

# Interior Lighting Design

Lighting design is mainly done within a framework of guidance and recommendations, rather than fixed rules of design. There will not be just one optimum solution to a particular lighting problem. Often there is a set of requirements to which priorities have to be set before a satisfactory compromise can be found.

This module gives general guidance on the:

1. requirements of lighting,
2. decisions needed in the design process, and
3. calculation procedures.

It should be read in conjunction with the current **CIBSE Code for Interior Lighting**.

## 1 Lighting Objectives

**Lighting objectives** are a clear description of the requirements and what needs to be created to provide the right conditions for the occupants and the intended use. It can include such things as what type of image must be created. For a successful design the **lighting objectives** need to be established by you or someone else involved in the design process.

The lighting objectives can be considered under three broad headings:

- Safety and health.
- Performance.
- Appearance and comfort.

### Safety and Health

Interior lighting should enable the occupants to see sufficiently well to work and move about in safety, both under normal conditions and in the event of an emergency involving a power failure. The lighting must not create conditions that are damaging to people's health. This requires, for example, the elimination of harmful radiation, the prevention of eye strain, and the control of glare.

### Performance

The type of work that takes place and the characteristics of the 'workforce' together define the nature and variety of the visual tasks in an interior. The quantity and quality of the lighting required to achieve satisfactory visual conditions depend on these tasks, ideally analysed in terms of size, contrast, duration, age of observer, colour discrimination and complexity. This is an impractical thing to do and a more practical approach is to use lighting organisation's recommendations simply specifying what has proved to give satisfactory visual performance in the past.

### Appearance and Comfort

The way in which a space is illuminated can affect its character and the appearance of objects within it. Where the creation of mood or atmosphere is predominant this must be the prime lighting objective, but some consideration should be given to this factor in all designs. You should attempt to weight these objectives according to their relative importance in an integrated approach. Quite clearly, safety objectives must never be ignored. For places, such as offices and factories, performance will normally be more important than appearance. In general interiors with sustained visual tasks for the majority of occupants, for example banks, shops, and transport termini, the balance between performance and appearance may be fairly even. In interiors devoted to relaxation and leisure with no primary visual tasks, such as discotheques, churches, homes, appearance is usually more important than performance. Not all the design objectives can be expressed as measurable quantities, for example, the need to make an environment appear "prestigious", "efficient", or "vibrant". Once the lighting objectives have been defined, they must be expressed in terms of physical parameters to form a design specification. To do that it is worthwhile making an integrated approach to lighting design.

## 2 Integrated Approach to Lighting Design

To create a good lighting installation an integrated design approach is necessary. This can be called a **holistic approach** where the whole, the entirety of the lighting objectives and the means to a lighting solution are considered rather than just selected parts. This means addressing all the requirements and constraints, balancing one against another to ensure that the best possible solution is determined. This can be made easier by a structured approach through what is known as the **Lighting Design Framework**. The framework contains six elements that influence lighting design, although a particular situation may require additional considerations. The elements may not all carry equal weight, nor do they need to be considered in any particular order, but they all need to be considered to ensure the best possible solution. The framework can be used for daylight, electric lighting, or as is more usual, a combination of the two, to help develop a conceptual design. Each element of the framework is covered in some detail in this module.

