11 Lighting

Learning objectives

Study of this chapter will enable the reader to:

1. explain the use of day and artificial lighting;
2. use lux and lumen per square metre;
3. state normal lighting levels;
4. explain general and task illumination;
5. understand permanent supplementary artificial lighting of interiors (*PSALI*);
6. understand artificial lighting terminology;
7. assess the importance of the maintenance of lighting installations;
8. calculate the room index;
9. find utilization factors;
10. discuss the problem of glare;
11. calculate the number of lamps needed to achieve a design illumination level;
12. calculate lamp spacing for overall design;
13. calculate the electrical loading produced by the lighting system;
14. consider how luminaires should be oriented in relation to room layout and visual tasks to be performed;
15. understand the use of air-handling luminaires;
16. understand lamp colour-rendering and colour temperature;
17. know the range of available lamp types;
18. apply appropriate lamp types to designs;
19. understand the working principles of lamp types and their starting procedures.

Key terms and concepts

artificial and natural illumination 261; *BZ* classification 264; colour-rendering 269; colour-rendering index 269; colour temperature 269; daylight factor 262; efficacy 264; electrical power consumption 268; glare 267; heat generation 262; illuminance 261; lamp types 269; *LDL* 262; lighting cost 272; light loss factor 265; lumen 265; luminaire 269; luminance factor 266; lux 262; maintenance 265; models 263; observed illumination pattern 264; presence detector 273; *PSALI* 261; reflection 263; room index 266; spacing-to-height ratio 268; starting arrangements 270; task illumination 262; utilization factor 266; working plane 261.

Introduction

Artificial illumination for both functional and decorative purposes is a major consumer of primary energy, and developed civilizations have become used to very high illumination standards with consequently high electricity consumption. The use of daylight is encouraged in order to reduce fuel consumption for lighting but this occurs at the expense of heating and cooling energy consumption at the building outer envelope, which is in contact with the external environment. A compromise solution is inevitable, and the building services engineer is at the centre of the calculations needed to minimize total energy consumption for all usages.

The factors involved in determining illumination requirements are discussed in relation to lighting levels for various tasks and the possible use of daylight. Lighting terms are introduced as are glare considerations. The lumen design method is demonstrated for office accommodation.

Lamp colour-rendering is discussed, and the use of luminaires with air-conditioning systems. Lamp types, their uses and control arrangements are explained.

Natural and artificial illumination

Natural illumination by penetration of direct solar and diffuse sky visible radiation requires correctly designed passive architecture. Large glazed areas may provide sufficient day lighting at some distance into the building but can also cause glare, overheating and high heating and cooling energy costs.

The other extreme of vertical narrow slot windows limits energy flows while causing very unequal lighting levels near the room's perimeter. Reflected illumination from other buildings, particularly from those having reflective glazing or metallic architectural features, may cause annoyance. A careful consideration of all the, largely conflicting, variable elements is necessary if a comfortable internal environment is to be produced.

Artificial lighting is provided to supplement daylight on a temporary or permanent basis. Local control of lights by manual and/or automatic switches aids economy in electricity consumption. The colours rendered by objects on the working plane should match the colours under daylight. The working plane may be a desk, drawing board or display area.

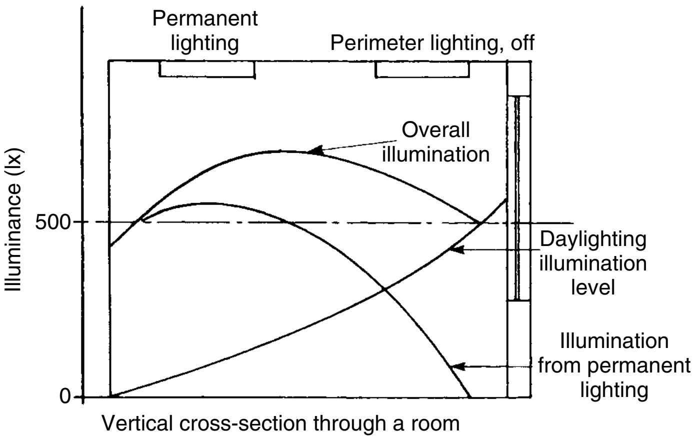
Illumination intensity, illuminance, measured in lux on the working plane, is determined by the size of detail to be discerned, the contrast of the detail with its background, the accuracy and speed with which the task must be performed, the age of the worker, the type of space within which the task is to be performed and the length of time continuously spent on the task. The working plane is the surface being illuminated. Other areas are lit by overspill from it and by reflections from other room surfaces. Table 11.1 gives some typical values for illuminance commonly encountered and used for design.

Higher levels of illuminance may be provided for particularly fine detail tasks at the area of use by local, or task, illumination: for example, up to 3000 lx for inspection of small electronic components and 50 000 lx on a hospital operating table. Bright sunlight provides up to 100 000 lx. Local spot lighting for display purposes and exterior illumination are used to accentuate particular features of the working plane.

Permanent supplementary artificial lighting of interiors (*PSALI*) has become common in modern office accommodation, shops and public buildings. Figure 11.1 shows the constituents of the overall design illumination.

Table 11.1 Typical values of illuminance.

Application	*Illuminance (lx)*
Emergency lighting	0.2
Suburban street lighting	5
Dwelling	50–150
Corridors	100
Rough tasks with large-detail storerooms	200
General offices, retail shops	400
Drawing office	600
Prolonged task with small detail	900



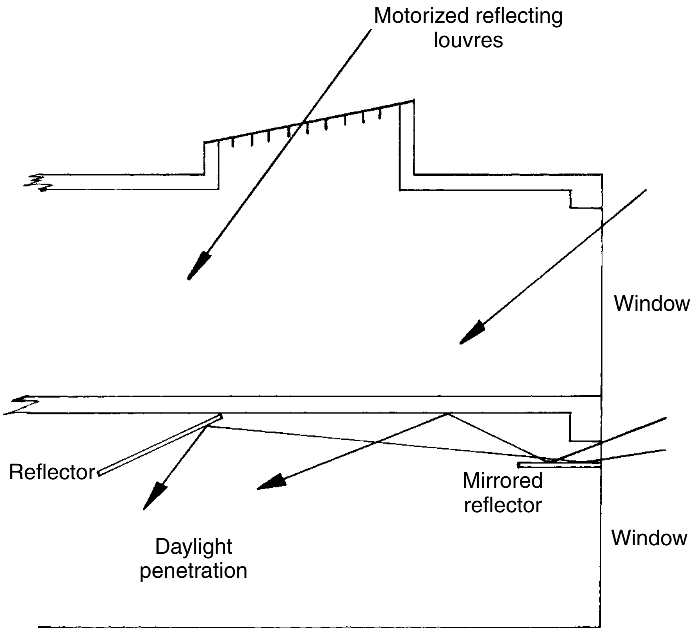
11.1 Permanent supplementary artificial lighting.

