\times I_b \times length\ of\ run}{1000}$ (3.6)

The value of the $(VD/A/_m)$ corresponding to I_t = 64A according to Table 3.8 is 4.2.

Therefore using equation (3.6),

The total volt drop = $\frac{(VD/A/_m)\times I_b \times length\ of\ run}{1000} = \frac{4.2\times 36 \times 25}{1000}$ = 3.7 V

This value is less than 6V. Hence the selected minimum size of 10mm^2 is appropriate.

Note, if the circuit were to be protected by a rewireable fuse to BS 3036, the design of the circuit would be slightly different. In this case an additional factor 0.725 will be applied

ie The cables are clipped to a non-metallic surface so they belong to the Reference method 1

The Design current I_b= 36A. Nominal rating of the protective device I_n= 40A (considering the current I_b= 36A.

There are three circuits grouped together so from Table 3.7, C_g= 0.79, From Table 3.6 the correction factor for ambient temperature of 35°C , C_a= 0.94 . The factor for a protective device of a rewireable fuse $C_p = 0.725$. The combined factor to be applied, C= $C_a \times C_g \times 0.725$ = 0.79×0.94×0.725 = 0.5384, I_n for a rewireable fuse =45A

The minimum tabulated rating $I_t = \frac{I_n}{C_a \times C_g \times 0.725} = \frac{45}{0.5383}$ = 83.60A

From table 3.8, the appropriate I_t= 85A. Therefore, the minimum size with respect to current carrying capacity is 16mm^2.

We now need to check that the voltage drop in the 16mm^2 cable is within the permissible value.

The value of the $(VD/A/_m)$ corresponding to I_t= 85 A according to Table 3.8 is

2.7 mV/.A / m

Therefore using equation (3.6),

$$\text{The total volt drop} = \frac{(VD/A/_m)\times I_b \times length\ of\ run}{1000} = \frac{2.7\times 36 \times 25}{1000} = 2.430\text{ V}$$

This value is less than 6V. Hence the selected minimum size of 16mm^2 is appropriate.

Note that semi-enclosed fuses should be rigorously avoided these days. BS 7671 expresses a preference for cartridge-type fuses.

Example 2.

A 230 V single phase load of 15kW operates at a power factor of 0.85 and is fed from a distribution board located at a distance of 40 m away by a 3 core PVC insulated and non armoured cable with copper conductors. The cable is clipped directly to a cable tray which also carries two other similar cables. The ambient temperature is 45°C and circuit is protected by catridge fuse BS88.

Solution 2

The maximum possible volt drop (MPVD) =2,5% of 240V = 6.0V .

Load current $I_b = \frac{W}{V \times p.f} = \frac{15000}{240 \times 0.85}$ =73.53 A

The required fuse rating I_n for a load current of 73.53 A is 100A.

The cables are clipped to a non-metallic surface so they belong to the Reference method 1

There are three circuits grouped together so from Table 3.6, C_g= 0.79, From Table 3.6 the correction factor for ambient temperature of 45°C, C_a= 0.79. The factor for a protective device of a cartridge fuse $C_p = 1.0$. The combined factor to be applied, C= $C_a \times C_g \times C_p$ = 0.79×0.79×1.0 = 0.6241, I_n for the catridge fuse =100A

The minimum tabulated rating $I_t = \frac{I_n}{C_a \times C_g \times C_p} = \frac{100}{0.6241}$ = 160.23A

Consulting table 3.8, the appropriate I_t= 163A. Therefore, the minimum size with respect to this current carrying capacity is 50mm^2.

We now need to check that the voltage drop in the 50mm^2 cable is within the permissible value.

The value of the $(VD/A/_m)$ corresponding to I_t= 163 A according to Table 3.8 is

0.92 mV/.A / m

Therefore using equation (3.6),

The total volt drop = $\frac{(VD/A/_m)\times I_b \times length\ of\ run}{1000}$ = $\frac{0.92\times 73.53\times 40}{1000}$ = 2.705 V

This value is less than 6V. Hence the selected minimum size of 50mm^2 is appropriate.

Example 3 .

A 240 V single phase load of 22 A is supplied from a distribution board located at a distance of 38 m . The cables are to be single core copper conductor with PVC 85^{o}C insulation and are to be enclosed in metallic conduit. The ambient temperature is to be taken as 60^{o}C. Protection is by MCB.

Solution 3

The maximum permissible volt drop (MPVD) =2,5% of 240V = 6V .

The design current I_b= 22A. Nominal rating of the protective device I_n= 30A (considering the current I_b= 22A.

Here there are no other circuits so, C_g= 1.0, From Table 3.6 the correction factor for ambient temperature of 60°C , C_a= 0.50 . The factor for a protective device of a MCB $C_p = 1.0$ **.** The combined factor to be applied, C= $C_a \times C_g \times C_P$ = 1.0×0.50×1.0 = 0.50, I_n for a rewireable fuse =30A.

The minimum tabulated rating I_t= $\frac{I_n}{C_a \times C_g \times C_P}$ = $\frac{30}{0.50}$ = 60A

Consulting table 3.8, the appropriate I_t= 70A. Therefore, the minimum size with respect to current carrying capacity is 16mm^2.

We now need to check that the voltage drop in the 16mm^2 cable is within the permissible value.

The value of the $(VD/A/_m)$ corresponding to I_t = 70 A according to Table 3.8 is

1.8 mV/.A / m

Therefore using equation (3.6),

The total volt drop = $\dfrac{(VD/A/_m)\times I_b \times length\ of\ run}{1000} = \dfrac{1.8\times 22 \times 38}{1000}$ = 1.504 V

This value is less than 6V. Hence the selected minimum size of 16mm^2 is appropriate.

Example 4.

A 240 V, 4kW fixed resistive load is to be fed by a PVC -insulated and sheathed cable. The installation condition involves the cable being run with four other similar cables surrounded by glass-fibre thermal insulation. The ambient temperature is accessed as 40^{o}C. Protection is by semi enclosed fuse to BS3936. The length of the run is 18m

Solution 4

The maximum possible volt drop (MPVD) = 2,5% of 240V = 6.0V .

Load current I_b = $\dfrac{W}{V} = \dfrac{4000}{240}$ =16.7 A

The required fuse rating, I_n for a load current of 16.7 A is 20A. The cables are surrounded by a thermal insulation material so C_i =0.5 There are four circuits grouped together so from Table 5.6, C_g= 0.73. From Table 3.6 the correction factor for ambient temperature of 40°C, C_a= 0.79 . The factor for a protective device of a semi enclosed fuses $C_p = 0.725$. The combined factor to be applied, C= $C_a \times C_g \times C_p \times C_i$ = 0.79×0.73×0.725×0.5 = 0.2091,

I_n for the catridge fuse =20A

The minimum tabulated rating $I_t = \frac{I_n}{C_a \times C_g \times c_p} = \frac{20}{0.2091}$ = 95.67A

From table 3.8, , the appropriate I_t= 98A (enclosed condition). Therefore, the minimum size with respect to this current carrying capacity is 35mm^2.

We now need to check that the voltage drop in the 35mm^2 cable is within the permissible value.

The value of the $(VD/A/_m)$ corresponding to I_t= 98 A according to Table 3.8 is

1.3 V/.A / m

Therefore using equation (3.6),

The total volt drop = $\frac{(VD/A/_m)\times I_b \times length\ of\ run}{1000} = \frac{1.3\times 16.7\times 18}{1000}$ = 0.390 V

This value is less than 6V. Hence the selected minimum size of 35mm^2 is appropriate.

SESSION 3-3: DESIGN OF A LIGHTNING PROTECTION SYSTEM

3-3.1 Design of a lightning arrestor

Electrical installation of tall building and factories will be incomplete without the inclusion of protection against lightning. Protection design is largely a matter of experience as most design formulae are imperical. Lightning discharge is characterized by the time taken to produce it, and by the fact that it usually strikes against the highest and most pointed object in the area.

The effects of a discharge on a structure are electrical, thermal and mechanical.