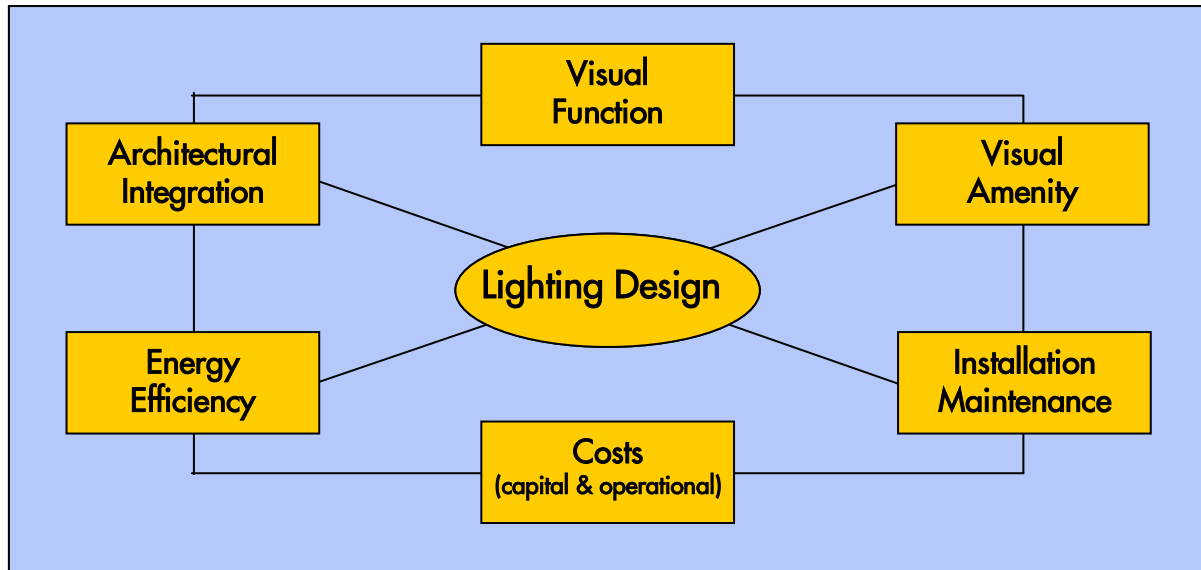


Fig 1 Lighting Design Framework

## 3 Visual Function

### Illuminance

In the United Kingdom, the Health & Safety at Work Act (1974) and the Factories Act (1961) require that the lighting at places of work shall be both sufficient and suitable. Sufficiency is normally taken to imply an adequate quantity of light (illuminance) both on work tasks and in areas where people circulate.

Legislation is normally concerned with what is adequate, which is less onerous than the recommendations in lighting guides, such as the CIBSE Interior Lighting Code, which are concerned with good practice. The schedule in the Code recommends **standard maintained illuminances** for interiors according to the tasks involved, where the standard maintained illuminance is the lowest illuminance throughout the maintenance cycle of the lighting system and averaged over the relevant area. The relevant area may be the whole of the interior or just that occupied by the tasks and their immediate surroundings. In this case the **maintained illuminance** of the general surround areas of a working environment should be based upon tasks that are carried out in these areas, but should not be less than one-third of the highest task illuminance or problems of adaptation will arise. Illuminances should be increased or decreased if task details are unusually difficult or easy to see or if the task is done for an unusually long or short time. They should be increased if errors would have unusually serious consequences. The CIBSE Interior Lighting Code shows a flow chart indicating the recommended changes in illuminance. Where eye protection is worn, or tasks must be viewed through transparent screens, the contrast of the task may well be reduced and, in such situations, the illuminance on the task should be increased in an attempt to compensate. Also,

if the most onerous visual tasks are to be carried out by occupants with poor sight or an average age that is higher than normal, say over 50 years, then the designer would be justified in increasing the illuminance.

The maintained illuminance should not be less than 500 lux for situations involving critical colour matching. The illuminance recommendations apply to the tasks themselves, which may be complex in both shape and position. This can cause major difficulties in both prediction and measurement. It is commonly assumed that the illuminance on the task will be the same as the illuminance on a plane at the same angle and position as the task. This is good enough for most practical purposes. It frequently happens that the location of the tasks is not precisely known, in which case a horizontal plane at work station height is usually taken. Where vertical tasks are involved, but their orientation is not known, then mean vertical (i.e. cylindrical) illuminance may be used. In addition to providing sufficient light for tasks to be carried out, the occupants must also feel that there is enough light. Experiments have shown that the correlation between average horizontal illuminance and observers' assessments of how well lit the room appears is poor. **Cylindrical illuminance** (which is the same as the average vertical illuminance - averaged over 360 degrees of rotation) is a valuable measure. It gives an indication of how, randomly placed vertical surfaces will be illuminated. It also relates reasonably well to the subjective appearance of how well lit the room appears to be. In crude terms, the higher the average cylindrical illuminance, the brighter lit the room will appear to be.