The heat generated by permanent lighting can be extracted from the light fitting (luminaire) by passing the ventilation extract air through it, thus raising the air temperature to 30–35°C, and then supplying this heated air to perimeter rooms in winter. Further air heating with finned tube banks and automatic temperature control would be part of a normal ventilation or air-conditioning system. This can be termed a heat reclaim system incorporating regenerative heat transfer between the outgoing warm exhaust air and incoming cold fresh air.

The penetration of daylight into a building can be enhanced with north-facing roof-lights, skylights having motorized louvres which are adjusted to suit the sun's position and weather conditions, or mirrored reflectors which direct light rays horizontally into the building. An example is shown in Fig. 11.2.

Localized task illumination can be provided in addition to a background lighting scheme but may not necessarily produce a reduction in total power consumption. Tests (Ellis, 1981; McKenna *et al.*, 1981) of combinations of overall lighting plus task illumination revealed a preference for two 40 W white fluorescent lamps 1200 mm long plus indirect background lighting.

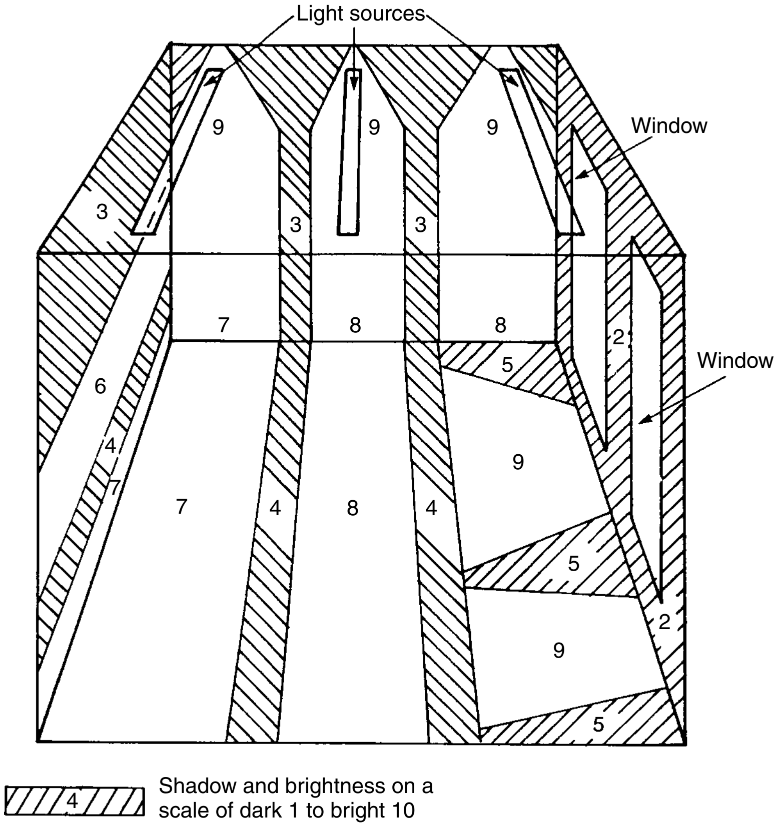
Desk-mounted lamps produce a range of up to 9 : 1 in illuminance values across the working surface and form strong contrasts between surrounding and working surfaces which may result in discomfort glare. Direct dazzle from unshaded lamps, reflected glare, shadows around objects and hands, and heat radiation can cause discomfort.



11.2 Use of daylight reflectors.

Lighting is, obviously, a visual subject and it may be treated as such for design purposes. It is not necessarily helpful to study lighting only as applied mathematics. Designs are an artistic and engineering combination of architecture, interior design, decoration, illumination functionality, economical use of electrical energy, maintainability, safety, environmental health, controllability, prestige and the overall and specific requirements of the user. Architects and engineers coordinate their skills to create an acceptable visual and technical solution.

To consider the design of lighting from a visual standpoint, acquire two or more cardboard boxes. These are to be used to represent rooms (W. Burt, Manchester University). The dimensions are unimportant as the principles of lighting apply to volumes of any size. They can be used to evolve answers to Questions 15–21 at the end of this chapter. This may be seen as a crude method of higher education; however, the use of scale models is a well-established artistic and scientific discipline. Computer-generated illumination plots are available for a similar design purpose but at much higher cost. The interior of the shoebox, or similar, can be covered or painted with dark or light colours. The source of light for the interior of the box is the indoor artificial illumination or daylight through a window of the user's location. Cut windows or roof-lights into the box that are in proportion to the room design that is to be modelled. Each window should be hinged so that different combinations of window opening, and night-time, can be reproduced. Battery lamps could be utilized for the illumination arrangements. Rectangular slots in the flat ceiling of the box can represent linear fluorescent luminaires. Small circular holes in the ceiling would model spot lighting. Advanced users can place objects within the scaled room to establish the effects upon desks, furniture, partitions and artifacts. Cut a small viewing window in the end of the box. Use this aperture to observe and sketch the areas of light and shade within the room. Try various combinations of surface colour, day, artificial and permanent supplementary artificial lighting. Figure 11.3 is an example of an observed lighting pattern in a model room that has both side windows and a representation of recessed tubular fluorescent luminaires in the ceiling.



11.3 Observed illumination pattern.

Definition of terms

Some of the terms that are used in lighting system design are as follows.