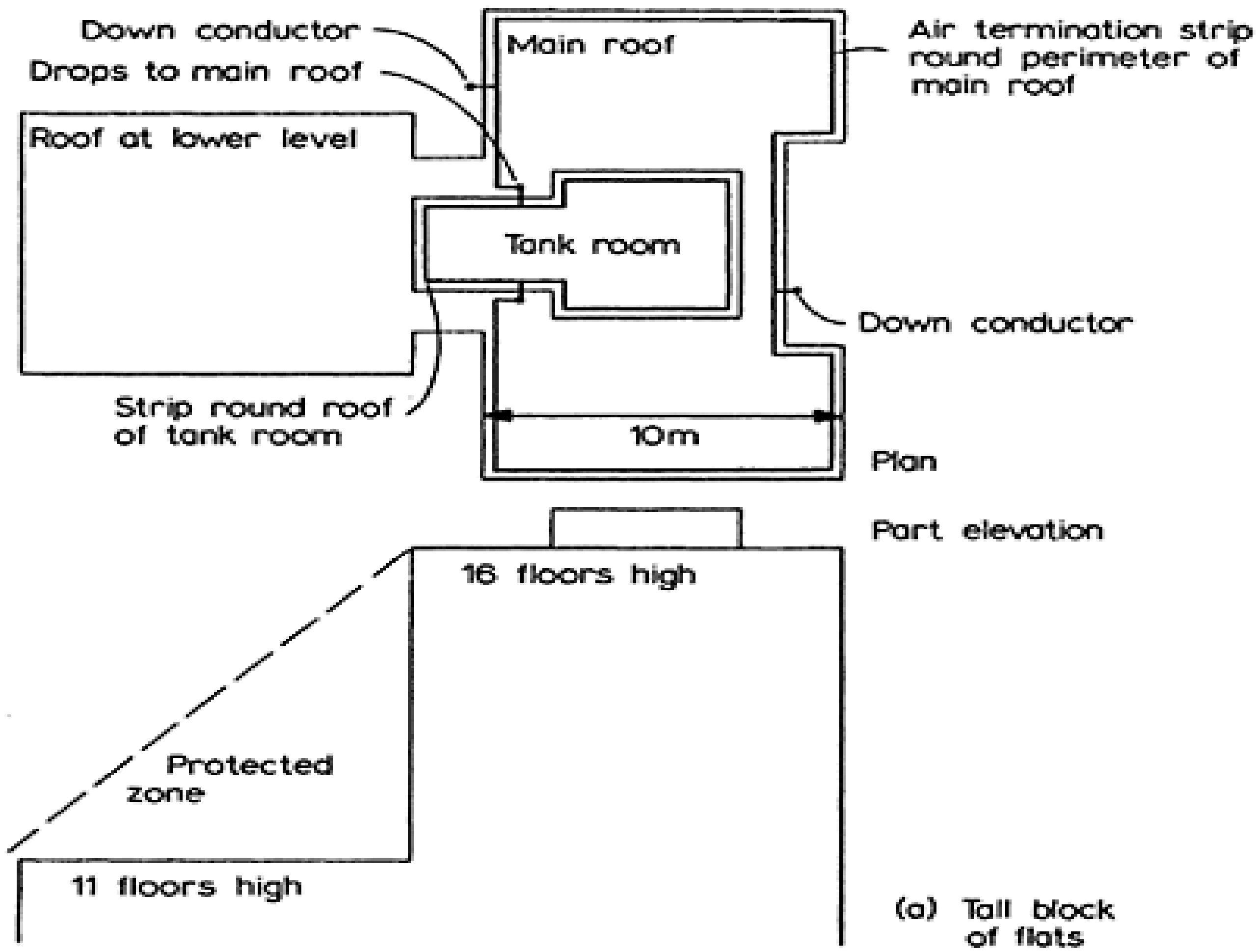
A complete lightning protective system consists of an ***air termination network***, ***a down conductor*** and ***an earth termination***.

The air termination network

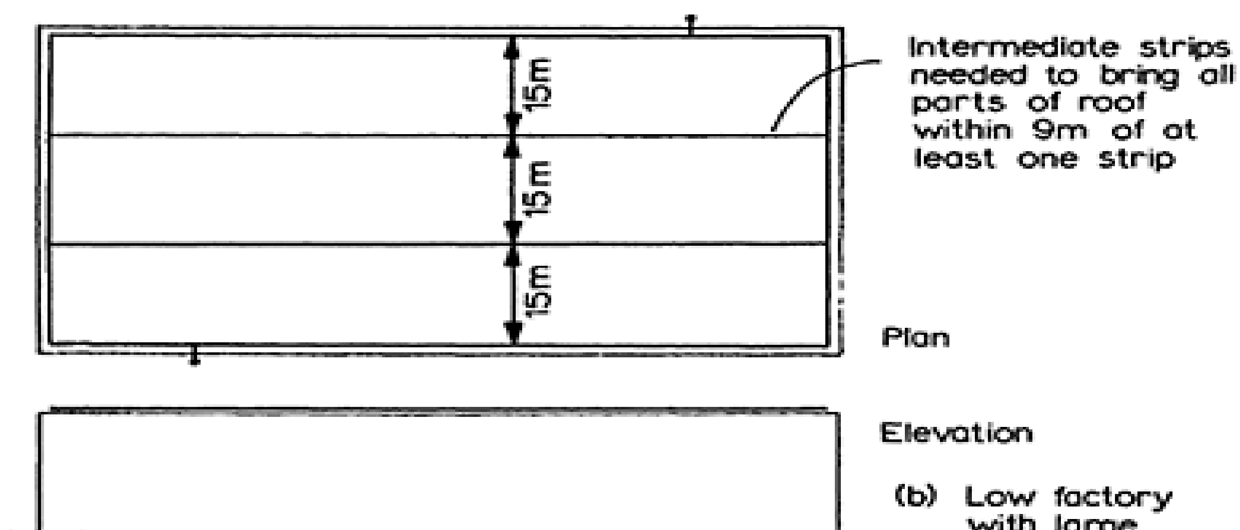
It is that part which is intended to intercept lightning discharges. It consists of vertical and horizontal conductors arranged to protect the required area in accordance with the empirical rules. Typical arrangements are shown in Figures 3.1 and 3.2 .

The earth termination

It is that part which discharges the current into the general mass of the earth. In other words, it is one or more earth electrodes. Earth electrodes for lightning protection are no different from earth electrodes for short-circuit protection systems. The total resistance of an earthing system, with all electrodes in parallel, should not exceed 10ohms. It is clearly safer to ensure that the resistance of each electrode is less than 10ohms. It is also recommended that the same earth termination system should be used for lightning protection as for all other services. The electrodes should be the rod or strip type, and should be either beneath or as near as possible to, the building being protected.