### Uniformity of Illuminance

Uniformity of illuminance is important for three reasons.

- excessive variations in illuminance mean that some parts receive less illumination than is desirable, whilst others receive more than is necessary.
- the luminance of the immediate surround to a visual task can affect visual performance and comfort.
- excessively uneven lighting is liable to be judged subjectively as unsatisfactory.

The CIBSE Code recommends that the uniformity of illuminance, measured as the ratio of the minimum illuminance to the average illuminance over the task area, should not be less than 0.8. This is not to say that the horizontal illumination over the room should be perfectly uniform. Although such lighting would ensure that the relevant visual tasks could be carried out anywhere in the space, it implies a considerable waste of energy in providing task lighting levels in non-critical areas.

Furthermore, there is no physiological reason why the illuminance should be controlled within such tight limits over the room area. Uniform lighting is, all too often, uninteresting; when correctly applied, non-uniformity can create interest and is frequently preferred. If non-uniform lighting is used, then the lighting designer must be careful to avoid excessive variation that can cause adaptation problems or, in the worst case, safety problems. The area which is visually surrounding the task (often most of the room) should be illuminated to not less than 1/3 of the task illuminance.

Shadows may be cast over the area of a visual task, reducing the illuminance, causing adaptation problems, and producing disturbance or distraction. To avoid excessive shadowing in industry, where high machines or racks are often closely spaced, it is often necessary to space luminaires less far apart than would be needed to satisfy illuminance and uniformity requirements.

### Glare

Excessively bright areas in view in an interior can, separately or together, impair visual performance (**disability glare**) or cause visual discomfort (**discomfort glare**). Lighting systems in most working interiors are unlikely to cause significant direct disability glare, but a minor degree of discomfort glare is probable.

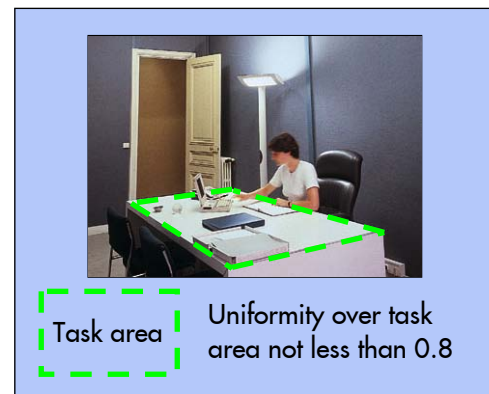


Fig 2 Uniformity over the task area

## Discomfort Glare

Discomfort glare systems, for quantifying glare for interior lighting, fall into two groups that:

- define luminance limits for acceptable luminaires
- evaluate discomfort glare indices for installations.

The second type of system is used in the UK. The degree of discomfort glare is represented by a **Glare Index**, which is calculated for the conditions of the installation. The degree of discomfort glare that can be tolerated decreases as the task difficulty increases, and the UK system specifies an upper limit for the glare index for different situations, selected through experience and practice to represent a standard of visual comfort acceptable to most people. This is called the **Limiting Glare Index**.

Limiting Glare Indices are specified in the range from 13 to 28 in steps of 3 units. It is tempting to judge different lighting schemes by their Glare Index, but this should be done with caution. The mathematics of the Glare Index system is such that no practical importance should be given to differences of only one or two units between different schemes. Also there is little merit in attempting to achieve a Glare Index lower than that required. This is because the Limiting Glare Index indicates the point at which, for the particular type of task activity, the lighting provides an acceptable standard of visual comfort. The standard will therefore be acceptable once the limit is reached and further reductions will not improve matters significantly but may result in other penalties.

An agreement is due on an international 'unified glare rating (UGR)'. Despite using a different glare formula there is negligible difference in real installations between UGR values and the values of glare index in the UK system. Therefore it appears that the numbers specifying limits to glare can remain unaltered.