BZ classification: British Zonal classification of 1–10 for the downward light emitted from a luminaire. The *BZ* class number relates to the flux that is directly incident upon the working plane in relation to the total flux emitted. *BZ*1 classification is for a downward directional luminaire. A *BZ*10 describes a luminaire that directs all its illumination upwards so that the room is illuminated by reflection from the ceiling.

Contrast: the difference in the light and dark appearance of two parts of the visual field seen simultaneously.

Daylight factor: the ratio of the natural illumination on a horizontal plane within the building to that present simultaneously from an unobstructed sky, discounting direct sunlight. A standard figure of 5000 lx is adopted for the external illuminance in the UK.

Efficacy: the luminous efficacy is the lamp light output in lumens per watt of electrical power consumption.

Glare: the discomfort or impairment of vision due to excessive brightness.

Glare index: a calculated numerical scale for discomfort glare.

Illuminance: the luminous flux density at a surface in lumens per square metre, l/m^2, lux. The surface is normally the working plane.

Illumination: the process of lighting an object or surface.

Light meter: a current-generating photocell which is calibrated in lumens per square meter, lux.

Lumen, lm: SI unit of luminous flux. It is the quantity of light emitted from a source or received by a surface. A 100 W tungsten filament lamp emits around 1200 lm.

Lux, lx: SI unit of illuminance; 1 lx = 1 lm/m^2.

Light loss factor, *LLF*: the overall loss of light from the dirtiness of the lamp (0.8), luminaire (0.95) and the room surfaces (0.95). Clean conditions *LLF* may be 0.7 but 0.5 when equipment and room become soiled. Preferred to maintenance factor.

Luminous intensity, *I* (candela): the power of a source or illuminated surface to emit light in a given direction.

Luminaire: the complete apparatus that contains the lamp, the light emitter and the electrical controls.

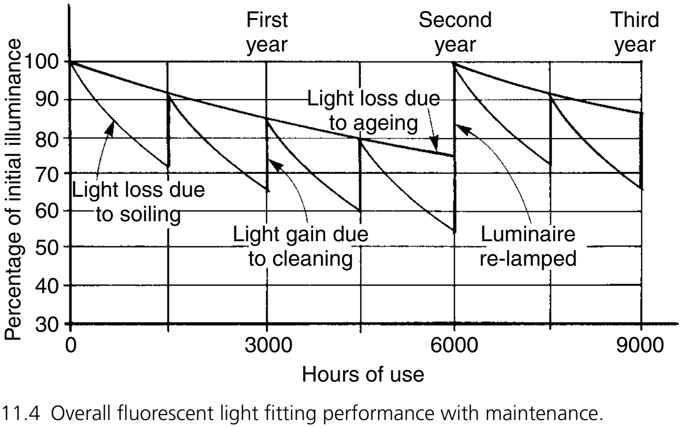
Maintenance factor, *MF*: an allowance for reduced light emission due to the build-up of dust on a lamp or within a luminaire. Normally 0.8 but 0.9 if the lamps are cleaned regularly or if a ventilated luminaire is used. Light loss factor is preferred.

Utilization factor, *UF*: the ratio of the luminous flux received at the working plane to the installed flux.

Maintenance

A planned maintenance schedule will include regular cleaning of light fittings and the lamp to ensure the most efficient use of electricity. Ventilated luminaires in air-conditioned buildings remain clean for quite long periods as the air flow through the building is mechanically controlled and filtered. The lamp also operates at a lower temperature, which prolongs its service and maximizes light output.

Because of gradual deterioration of the light output from all types of discharge lamps after their design service period, lamp efficacy could fall to half its original figure. Phased replacement of lamps after 2 or 3 years maintains design performance and avoids breakdowns. Figure 11.4 shows a typical illuminance profile for a tubular fluorescent light fitting with 6-monthly cleaning and a 2-year lamp-replacement cycle.



11.4 Overall fluorescent light fitting performance with maintenance.

Utilization factor

The utilization factor is provided by the manufacturer and takes into account the pattern of light-distribution from the whole fitting, its light-distributing efficiency, the shape and size of the room for which it is being designed and the reflectivity of the ceiling and walls. Values vary from 0.03, where purely indirect distribution is employed, the room has poorly reflecting surfaces and all the light is upwards onto the ceiling or walls, to 0.75 for the most energy-efficient designs. Spot lighting can have a utilization factor of nearly unity.

The configuration of the room is found from the room index:

$$\text{room index} = \frac{lW}{H(l + W)}$$

where l is the room length (m), W is the room width (m) and H is the height of the light fitting above the working plane (m).

The ability of a surface to reflect incident light is given by its luminance factor from BS 4800 : 1972. Sample values are given in Table 11.2.

Utilization factors for a light fitting comprising a white metal support batten and two 58 W white fluorescent lamps 1500 mm long (New Streamlite by Philips Electrical Limited) are given in Table 11.3. The data refer to bare fluorescent tubes suspended under the ceiling as used in commercial buildings. Enclosing the fitting with a plastic diffuser to improve its appearance

Table 11.2 Luminance factors for painted surfaces.

Surface	*Typical colour*	*Luminance factor range (%)*
Ceiling	White, cream	70–80
Ceiling	Sky blue	50–60
Ceiling	Light brown	20–30
Walls	Light stone	50–60
Walls	Dark grey	20–30
Walls	Black	10
Floor	—	10

Table 11.3 Utilization factors for a bare fluorescent tube fitting with two 58 W 1500 mm lamps (%).

Luminance factors		*Room index*								
Ceiling	*Walls*	*0.75*	*1*	*1.25*	*1.5*	*2*	*2.5*	*3*	*4*	*5*
70	50	48	53	59	64	71	75	79	83	86
70	30	40	46	51	57	64	69	73	78	82
70	10	35	40	46	51	59	64	68	74	78
50	50	43	48	52	57	63	67	70	74	76
50	30	37	41	46	51	57	62	65	70	73
50	10	33	37	42	46	53	58	61	67	70
30	50	39	42	46	50	55	59	61	65	67
30	30	34	37	42	46	51	55	58	62	65
30	10	30	33	38	42	48	52	55	59	62

usually lowers the utilization factor. This fitting has a *BZ*6 rating, operates at 240 V, consumes 140 W and has a power factor of 0.85 and a running current of 0.68 A.