(a) Tall block of flats



(b) Low factory with large horizontal roof

Figure 3.1 Typical lightning conductors

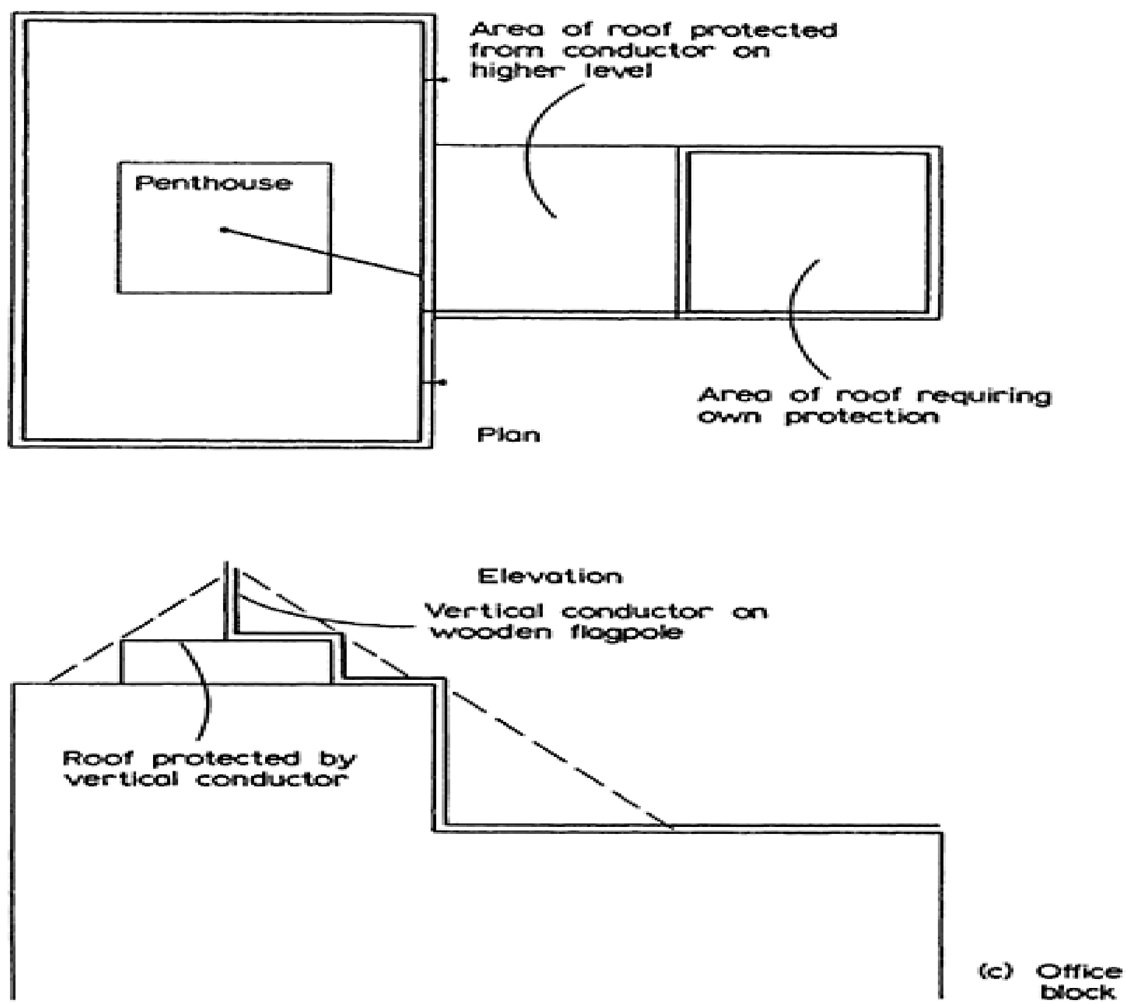


Figure 3.2 Typical lightning conductors

The down conductor

It is the conductor which runs from the air termination to the earth termination. There should be one down conductor for every 20m of perimeter. For buildings higher than 20m there should be one down conductor for every 10m of perimeter. A tall non-conducting chimney should have two down conductors equally spaced, with metal conductors joining the two down conductors round the top and bottom of the chimney and at intervals along its height. The down conductors should preferably be distributed round the outside walls of the building.

A lightning conductor works by diverting to itself a stroke which might otherwise strike part of the building being protected. The zone of protection is the space within which a lightning conductor provides protection by attracting the stroke to itself.

It has been found that a single vertical conductor attracts to itself strokes of average or above average intensity which in the absence of the conductor would have struck the ground within a circle, having its centre at the conductor and a radius equal to twice the height of the conductor. For weaker than average discharges the protected area becomes smaller.

For practical design it is therefore assumed that statistically satisfactory protection can be given to a zone consisting of a cone with its apex at the top of the vertical conductor and a base of radius equal to the height of the conductor. This is illustrated in Figure 3.3.

A horizontal conductor can be regarded as a series of apexes coalesced into a line, and the zone of protection thus becomes a tent-like space (Figure 3.5). When there are several parallel horizontal conductors the area between them has been found by experience to be better protected than one would expect from the above considerations only.

On the basis of experience the recommended design criterion is that no part of the roof should be more than 5m from the nearest horizontal conductor except that an additional 1.0m may be added for each 1.0m by which the part to be protected is below the nearest conductor.

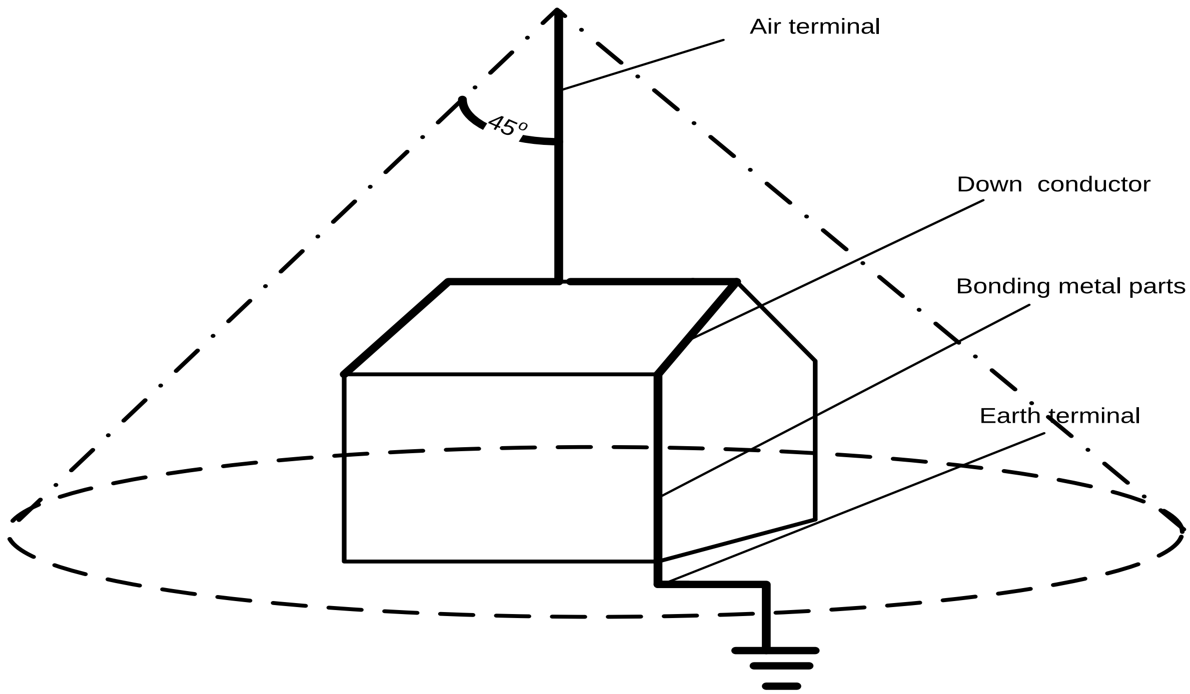


Fig 3.3 illustration of Cone of protection in lightning design

All objects inside this cone of 45° will be protected by this lightning arrangement