## Surface Colours

It is rare for lighting designers to be in control of the selection of room surfaces, which is unfortunate when the characteristics of these surfaces affect glare, modelling, and lighting system efficiency as well as the appearance of the room.

When the opportunity does arise to select colours, designers may find it best to consider first how light or dark the colours should be (**Munsell value**), then select the hue (i.e. which colour), and then the saturation (**Munsell chroma**). (Refer to Colour in Lighting Theory module.) Subdued colours are often chosen where a restful or dignified atmosphere is required, whilst strong colours and high contrasts are normally used to create lively and exciting effects. The colour appearance of a surface is a function of the surface itself and the type of light source. When trying to assess the effect that a particular light source will have on coloured surfaces, there is no substitute for a practical test.



Fig 3 Strong red used on wall

## Reflectance of Room Surfaces

The recommended ranges of reflectance of the major room surfaces are shown in **fig 4**. To achieve a ceiling cavity reflectance of 0.6 is fairly easy with a flat ceiling, but it may be difficult, if not impossible, when luminaires are suspended a long way beneath the ceiling. The upper limit of 0.7 for effective wall reflectance is also difficult to realise in practice, and floor cavity reflectances within the recommended range (0.2 to 0.4) are seldom achieved. In installations using luminaires with little or no upward light, the ceiling is illuminated by inter-reflected light. When the **Room Index** is large, most of this inter-reflection is from the floor, which may produce problems. A highly coloured carpet gives rise to a highly coloured ceiling, also variations in floor cavity reflectance give rise to an uneven ceiling appearance. The room surface reflectances have a direct effect upon the efficiency of the installation.

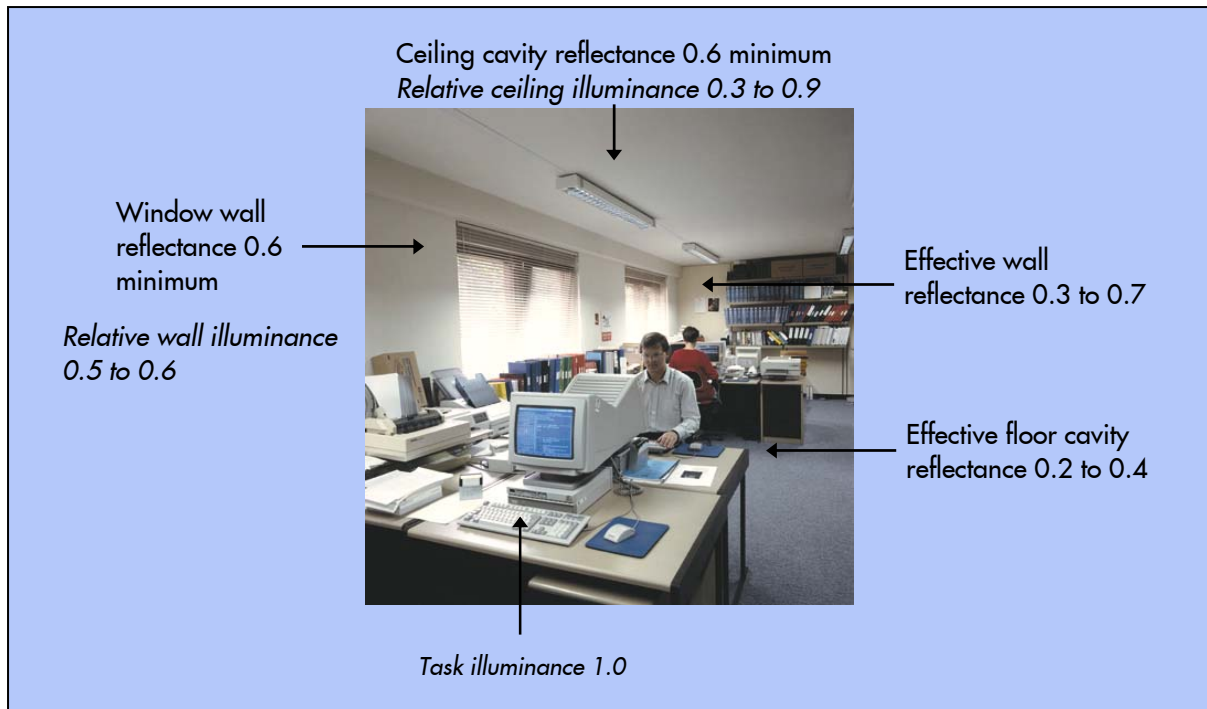


Fig 4 Recommended Room Reflectances & Illuminance Ratios (CIBSE)