Glare and reflections

Disability glare is when a bright light source prevents the subject from seeing the necessary detail of the task. Veiling reflections can be formed on windows and visual display unit (VDU) screens from nearby lamps. A limiting glare index is recommended for each application, for example, general office 16, and this can be calculated (CIBSE, 1986).

To maximize contrast on the working plane, luminaires should be placed in rows parallel to the direction of view. The rows should be widely spaced to form work areas between them.

The zone of the ceiling that would cause glare or veiling reflections can be viewed with a mirror on the working plane from the normal angle of work. A luminaire or direct sunlight should not appear in the mirror.

Lumen design method

The number of light fittings is found from the total lumens needed at the working plane and the illumination provided by each fitting using the formula:

$$\text{number of fittings} = \frac{\text{lux} \times \text{working plane area m}^2}{LDL \times UF \times MF}$$

where *LDL* is the lighting design lumens produced by each lamp, *UF* is the utilization factor and *MF* is the maintenance factor. A typical high output luminaire with two fluorescent lamps, 1500 mm long, emits 5100 lm measured at 2000 h of use. This is known as its lighting design lumens (*LDL*).

EXAMPLE 11.1

A drawing office 16 m × 11 m and 3 m high has a white ceiling and light-coloured walls. The working plane is 0.85 m above the floor. 5100 lm double-lamp luminaires are to be used and their normal spacing-to-height ratio *SHR* is 1.75. Calculate the number of luminaires needed and draw their layout arrangement. Find the electrical power consumption of the lighting system.

From Table 11.2 the luminance factors are 70 for the ceiling and 50 for the walls. A high standard of maintenance will be assumed, giving a maintenance factor of 0.9. The lighting design lumens is taken as 5100 lm for the whole light fitting.

From Table 11.1 the illuminance required is 600 lm/m^2. The height *H* of fittings above the working plane is

$$H = (3 - 0.85)\ \text{m}$$

$$= 2.15\ \text{m}$$

$$\text{room index} = \frac{lW}{H(l+W)} = \frac{16 \times 11}{2.15 \times (16+11)} = 3.03$$

From Table 11.3, for a room index of 3,

$$\text{utilization factor} = 79\% = 0.79$$

$$\text{number of fittings} = 600\ \frac{\text{lm}}{\text{m}^2} \times \frac{16\ \text{m} \times 11\ \text{m}}{0.79 \times 0.9} \times \frac{\text{luminaire}}{500\ \text{lm}} = 29.12$$

The ratio of the spacing S between rows to the height H above the working plane is:

$$SHR = \frac{S}{H} = 1.75$$

Therefore,

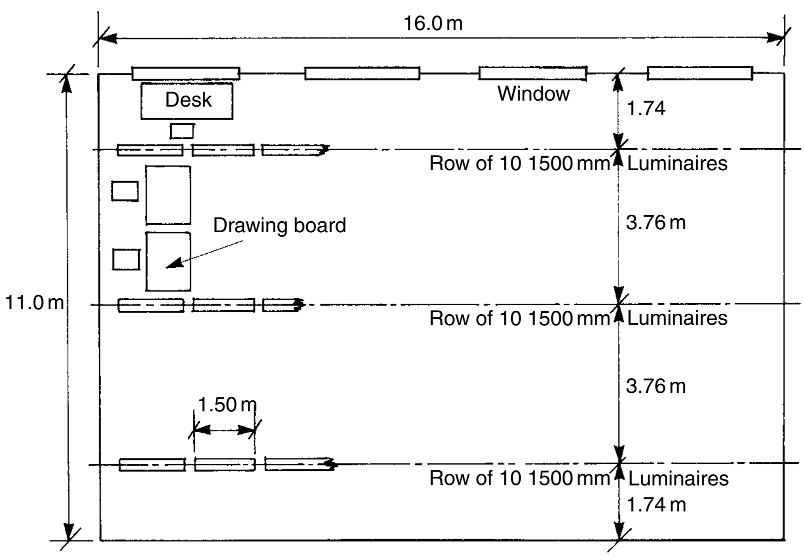
$$S = 1.75\ H$$
$$= 1.75 \times 2.15\ \text{m}$$
$$= 3.76\ \text{m}$$

If it is assumed that windows are along one long side of the office and that rows of luminaires will be parallel to the windows, this will produce areas between rows where drawing boards, desks and VDU terminals can be sited to gain maximum benefit from side day lighting without glare and reflection. The perimeter rows of luminaires are spaced at about half of S, 1.74 m, from the side walls.

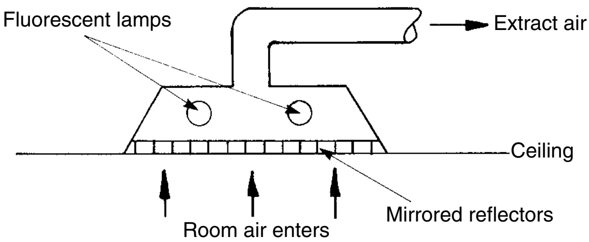
Three rows of 10 luminaires are required, as shown in Fig. 11.5, giving 30 luminaires and a slightly increased illuminance.

The electrical power consumption of each luminaire is 140 W. For the room the power consumption will be 30 × 140 W, that is, 4200 W, which is:

$$\frac{4200\ \text{W}}{16\ \text{m} \times 11\ \text{m}} = 23.86\ \text{W/m}^2\ \text{floor area}$$



11.5 Arrangement of the luminaires in a drawing office in Example 11.1.



11.6 Ventilated luminaire.

Air-handling luminaires

Luminaires that are recessed into suspended ceilings are ideally placed to be extract air grilles for the ventilation system. The heat generated is removed at its source and the lamp can be maintained at its optimum operating temperature to maximize light output and colour-rendering properties. Dust build-up should also be less in an air-conditioned building where all the circulating air is filtered in the plant room. Figure 11.6 shows the air flow through a luminaire that has ventilation openings and mirrored reflectors.

Up to 80% of the electrical energy used by the light fitting can be absorbed by the ventilation air as it passes through. Air flow rates are around 20 l/s through a 1500 mm twin tube fluorescent luminaire and a temperature increase of about 8°C is achieved. Extract air at about 30°C can be produced and the heat it contains can be reclaimed for use in other parts of the building.