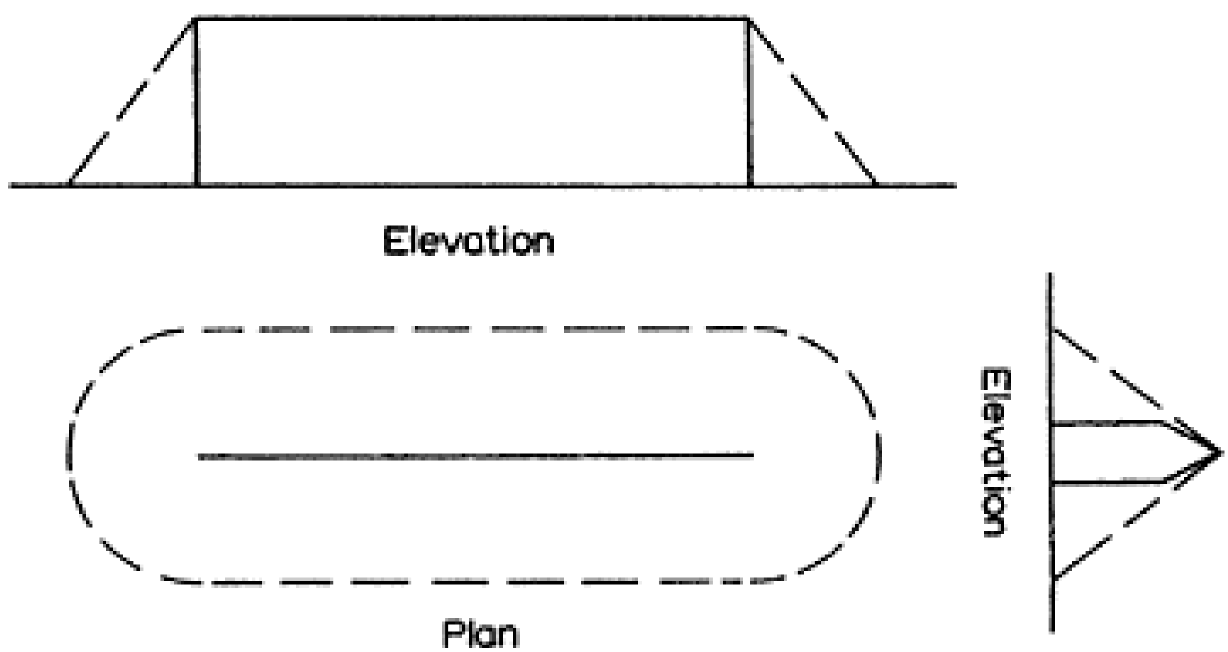


Figure 3.5 Protected zones— horizontal conductor

For structure of a complicated nature a ‘rolling sphere’ of a given diameter method is used.

The rolling sphere involves rolling an imaginary sphere of radius, practically, 60m over structures .The area that is touched by the sphere is deemed to require a protection .On tall structures this can obviously include the sides of the building.

The rolling sphere theory is based on two assumptions: (a) the point of strike of lightning is determined when the downward leader approaches the earth or a structure within a striking distance of about 46m, and (b) lightning strikes the nearest object on earth from the orientation point and so its worst position is the center of a sphere which attaches several earth objects. The conclusion is no lightning will strike the structure to be protected if its striking distance is greater than the radius of the sphere. The rolling sphere method of lightning protection is illustrated in fig 3.6 .

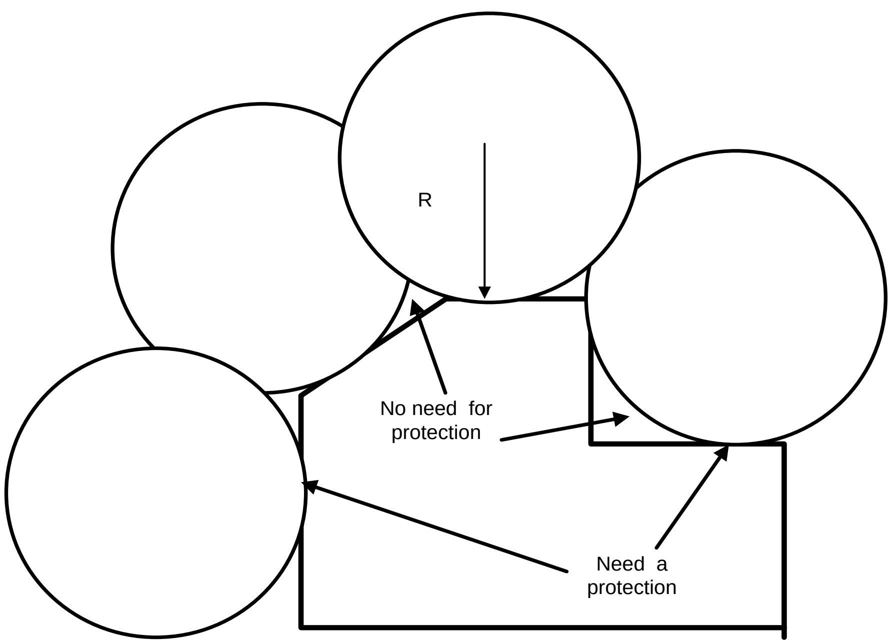


Fig 3.6 Rolling sphere method of lightning protection design.

Whether or not a building needs protection against lightning is a matter of judgement. It obviously depends on the risk of a lightning stroke and also on the consequence of a stroke. Thus a higher risk of a strike can probably be accepted for an isolated small bungalow than for, say, a children's hospital. While no exact rules can be laid down that would eliminate the designer's judgement entirely, some steps can be taken to objectify the assessment of risk and of the magnitude of the consequences.

The method recommended in BS 6651:1999 is to determine the probable number of strikes per year, apply a weighting factor to this, and see if the result is more or less than an acceptable level of risk. The weighting factor is the product of individual factors which take into account the use of the structure, the type of construction, the consequential effects of a strike, the degree of isolation and the type of country.

An example will illustrate how a typical lightning protection can be designed

Worked Example 3-3

Example 1

A large factory is in a built-up area within Greater London. It is assumed to be 80m long by 15m wide and to be 6m high. Design a suitable lightning protection for the building.

Solution1

Vertical rods on the roof to give protection over such an area would be impracticably high, so the air termination

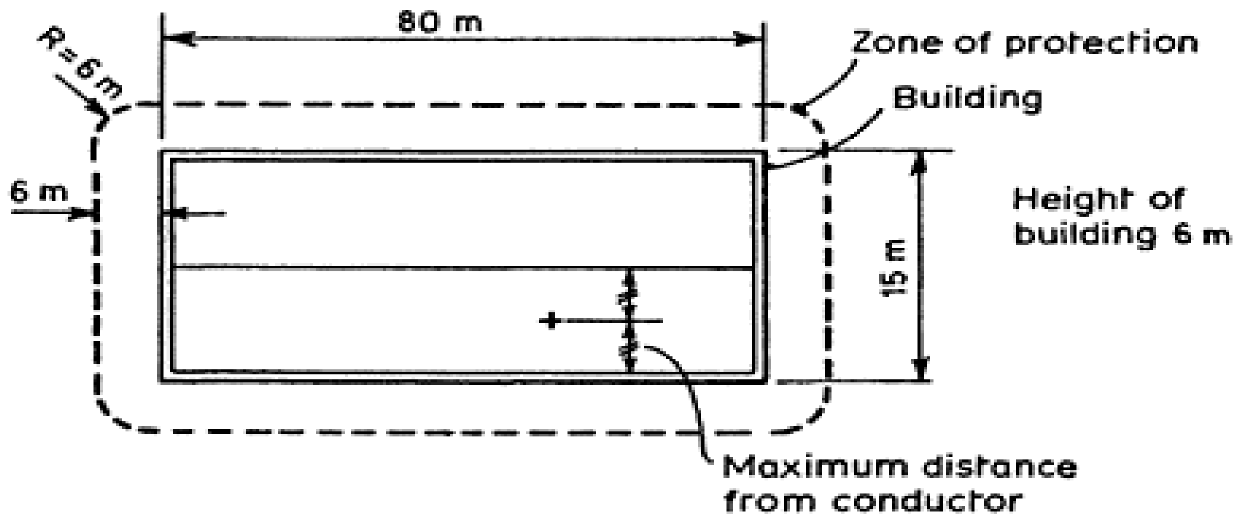


Figure 3.7 Zone of protection and spacing of air termination

must be a network of conductors on the roof. One strip will run round the perimeter, and an additional lengthwise strip down the centre of the roof will ensure compliance with the requirement that no part of the roof is more than 5m from the nearest horizontal conductor. This is shown in Figure 3.7 which also shows the area protected; the latter extends outside the building by a distance equal to the height. This amount of preliminary design had to be done to establish the area protected, which is needed to determine whether or not protection is necessary.

The steps needed to be taken to establish the zone of protection are as follows.

i) We calculate the area of the protected zone (fig 3.7), A_c

The protected area, $A_C = (80 + 6 + 6) \times (15 + 6 + 6) + \pi 6^2 = 2600\text{m}^2$.

We then consult a graph as in fig 3.8 to determine N_g - lightning flash density, i.e. the number of flashes to ground per km^2 per year. For Greater London, this value Ng =0.6

We then calculate the probable number of strikes $P=A_c \times N_g \times 10^{-6}$.

With A_C =2600m^2 and Ng =0.6

$P = 2600 \times 0.6 \times 10^{-6} = 1560 \times 10^{-6}$

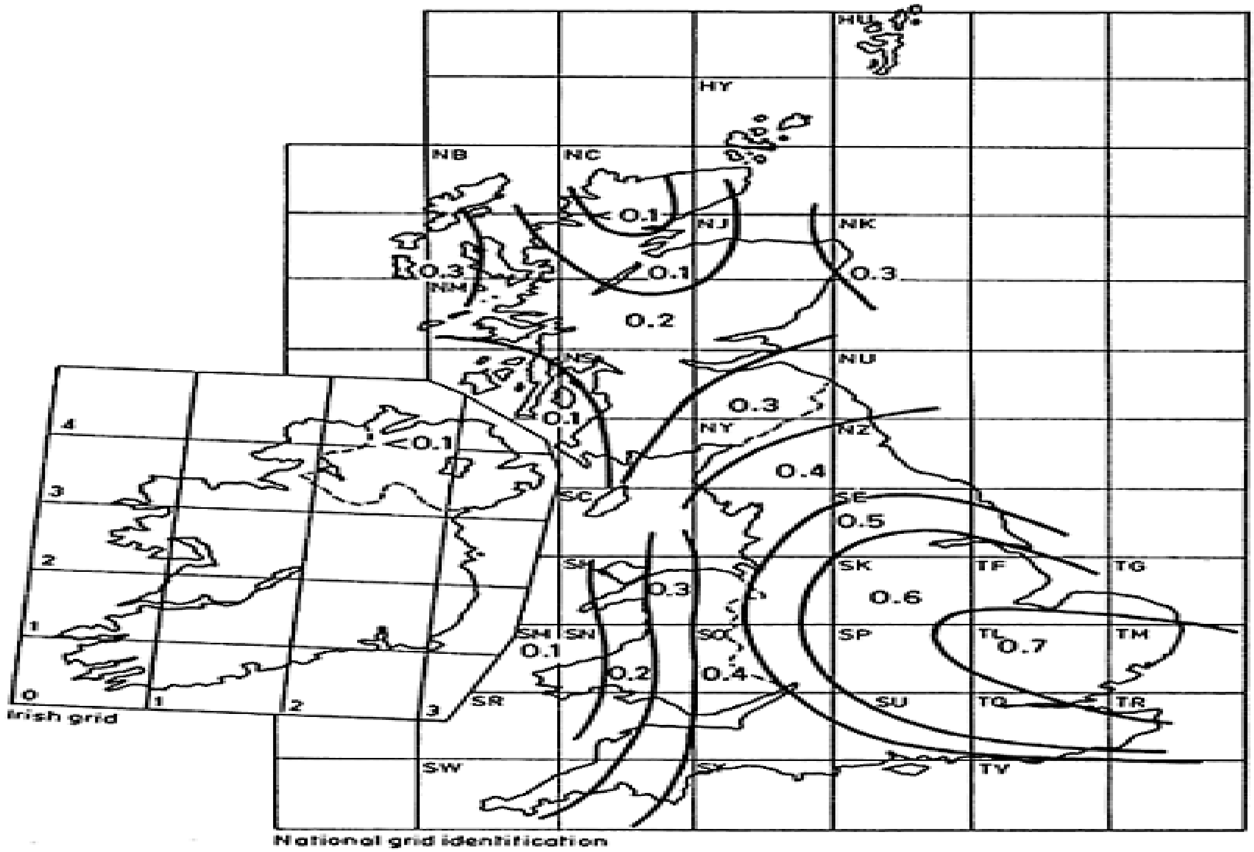


Figure 3.8 Number of lightning

We then consult a table 7.1 for what is called weighing factors for our building.

Table 3.10 Need for lightning protection

Weighting factor	*Factor*
A Use of structure	
Houses and similar buildings	0.3
Houses and similar buildings with outside aerial	0.7
Factories, workshops, laboratories	1.0
Offices, hotels, blocks of flats	1.2

Places of assembly, churches, halls, theatres, museums, department stores, post offices, stations, airports, stadiums	1.3
Schools, hospitals, children’s and other homes	1.7

B Type of construction

Steel framed encased with non-metal roof	0.2
Reinforced concrete with non-metal roof	0.4
Steel framed encased or reinforced concrete with metal roof	0.8
Brick, plain concrete, or masonry with non-metal roof	1.0
Timber framed or clad with roof other than metal or thatch	1.4
Brick, plain concrete masonry, timber framed, with metal roof	1.7
Any building with a thatched roof	2.0

C Contents or effects

Contents or type of building

Ordinary domestic or office building, factories and workshops not containing valuable Materials	0.3
Industrial and agricultural buildings with specially susceptible contents	0.8
Power stations, gas installations, telephone exchanges, radio stations	1.0
Industrial key plants, ancient monuments, historic buildings, museums, art galleries	1.3
Schools, hospitals, children’s and other homes, places of assembly	1.7

D Degree of isolation

Structure in a large area of structures or trees of same height or greater height, e.g. town or forest	0.4
Structure in area with few other structures or trees of similar height	1.0

Structure completely isolated or twice the height of surrounding structures of trees	2.0
E ***Type of country***	
Flat country at any level	0.3
Hill country	1.0
Mountain country between 300m and 900m	1.3
Mountain country above 900m	1.
Weighting factor	*Factor*

Multiplying P by these weighing factors we get

P_o=1560×10^{-6} × 1.0×0.2×0.3×0.4×0.3=11×10^{-6}=1.1×10^{-5}

This is greater than 1.0×10^{-5} and therefore protection is needed.

The building perimeter is

(2×80)+(2×15)=190m

The building perimeter is

(2×80)+(2×15)=190m

The number of down conductors required will therefore be 190/20=10.

Each will terminate in a rod type earth electrode. There are metal rainwater pipes running down the building, and it is necessary to consider whether they should be bonded to the down conductors. The down conductors may be 20mm×3mm, then from

$$R_e = \frac{w+t}{3.5} \tag{3.2}$$

where R_e = equivalent radius of down conductor, m.

w= width, m

t = thickness, m.

$R_e = \frac{w+t}{3.5} = \frac{0.02+0.003}{3.5} = 0.00657$ m

Suppose there is a rainwater pipe 1.5m from a down conductor. Then from

$$M_T = 0.46 \log_{10} \frac{S}{R_e} \qquad (3.3)$$

where

M_T = transfer inductance, μH m−1

S = distance between centre of down conductor and centre of nearest vertical metal component, m

$$M_T = 0.46 \log_{10} \frac{S}{R_e} = 0.46 \log_{10} \frac{1.5}{0.00657} = 1.08$$

The inductive voltage is proportional to the rate of change of current, and for design purposes this must be taken as the maximum likely to occur, which is 200kA s−1. The voltage is therefore calculated from the formula

$$V_L = 200 \times \frac{l \times M_T}{n} \qquad (3.4)$$

where

V_L= inductive voltage, kV

L = length of inductive loop, m

M_T=transfer inductance μH m−1

n =number of down conductors.

Since both rainwater pipe and down conductor runs the full height of the building, l=6 and the number of down conductors is 10. Then from equation (6.3)

$V_L = 200 \times \frac{l \times M_T}{n} = 200 \times \frac{6 \times 1.08}{10} = 130$ kV

The down conductor is not at a corner, so this figure can be reduced by 30 per cent.

$V_L = 130 \times 0.7 = 90.7$kV

The resistive voltage V_R is $200 \times 10 = 2000$kV

The flashover voltage $V_L + V_R = 90.7 + 2000 = 2100$kV.

From Figure 6.9 the safe spacing for 2100kV is 5m. The rainwater pipe is less than this distance from the down conductor and therefore bonding is required. Without bonding, the flashover voltage arises almost completely from the resistive component and in order to eliminate this along the whole length of the pipe bonding is required at both top and bottom.