Colour temperature

Colour temperature is a term used in the description of the colour-rendering property of a lamp. Colours of surfaces under artificial illumination are compared with the colours produced by a black body heated to a certain temperature and radiating in the visible part of the spectrum between the ultraviolet and infrared bands. Any colour that matches that shown by the heated black body is said to have a colour temperature equal to the temperature of the black body. A candle has a colour temperature of 2000 K and blue sky has a colour temperature of 10 000 K. Correlated colour temperature is that temperature of the heated black body at which its colour most closely resembles that of the artificial source.

The colour-rendering index Ra8 is used to compare the colour-rendering characteristics of various types of lamp. Eight test colours are illuminated by a reference source, which is a black body radiator of 5000 K correlated colour temperature or 'reconstituted' daylight if more than 5000 K is needed. These eight colours are then illuminated by the test lamp. The average of the colour differences produced between the source and test lamps provides a measure of the colour-rendering properties of the test lamp. An Ra8 of 50 corresponds to a warm white fluorescent lamp. An Ra8 of 100 would be produced by a lamp that radiated identically with the reference source.

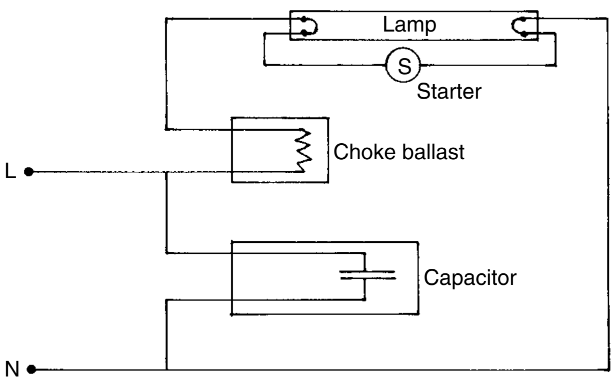
Lamp types

A summary of lamp types, their performances and applications is given in Table 11.4.

General lighting service (GLS) tungsten filament lamps are inexpensive, give good colour matching with daylight and last up to 2000 h in service. They can be controlled by variable-resistance dimmers and are used in a supplementary role to higher-efficacy illumination equipment. Tungsten halogen spot or linear lamps have a wide variety of display and floodlighting applications.

Table 11.4 Lamp data.

Lamp	*Lamp designation BS colour*	*Efficacy (lm/W)*	*Colour temperature*	*Colour-rendering index Ra8*	*Application*
Incandescent	GLS, tungsten	18	2900	100	Interiors
Incandescent	GLS, tungsten–halogens	22	3000	100	Interior displays, outdoors
Fluorescent	White	80	3500	50	Industrial
Fluorescent	Natural	85	4000	85	Commercial
Fluorescent	Warm white	85	3000	85	Social
Discharge lamps					
Low-pressure sodium	SOX	183	2000	—	Roads, car parks, floodlighting
High-pressure sodium	SON	112	2250	29	Floodlighting, exteriors, large hall interiors
Mercury fluorescent	MBF	50	4300	47	Roads, floodlights, factory interiors
Metal halide	MBI	85	4400	70	Industrial interiors, floodlighting
Mercury-blended tungsten fluorescent	MBTF	25	3700	—	Road, floodlights, factory interiors



11.7 Switch-start circuit diagram for fluorescent and discharge lamps.

Miniature fluorescent lamps (SL) can be used as energy-saving replacements for GLS lamps. Folded-tube and single-ended types are available. A typical folded lamp, SL18 18 W, produces 900 lm at 100 h, has a correlated colour temperature of 2700 K, an Ra8 of 80 and a service period of 5000 h. Its lumen output is equivalent to a 75 W GLS filament lamp.

Low-pressure mercury-vapour-filled fluorescent tubular lamps (MCF) are the most common. The tube diameter is 38 mm. Electrical excitation of the mercury vapour produces radiation, which causes the tube's internal coating to fluoresce. The colour produced depends on the chemical composition of the internal coating. High-efficacy 26 mm diameter lamps (TLD) are filled with argon or krypton vapour and have a phosphor internal coating. A circuit diagram for a switch-start fluorescent lamp is shown in Fig. 11.7.

The glow-switch starter S has bimetallic electrodes, which pass the lamp electrode preheating current when starting cold. Upon becoming warmed, the bimetallic electrodes move into contact and establish a circuit through the lamp electrodes. Making this contact breaks the starter circuit, whose electrodes cool and spring apart after about a second, subjecting the lamp to mains voltage. Twin lamp and starterless controls are used in new installations to minimize running costs.

Luminaires are designed to run in air of 5–25°C d.b., and their service period will be reduced at higher temperatures. Circuit-breakers or high rupturing capacity (HRC) fuses, rather than rewirable fuses, should be used for circuit protection. All fluorescent luminaires make an operating noise, which may be noticeable against very low background noise levels. Some radio interference is inevitable but this diminishes with distance from the radio set.

Low-pressure sodium discharge lamps emit light from electrically excited sodium vapour in a glass discharge tube. High-pressure sodium discharge lamps comprise a discharge tube of sintered aluminium oxide containing a mixture of mercury and sodium vapour at high pressure.

Mercury fluorescent lamps consist of electrically excited mercury vapour in a quartz discharge tube, which emits ultraviolet radiation, an infrared component from the mercury arc, and visible light. A phosphor internal coating fluoresces to produce the desired colour. Metal halide lamps contain metal halides in a quartz discharge tube, which gives a crisp white light. MBTF lamps are the mercury fluorescent type with additional tungsten filaments, which need no control gear and give light immediately. Other discharge lamps incorporate current-limiting ballasts and power-factor-correcting capacitors in a similar arrangement to that in Fig. 11.7.

EXAMPLE 11.2

A windowless office is to be illuminated for 15 h per day, for 6 days per week for 50 weeks per year. The floor is 20 m long and 12 m wide. An overall illumination of 450 lx is to be maintained over the whole floor. The total light loss factor for the installation is 70%. The designers have the choice of using 100 W tungsten filament lamps, which have an efficacy of 12 lm/W and need replacing every 3000 h, or 65 W tubular fluorescent warm white lamps, which have an initial output of 5400 lm and are expected to provide 12 000 h of service. The room layout requires an even number of lamps. Electricity costs 8 p/kWh. The tungsten lamps cost £1 each while the fluorescent tubes cost £10 each. Compare the total costs of each lighting system and make a recommendation as to which is preferable, stating your reasons.

For the lighting system,

$$\text{lighting hours} = 15 \times 6 \times 50 = 4500 \text{ h/year}$$

$$\text{floor area} = 20 \text{ m} \times 12 \text{ m} = 240 \text{ m}^2$$

$$\text{installed lumens} = \frac{450 \times 240 \times 100}{70}$$

$$= 154\,286 \text{ lm}$$

For the tungsten lamps:

$$\text{input power} = \frac{154\,286}{12 \times 1000}$$

$$= 12.857 \text{ kW}$$

$$\text{number of lamps} = \frac{12.857 \times 1000}{100}$$
$$= 129 \text{ lamps}$$

Next even number is 130 lamps.

$$\text{installed power} = \frac{130 \times 100}{1000}$$
$$= 13 \text{ kW}$$
$$\text{electricity cost} = \frac{13 \times 4500 \times 8}{100}$$
$$= \pounds 4680/\text{year}$$

The average annual cost for replacing the lamps can be found by multiplying the number of installed lamps by the anticipated hours of use, dividing by the lamp manufacturer's rated average life hours and then multiplying by the replacement cost for each lamp. In this case,

$$\text{lamp cost} = \frac{130 \times \pounds 1 \times 4500}{3000}$$
$$= \pounds 195/\text{year}$$

These tungsten lamps expire within a year, so there will be annual expenditure. A new lighting system that has lamps providing reliable service for more than a year will not produce replacement expenditure in the first year or two. The owner needs to budget for the eventual replacement costs by assessing the average annual cost. A planned maintenance programme will have lamps replaced, and luminaires cleaned, prior to expiry. This work may be performed out of normal working hours for the building to avoid disturbance to its normal functions.

$$\text{Total annual cost} = \pounds(4680 + 195) = \pounds 4875/\text{year}$$

For the fluorescent lamps

$$\text{number of lamps} = \frac{154\,286}{5400}$$
$$= 29 \text{ lamps}$$

Next even number is 30 lamps

$$\text{input power} = \frac{30 \times 65}{1000}$$
$$= 1.95 \text{ kW}$$
$$\text{electricity cost} = \frac{1.95 \times 4500 \times 8}{100}$$
$$= \pounds 702$$

$$\text{lamp cost} = \frac{30 \times £10 \times 4500}{12\,000}$$
$$= £112.5/\text{year}$$

$$\text{total annual cost} = £(702 + 112.5) = £814.5/\text{year}$$

Both methods of lighting require at least the annual cleaning of lamps and luminaires.

The reasons for using fluorescent lamps are as follows.

1. They produce an annual cash saving of £(4875 − 814.5) = £4060.5/year.
2. They only need changing (12 000/4500) after 2 years 8 months of use.
3. Tungsten lamps need changing (12 × 3000/4500) every 8 months.
4. There is less heat emission from fluorescent lighting, particularly radiant heat, so the air-conditioning cooling load is lower.
5. They give better colour rendering.
6. They give better diffused light distribution.

Control of lighting services

The energy that is consumed by artificial lighting systems is both an expensive use of resources and a high monetary cost. A minimum level of illumination may be desirable for the security of personnel or monitoring of the building and its contents for the detection of intruders. The changes from day lighting to full artificial lighting and then to security illumination can be achieved with manual and automatically timed operation of switches. This usually leaves unoccupied areas illuminated. A light-sensitive photocell can be used to detect illumination level and an automatic controller may be programmed to reduce the use of the electrical lighting system. The presence of the occupants, or an intruder, can be detected by passive infrared, acoustic, ultrasonic or microwave-radar-based systems.

The detector and control system needs to be sufficiently fast-acting and sensitive so that the occupant is not stranded within a darkened room and suffers injury or fear. It is equally important that only those lights that are actually needed are switched on, and not for the entire room or space to be illuminated when only one person enters to use a small area. Local control of the light switching may be preferable to a system that is operated from a remote energy management system computer. The local system should be faster in operation and will be less subject to distribution system or computer breakdown.

The design of a control scheme for an occupied space may include a minimum number of luminaires, which are switched on from a time switch or by the occupant to provide safe access. Groups of luminaires that are near windows may be controlled from local photocell detectors to ensure that the perimeter lighting remains off as long as possible. The internal parts of the space may be operated from automatic presence detectors. Data on the length of operation of each lighting unit can be transmitted to the computer-based building management system so that real-time usage and electrical power consumption can be recorded. Timed-off controllers avoid lights left on excessively after working hours and when nobody is present.

Questions

1. Explain, with the aid of sketches, how interiors can be illuminated by daylight. State how natural illumination is quantified.
2. State the relationship between the visual task and the illuminance required, giving examples.

3. Sketch and describe how supplementary artificial lighting is used to achieve the desired illuminance.
4. Discuss the use of localized task-illumination systems in relation to the illumination level provided, reflection, energy conservation, shadows and user satisfaction.
5. Define the terms used in lighting system design.
6. Draw a graph of illumination provided versus service period for an artificial illumination installation to show the effect of correct maintenance procedure.
7. Calculate the room index for an office 20 m $\times$ 12 m in plan, 3 m high, where the working plane is 0.85 m above floor level.
8. State the luminance factors for a room having a cream ceiling and dark grey walls.
9. Find the utilization factor for a bare fluorescent tube light fitting having two 58 W, 1500 mm lamps in a room 5 m $\times$ 3.5 m in plan and 2.5 m high. The working plane is 0.85 m above floor level. Walls and ceiling are light stone and white respectively.
10. Sketch satisfactory arrangements for natural and artificial illumination in modern general and drawing offices, a library and a lounge. Comment particularly on how glare and reflections are controlled.
11. A supermarket of dimensions 20 m $\times$ 15 m and 4 m high has a white ceiling and mainly dark walls. The working plane is 1 m above floor level. Bare fluorescent tube light fittings with two 58 W, 1500 mm lamps are to be used, of 5100 lighting design lumens, to provide 400 lx. Their normal spacing-to-height ratio is 1.75 and total power consumption is 140 W. Calculate the number of luminaires needed, the electrical loading per square metre of floor area and the circuit current. Draw the layout of the luminaires.
12. Discuss how the use of air-handling luminaires improves the performance of the lighting installation and makes better use of energy.
13. Explain how the rendering of colours by illumination systems is measured.
14. Compare the energy efficiency and colour-rendering of different lamp types, stating suitable applications for each.
15. Use the cardboard box small-scale models of rooms to investigate the visual design of lighting systems.