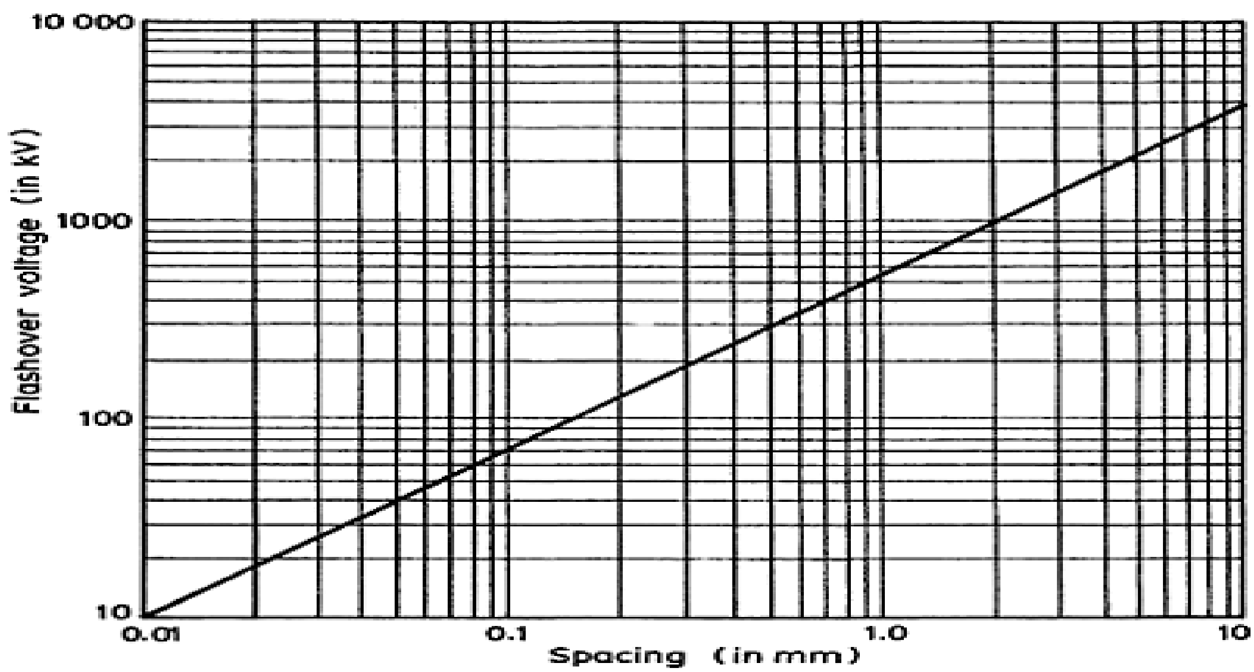


Figure 3.9 Flashover voltage in air as a function of spacing

Worked example on Electrical service design (project work)

The floor plan of a block of flats for a guest house fig A has been provided.

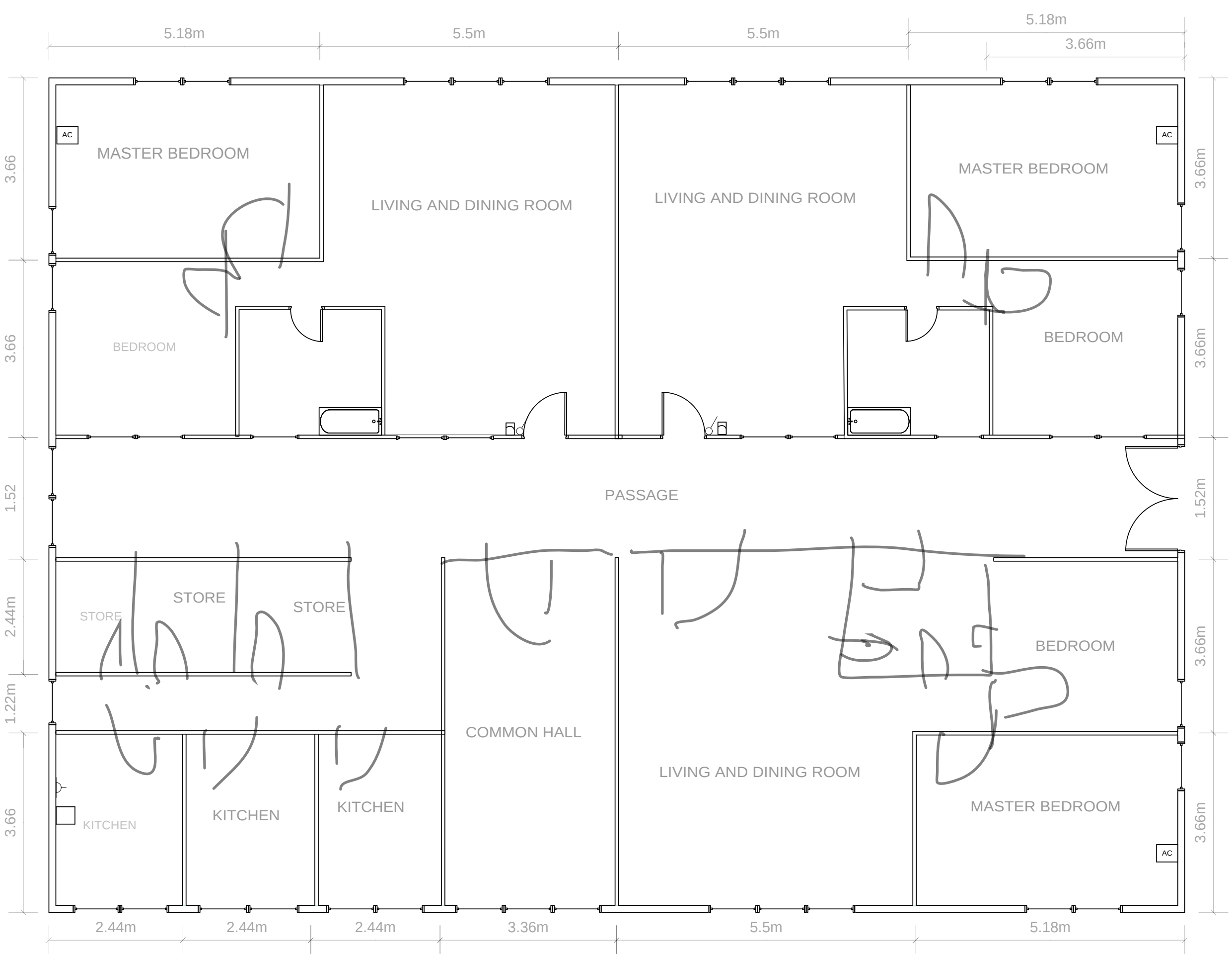


Fig A The floor plan of a block of flats for a guest house

a) On the floor plan you are required to provide the following:

1) 4ft (1200mm), 40 watts bare fluorescent fittings, showing their circuits and switching arrangements.

Lighting in the living and dining rooms and the common hall is to be designed using the **ZonalCavity Method**.

Data:

i) .Ceiling height is 3 meters from the working plain

ii). Initial reflectance of the ceiling, wall and floor may be taken as 80%, 50% and 20% respectively.

iii) Light output of a 4ft 40W fluorescent tube may be taken as 2800 lumens.

iv) The illuminance of the living and dining rooms as well as the common hall may be taken as 150 lux .

v) Assume the heights of work planes in the living and dining and the common hall are 0.5 meters from the floor and a maintenance factor of 0.8.

vi) The “recommended wattage” method may be used for lighting at all other places.

2. Number of 80 watts ceiling fans in the living and the dining rooms.

3. 13 amperes flush socket outlets and their circuit arrangements.

4. One **20 amperes** air conditioner outlet in the master bedrooms. Show their circuits.

5. One cooker control unit for a 6 kW cooker in each kitchen. The cooker control units incorporate 13 amperes socket-outlets.

6. Any additional distribution boards. State the ratings and number of ways of the distribution board (s).

7. Legend of the symbols you will use. Standard symbols should be used throughout.

8. Simple installation instructions or notes.

Using the following information:

i) The height of the Distribution Board and the Main Switch above the floor is 1.5 metres

ii) The height of the lighting and fan switches above the floor is 1.3 metres.

iii) Dimensions shown on the floor plan are that of the rooms.

iv) The thickness of walls is 0.2 metres.

v) The height from the ceiling to the point where the conduit passes through the wall is 0.5 metres.

vi) The Main Switch that supplies the DBs is situated at the main entrance.

vii) Ambient temperature of the rooms may be taken as 40^{o}C.

viii) HBC fuses are employed.

ix) Justify assumptions that may be necessary.

b) Determine the size of P.V.C. insulated single core copper cable that should be used to supply power to the cooker control unit of KITCHEN 3 from the distribution board marked A, assuming that the circuits of all the cookers are enclosed in a single conduit. The DB voltage is 240V, single phase and neutral.

c) Determine the size of P.V.C. insulated single core copper cable which should be used to supply power to the air conditioner of APARTMENT 1, assuming that it is fed by the DB marked B. The DB voltage is 240V, single phase and neutral.

d) Determine the size of P.V.C. insulated single core copper cable which is to be used as service cable to draw power from the Electricity Company of Ghana (E. C. G.) overhead lines, 20 meters away from the Main Switch (MS) if the supply is a 3-phase supply. The allowable voltage drop in the service cable should not exceed 1.5% of the E. C. G. lines voltage. The E C. G. overhead lines are rated 415 volts, 3-phase and neutral.

Solution

Calculation the number of lamps in the rooms

Using the Zonal Cavity method:

Known parameters are ρ_c= 80%, ρ_f = 20%, ρ_w = 50%, h_{cc} = 0m, h_{fc} = 0.5m, h_{rc} = 3m

Parameters needed are CCR, FCR and RCR.

$$\text{CCR}= \frac{5\times(l+w)\times h_{cc}}{l\times w}$$

$$\text{FCR} = \frac{5\times(l+w)\times h_{fc}}{l\times w}$$

$$\text{RCR} = \frac{5\times(l+w)\times h_{rc}}{l\times w}$$

Living room (size = 5.5m × 3.66m) , for fluorescent lamp fittings, h_{cc} = 0m

$\therefore$ CCR = 0,

$$\text{FCR} = 5 \times \frac{(5.5 + 3.66)}{5.5 \times 3.66} \times 0.5 = 1.145,$$

$$\text{RCR} = 5 \times \frac{5.5 + 3.66}{5.5 \times 3.66} \times 3 = 6.87$$

At ρ_c = 80, ρ_w = 50 and CCR =0, from tables 2.10 ρ_{cc} = 80

We then use ρ_f, ρ_w and FCR to acquire ρ_{fc} from table 2.10.

From table 2.10 we find ρ_{fc} at ρ_f = 30 , ρ_w = 50 and FCR=1.145 and then we find ρ_{fc} at ρ_f = 10 , ρ_w = 50 and FCR=1.145 , and finally interpolate between the two values to determine ρ_{fc} at 20. Note that 1.145 is between 1.0 and 1.2 whose value is correspondingly between 27 and 26. Thus

$\rho_{fc(30)} \Rightarrow \quad \frac{1-1.2}{27-26} = \frac{1-1.145}{27-\rho_{fc(30)}}$

$\therefore \rho_{fc(30)} = 26.275$

$\rho_{fc(10)} \Rightarrow \frac{1-1.2}{11-12} = \frac{1-1.145}{11-\rho_{fc(30)}} = \frac{-0.2}{-1} = \frac{-0.145}{11-\rho_{fc(10)}} \Rightarrow 0.2 \times (11 - \rho_{fc(10)}) = -0.145$

$\Rightarrow \frac{0.145}{0.2} + 11 = \rho_{fc(10)} = 11.725$

If $\rho_{fc(30)} = 26.275$, $\rho_{fc(10)} = 11.725$ then, using $\rho_f = 30$, $\rho_f = 10$ and $\rho_f = 20$ then the effective value of floor reflectance at $\rho_f = 20$ is

$\rho_{fc(20)} \Rightarrow \frac{30-10}{26.275-11.725} = \frac{30-20}{26.275-\rho_{fc(20)}} \Rightarrow 20 \times (26.275 - \rho_{fc(20)}) = 10 \times (14.55)$

$\Rightarrow (26.275 - 7.275 = \rho_{fc(20)} \Rightarrow \rho_{fc(20)} = 19$

Using RCR= 6.87, ρ_w =50 and ρ_{cc} = 80 we determine the Utilization factor

Note that although the value of ρ_{fc} is less than 20, our utilization factor to be acquired is used without applying any factor to it.

From the table 2.4 it is found that for ρ_w = 50 and ρ_{cc} = 80, and 6.87 is between 6.0 and 7.0

When RCR = 6, U.F. = 0.43 and when RCR = 7, U.F. = 0.39

$\therefore$ for RCR = 6.87,

$\frac{6-7}{0.43-0.39} = \frac{6-6.87}{0.43-\text{U.F.}} \quad \Rightarrow -0.43+\text{U.F} = 0.04 \times (-0.87) \Rightarrow -0.0348 + 0.43 = \text{U.F}$

$\therefore \mathrm{U.F.} = 0.3952$

Now using equation (1.19), and noting that $\mathrm{U.F.} = 0.3952$, light output =2800,M.F =0.8 and illuminance expected in room is 150lux, room size we determine the number of lamps in the room as follows

$$\text{Number of lamps} = \frac{\text{Illuminance} \times \text{Area of room}}{\text{lumen output} \times \mathrm{U.F.} \times \text{maintenance factor}}$$

Also note that the maintenance factor is in the denominator region. This is because its value is less than 1. For values greater than 1 the maintenance factor is placed in the numerator region of the fraction.

$$\therefore \text{Number of lamps} = \frac{150 \times 5.5 \times 3.66}{2800 \times 0.3952 \times 0.8} = 3.4 \cong 4 \text{ lamps}$$

The above method has been employed for all succeeding Zonal Cavity calculations.

Dining Room (3.66m × 4.73m)

RCR = 7.27, FCR = 1.2, CCR = 0

ρ_{cc} =80, ρ_{cf} = 19

U.F. = 0.3765

Number of lamps $\cong$ 4 lamps

Common Hall (3.36 × 7.32)

RCR = 0.47, FCR = 1.086, CCR = 0

ρ_{cc} =80

U.F. = 0.47

number of lamps = 4

Using table 4.1, we assign the following numbers of lamps to the other rooms

Kitchen -		2 lamps
Store -		1 lamp
Bathroom	-	1 lamp
Outside light	-	6 lamps
Passage	-	6 lamps
Bedroom	-	2 lamps

Also there will be 3 fans in each of the living and dining rooms , a fan in each bed room

b) Size of cable for cooker control unit

Say, maximum possible distance of cooker from BD = 21.7m

Rating of cooker = 6000W ∴ current rating of cooker $= \frac{6000\text{W}}{240\text{V}} = 25\text{A}$

Fuse rating of cooker circuit = 30A = I_n

Applying diversity to this current, the actual current becomes I_B =10 +0.3$\times$ 15 +5 =19.5 A

From the question we assume that all three cooker circuits pass through the same conduit therefore the grouping factor used should be that for three circuits .

The ambient temperature is 40 degrees hence select the corresponding factor from the tables.

Lastly the protective device factor for a HRC fuse or miniature circuit breaker is 1

The minimum conductor current (I_z), using factors of temperature, grouping and fuse type,

$$= \frac{I_n}{0.79 \times 0.87 \times 1} = \frac{30}{0.79 \times 0.87} = 43.65\text{A}$$

Now, with this current we select from table 4.4 the appropriate cable size .

is 6mm^2 which is capable of carrying current up to 46A.

We need test this cable against the permissible voltage drop. The allowable voltage drop per meter run per amp of this current and cable size is 7.1mV.

Now we test the cable to find out if it satisfies the allowable voltage drop criterion.

Allowable voltage drop = $\frac{2.5}{100} \times 240$ = 6V

Voltage drop in cable

= (ΔmV/m/A$\times$ length of cable $\times$ current running through circuit)/1000

= $\frac{7.1 \times 21.7 \times 19.5}{1000}$ = 3,00V which is less than 6V hence the cable we have selected is suitable for the job at hand.