    (a) Cut different shapes and locations of windows and roof-lights such that they all have the same open area.
    (b) Colour the internal surfaces differently by means of dark, light, removable and reflective sheets of materials.
    (c) Cut slots and holes into the ceiling to model different designs of strip fluorescent and filament lighting layouts; replaceable ceilings with different designs are helpful.
    (d) View the interior of the room under various day lighting and artificial lighting arrangements.
    (e) Make three-dimensional sketches of what you see of the lighting layouts produced, showing the shading. Write the lighting level found on each area on a scale of 1 (dark) to 10 (bright).

16. Using the models created for Question 15, answer the following.

    (a) What is the effect of *quantity* of daylight on the *quality* of the day lighting system created?
    (b) What effect do the colours of the room interior surfaces have on the quality of the lighting produced?
    (c) What colours should the room surfaces be?

    Justify your views in relation to the use of the room, its maintenance costs and design of the decoration.

17. Using the models created for Question 15, answer the following.

    (a) What patterns of illumination are produced on the end walls by differently spaced rows of strip lighting?
    (b) What are the best spacing arrangements between rows of strip or circular lamps? These depend upon what is being illuminated, so state the objectives of the lighting design first.

18. Create an approximate scale model of the interior of a room that is known to you. Experiment with three combinations of day lighting and artificial lighting to find the best overall lighting scheme for the tasks to be performed in the room.
19. Write a technical report to explain how the reflectance of room surfaces, the location, dimensions and shape of glazing, the spacing of rows of luminaires and their height above the working plane are related to the efficient use of electrical energy in the overall lighting design.
20. Put small boxes and partitions into a scale model of a room to represent furniture, desks, horizontal and vertical working planes. Carry out an experimental investigation of the problems that arise for the lighting designer.
21. State how the lighting design can be made to feature particular parts of the interior of the building and the parts that should be featured for safety and appearance reasons.
22. Analyse the costs of these competitive lighting systems and recommend which is preferable, stating your reasons.

    A heavy engineering factory is to be illuminated for 15 h per day, for 5 days per week for 50 weeks per year. The floor size is 120 m long and 80 m wide. An overall illumination of 250 lx is to be maintained over the whole floor. The overall light loss factor for the installation is 63%. The designers have the choice of using 150 W tungsten–halogen lamps, which produce 2100 lm and need replacing every 2000 h, 80 W tubular fluorescent lamps, which produce 6700 lm and are expected to provide 12 000 h of service, and 250 W high-pressure sodium lamps, which produce 27 500 lm and are expected to last for 24 000 h. The lighting layout needs an even number of lamps. Electricity costs 7.2 p/kWh. The tungsten lamps cost 90p each, the fluorescent tubes cost £10.50 each and the sodium lamps cost £61 each. Replacing any lamp takes two people 2 min and their combined labour rate is £17 per hour. The hire cost of scaffolding is £120 per 8-h day.
23. A lecture theatre is to be illuminated for 8 h per day, for 5 days per week for 30 weeks per year. The floor is 32 m long and 16 m wide. An overall illumination of 350 lx is to be maintained over the whole floor. An even number of lamps is to be used.

    The utilization factor for the installation is 0.73 and the maintenance factor is 0.7.

    The designers have the choice of using 100 W tungsten filament lamps, which have luminous efficacy of 10 lm/W and need replacing every 2000 h, 100 W quartz halogen low-voltage lamps in reflectors, which have an efficacy of 95 lm/W and provide 23 000 h use, and 65 W tubular fluorescent lamps, which have an efficacy of 57 lm/W and are expected to provide 7500 h of service. Electricity costs 8 p/kWh. The tungsten lamps cost 85 p each, the halogen cost 29 p each and the fluorescent tubes cost £11.25 each. Compare the total costs of each lighting system and make a recommendation as to which is preferable, stating your reasons.
24. When 900 lm fall onto a 2.0 m^2 surface from a fluorescent lamp, and a light meter finds that 360 lm are reflected, the luminance of the surface is:

    1. 0.71
    2. 0.4
    3. 0.2

4. Insufficient information.
5. 1.25

25. Which is illumination intensity?

    1. Luminosity.
    2. Light level.
    3. Lumens.
    4. Lux.
    5. Lumen per watt.

26. Illumination intensity provided is related to which?

    1. Contrast between detail and background on the working plane.
    2. Cleanliness of luminaires.
    3. Task lighting needed.
    4. Lighting colour temperature.
    5. Provision of shadow-free lighting.

27. Which illuminance levels are correct? More than one correct answer.

    1. Small electronic component inspection 3000 lx.
    2. Corridor 250 lm/m^2.
    3. Bright sunlight 100 000 lx.
    4. Rough tasks 500 lm/m^2.
    5. Hospital operating theatre table 10 000 lx.

28. Which is lighting design?

    1. A primarily scientific application.
    2. Engineering design.
    3. A unique combination of technology and visual effects.
    4. Entirely a mathematical application.
    5. Best achieved by an iterative design technique.

29. Efficacy of a lamp means:

    1. Efficiency at converting colour temperature into illuminance on the working plane.
    2. Percentage of lamp globe or tube surface area that emits light.
    3. Proportion of lamp light output directed towards the working plane.
    4. Lumens light output per watt of electrical input power to lamp.
    5. Luminous efficacy is total illuminance produced divided by lamp electrical input power including all control equipment consumption.