The size of cable for air-conditioner unit

The approximate length of cable = 18.6m

Fuse rating = 20A

Applying the correction factors, the minimum conductor current,

$I_Z = \frac{20}{0.87 \times 1 \times 1} = 23$ A

From tables 2.4 the appropriate cable size that has at least this current of 23A is 2.5mm^2.

Now let us test it against the voltage drop criterion.

The cable has an allowable voltage drop per meter run per amp of 17mV.

Hence the voltage drop $= \frac{17}{1000} \times 18.57 \times 20 = 6.3$ V

We find that this voltage is more than the permissible voltage drop of 6V.

So we select the next larger size of cable 4.0mm^2 which has an allowable voltage drop per meter run per amp of 11mV.

The corresponding voltage drop $= \frac{11}{1000} \times 18.57 \times 20 = 4.11$V

which is less than 6V hence the cable we have selected, 4mm^2 , is suitable for the job at hand.

Load estimation

Maximum number of 40W lamps per circuit = 13 lamps

Number of lamps and fans in the whole house = 81

Therefore approximate number of lamp circuits = 7

Number of socket outlet circuits = 4 (based on $100m^2$ principle).

Number of cooker circuits = 3

Number of air condition circuits = 3

From table 5.4 on diversity we get the following

The approximate total current

$$= (0.75 \times 7 \times 5) + (30 + 0.5 \times 3 \times 30) + (30 + 0.5 \times 30 \times 2) + (20 + 0.5 \times 20 \times 2)$$

= 22.5 +75+60+40 = 201.25A

From this approximation we find that not less than 3 DBs are needed.

Rating of DBs = 240V, 100A, 8 – way

Now we have to distribute the load evenly

Loading of DBs

DB A

Lighting of apartment 1, lighting of living and dining room and passage, cooker of kitchen 1, socket outlets of apartment 1 and 2.

Total load current from DBA to main switch = $(2 \times 5 \times 0.75) + 30 + (30 + 15) = 82.5$A

DB B

Lighting and fans of apartment 2 and outside lights and kitchen, cooker of kitchen 2, AC of apartment 1, 2, 3.

Total load current from DBB to -main switch = $(2 \times 5 \times 0.75) + 30 + (20 + 0.5 \times 2 \times 20) = 77.5$A

DB C

Lighting and fans of apartment 3, kitchen, store etc, cooker of kitchen 3, socket outlets of apartment 3, socket outlets of kitchen

Total load current from DBC to sub-main switch = $(3 \times 0.75 \times 5) + 30 + (30 + 15) = 86.25$A

Total current = 82.5 +77.5+86.25=246.25 A

Each phase of the 3 phase service cable = 246.25/3 = 82.08 A

The size of cable for this current, according to table 4.4, is 16 mm^2 .

Now the length of the cable from the intake to the main switch is 20m and allowable voltage drop is 1.5% of line voltage .

The allowable voltage drop $= \frac{1.5}{100} \times 240$ = 3.6V

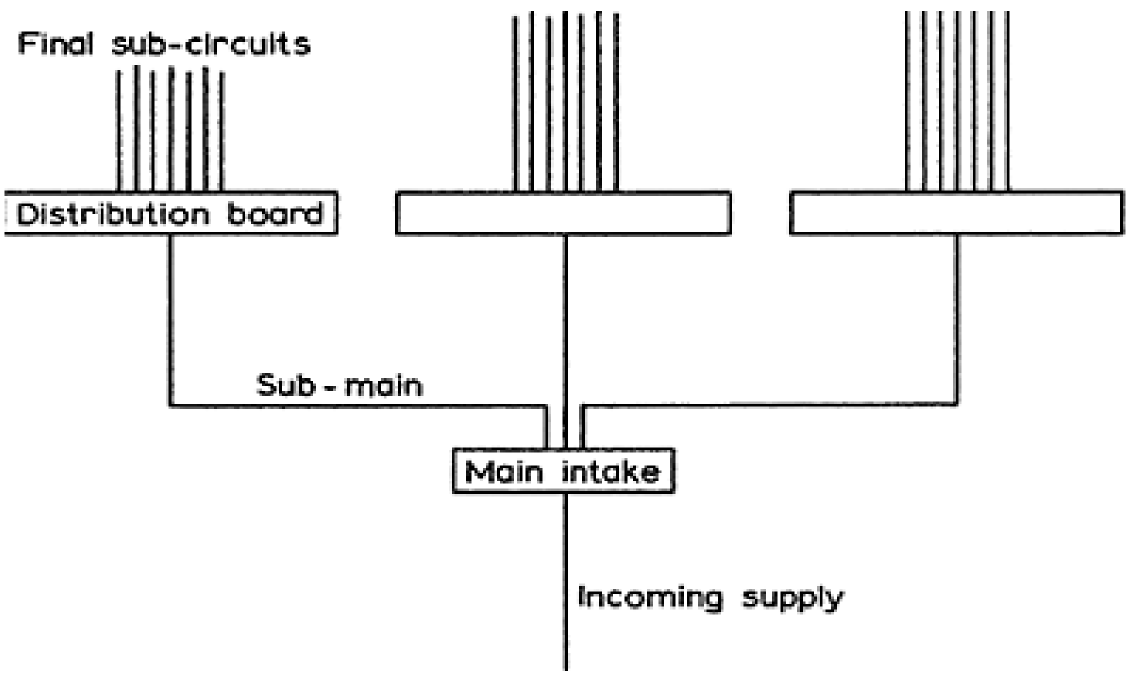
The voltage drop in our selected cable $= \frac{2.7}{1000} \times 82.5 \times 20$ = 4.45V

This voltage drop is more than the allowable voltage, 3.6V, therefore the cable size it is not suitable . We must select the next larger size of cable which is 25mm^2 .

We again test this cable size on voltage drop criteria

The voltage drop in 25mm^2 cable $= \frac{1.8}{1000} \times 82.5 \times 20$ = 2.97V

This voltage drop is less than the allowable voltage, 3.6V, therefore the cable size is suitable.



MY PERSONAL PAGE

Name: ____ Learning Centre: _________________

Contact: Tel. ____________ Email: ________________ Emergency Name/Phone: ___________

Important numbers: Student number ______________ Examination number ________________

Program: ___________ Year: _______ Course code/title: ______________________________

Course objectives: ____

____

Course dates/Semester No (   ): Starts_____________________ Ends ____________________

FFFS schedule/Dates: ____

Quiz dates: ____

Assignments hand in dates: ____

Revision dates: ____

Group discussion/work members (names and contacts): _________________________________

____

____

End of course Self Evaluation:

I have completed all Units & interactive sessions□, mastered all learning objectives, completed all self Assessments, unit summary, key words and terms, discussion questions, review questions, reading activity, web activity, unit assignments, and submitted all CA scoring assignments, learner feedback on this course and submitted my comments and course focus contributory questions to facilitator for discussion.

Self-grading: self assessment questions score ______ %   Unit Assignments scored ______ %

My course conclusion remarks: ____

____

____

____ (may continue on reverse side) detach and return to IDL, KNUST

Learner Feedback Form/[insert course code]

Dear Learner,
While studying the units in the course, you may have found certain portions of the text difficult to comprehend. We wish to know your difficulties and suggestions, in order to improve the course. Therefore, we request you to fill out and send the following questionnaire, which pertains to this course. If you find the space provided insufficient, kindly use a separate sheet.

1. How many hours did you need for studying the units

Unit no.	1	2	3	4	5	6
No. of hours						

2. Please give your reactions to the following items based on your reading of the course

Items	**Excellent**	**Very good**	**Good**	**Poor**	*Give specific examples, if poor*
Presentation quality	☐	☐	☐	☐	
Language and style	☐	☐	☐	☐	
Illustrations used (diagrams, tables, etc.)	☐	☐	☐	☐	
Conceptual clarity	☐	☐	☐	☐	
Self assessment	☐	☐	☐	☐	
Feedback to SA	☐	☐	☐	☐	

3. Any other comments (may continue on reverse side)

Unit 1: ______________________________

Unit 2: ______________________________

Unit 3: ______________________________

Unit 4: ______________________________

Unit 5: ______________________________

Unit 6: ______________________________