30. Light system glare means:

    1. Whether discomfort is created in a particular viewing direction.
    2. Impairment of vision due to excessive brightness.
    3. Sedentary position includes direct view of sunshine.
    4. Florescent indoor lighting systems do not cause glare.
    5. All lighting causes glare when viewed directly.

31. What is an air-handling luminaire?

    1. A sealed light fitting inside an air-handling unit to allow servicing work.
    2. A light fitting open to the room air allowing cooling.

3. Luminaire passing air returning to the ductwork system from the conditioned room.
4. Lamp designed for low-temperature operation.
5. Sealed luminaire to keep out moisture.

32. What is meant by lamp colour temperature?

    1. Description of colour-rendering property.
    2. Colour shift in surface caused by the type of lamp.
    3. Colour of the lamp when viewed directly.
    4. Infrared fraction of the sun produced by the lamp.
    5. Calculated average temperature from each of eight wavelength bands in the light produced by a lamp.

33. Which are correct descriptions of lighting system sensor operation? More than one correct answer.

    1. Sensor detects light level in room and switches on rows of luminaires to maintain set lux level.
    2. All sensor types are used by the building management computer system, BMS, to switch rows of luminaires on and off.
    3. Groups of luminaires switched on from a sensor detecting occupancy within controlled space.
    4. Microwave sensor detects use of electrical equipment within room and switches lights on.
    5. Microwave sensor detects any small movement within controlled space and switches luminaires on and then off when no movement is detected for a set time interval.

34. Which is correct about lighting?

    1. Light and heat energy are mutually convertible.
    2. Light radiation is the same as heat radiation.
    3. In the absence of humans or animals, there would be no light.
    4. Light energy only exists within a visible spectrum.
    5. Low-power laser beams are for heat energy.

35. Which is correct about units for lighting?

    1. W/m^2.
    2. Light intensity is 5.67×10^{-8} W/m^2K^4.
    3. Lumens.
    4. Flux in Webber/m^2.
    5. Light intensity increases with distance from source.

36. Which is correct about lighting?

    1. Light intensity varies inversely with the square of the distance from the source.
    2. Light intensity varies inversely with the distance from the source.
    3. Light intensity reduces with the distance from the source.
    4. Light intensity varies inversely with the square root of the distance from the source.
    5. Light intensity varies inversely with the distance cubed from the source.

37. Which is the recommended design illumination for office work?

    1. 40 lx.
    2. 400 lx.

3. 800 lm/m^2.
4. 2600 lx.
5. 200 lm/m^2.

38. Which is a valid technical reason for burning primary energy resources to provide artificial lighting?

    1. Overcomes affect of dull sky.
    2. Makes outside of building appear more impressive.
    3. Human task illumination.
    4. Good colour-rendering of exteriors.
    5. Increases lighting available during daytime.

39. What has been the most significant benefit to humans since ancient ages?

    1. Air conditioning in hot climates.
    2. Refrigeration.
    3. Central heating and cooling providing comfort.
    4. Computers, mobile telephones and television.
    5. Indoor electric lighting.

40. What is supplementary daylight?

    1. Manually operated blinds or curtains.
    2. Mechanically operated shading devices.
    3. Perimeter fluorescent lighting.
    4. Artificial lighting temporarily or permanently used to stabilize variations in day lighting.
    5. Artificial lighting having the same colour-rendering temperature as daylight.

41. Which of these correctly describe *BZ* classification?

    1. *BZ*0 means equal spherical illuminance.
    2. *BZ*10 means light projection all downwards.
    3. *BZ*5 projects only sideways and is used for wall-mounted luminaires.
    4. *BZ*10 has a luminaire directing all light output upwards providing only reflection off the ceiling.
    5. *BZ* defines the solid angle projection from a lamp in steradians.

42. What is illuminance?

    1. Proportion of available light flux received on working plane.
    2. Lux received on working plane.
    3. Colour brightness index.
    4. Luminous flux intensity reflected from a surface.
    5. Brightness of perceived detail relative to background.

43. What is a light meter?

    1. Easily portable data logger.
    2. 1 lm/m^2 projected for 1 m.
    3. Current-generating photocell calibrated in lux.
    4. Current-generating photocell that activates an alarm in a BMS security control room.
    5. Photocell that receives a laser beam from an emitter as part of a security, smoke or heat detection system.

44. What is a lumen?

    1. Unit of lighting not presently in use.
    2. 1000 candela/m^2.
    3. SI unit of light output or received.
    4. A directional measurement of light.
    5. Lighting power of a source.

45. What are lux?

    1. Total light output from a source.
    2. A measurement of glare.
    3. 31.4 candela.
    4. 1 lm/m^2
    5. A measurement of reflected light.

46. What does luminaire mean?

    1. A part of the lamp control system.
    2. The complete light fitting.
    3. A unit of light output flux.
    4. A unit of reflected light.
    5. Those parts of the lighting fitting other than the lamp.

47. Which is not true about fluorescent lamps?

    1. Low cost and reliable.
    2. Poor colour-rendering compared to daylight.
    3. Visible flicker may be observed from 50 Hz single-phase.
    4. Energy efficiency around 85 lm/wt.
    5. Colour temperature 4000 K and Ra8 of 85.

48. Where are sodium discharge lamps used?

    1. Low-pressure SOX sports facilities.
    2. Not used for street lighting.
    3. High-pressure SON produces industrial indoor white lighting.
    4. Where good colour-rendering is preferred.
    5. Regular replacement installations.

49. How does a fluorescent lamp work?

    1. Fluorescing powder-filled tube is electrically heated.
    2. Fluorescent lining of tube becomes heated.
    3. Vapour within tube fluoresces.
    4. Vapour within tube is electrically charged.
    5. Tube interior coating fluoresces when irradiated.

50. Which is a feature of an energy-efficient lighting control system?

    1. BMS reports maintained of all lighting system usage.
    2. All rows of luminaires remain switched on during working day as frequent starting uses more energy.
    3. Lamp deterioration increases with frequent switching, so should remain on continuously.
    4. Occupancy sensors are programmed to keep lights on for half an hour after occupants leave.
    5. Timed switch-off controller minimizes lighting use after occupation ceases.