### Task Reflectance

The reflectances of tasks and their background must be considered. If the outline of the task is the prime consideration, then good contrast with the background is essential. Where detail within the task is more important, then the contrast between the task and its background should be low to avoid adaptation problems. In which case the luminance of the immediate background to a task should be no less than one-third of the task luminance. Usually the characteristics of the visual task are fixed and the easiest way to ensure that the background has a satisfactory luminance is to vary its reflectance.

### Luminance and Illuminance Distributions

The relative brightnesses of the major surfaces have a significant effect on the appearance of a room. Brightness depends on luminance, but since surface reflectances are recommended it is possible to cover this aspect of appearance by recommending illuminance ratios. The recommendations in [fig 4](#) are only guidelines. They will produce acceptable results in most situations, the designer should be aware of the possible room appearance created by the relative brightnesses of the room surfaces.

Surfaces	Possible Room Appearance
Bright walls	Larger and perhaps more spacious
Dark walls	Smaller and possibly cramped
Bright ceiling and dark walls	Formality and tension
Dark ceiling and bright walls	Informal and relaxed atmosphere

When well-designed **uplighting** is used, then the ceiling can be brighter than the recommendations; firstly because there are no bright luminaires in the ceiling plane and secondly because of the gradual variation in ceiling luminance.

These recommendations are not rules, but are well supported by experiments and experience. The lighting designer should not feel inhibited by them, but should only go outside them when the implications of doing so are understood.

## Modelling

Modelling embraces lighting effects that reveal form and texture. (See section 8 Modelling in the Lighting Theory module.) Modelling can be expressed as a lighting criteria using **display illuminance ratios** as a guide for degrees of modelling from 'subtle' to 'dramatic'. The display illuminance ratio (DIR) is that between the general horizontal illuminance in the room and the value of illuminance in the plane of the object to be displayed. Greater degrees of emphasis are likely to require lower values of general lighting to avoid the need for excessive local display illuminance. The DIR is a measured ratio using a light meter whereas the subjective apparent brightness ratio is a guide to how people may perceive the difference between the display and the background.

### Lighting criteria for display effect

Display Effect	Objective display illuminance ratio (DIR)	Subjective apparent brightness ratio
Subtle	5:1	2.5:1
Moderate	15:1	5:1
Strong	30:1	7:1
Dramatic	50:1	10:1

## Colour rendering and appearance

The characteristic of colour rendering and appearance, together with means of specifying them, are in the Lighting Theory module in section 6. The colour rendering and colour appearance properties of lamps are important elements in lighting design. It is almost invariable a false economy to select lamps of poor colour rendering properties for the sake of a minor price advantage on lamps that themselves are a fraction of the luminaire price, even before installation costs are taken into account. If possible take the opportunity to see demonstrations of both colour rendering and colour appearance. Photographs can go some way to conveying this, as in the **Modern Office Lighting design brochure**, but it is best that you have a direct appreciation for yourself.



Fig 5 Good colour rendering in retail stores aids selling

### Questions 1

1. What broad aspects do lighting objectives cover?
2. What are the values of maintained illuminance recommended in the CIBSE Interior Lighting Code between the range 200 and 1500lux?
3. In an area where the standard maintained illuminance is recommended to be 500lux and the tasks details are unusually easy to see, what value of illuminance can be designed to? (See flow chart in Code)
4. Over what area does the CIBSE Code recommend uniformity of illuminance?
5. What is uniformity a measure of?
6. What is the recommended glare index for an area in a pottery where there is enamelling work?
7. What is the recommended minimum percentage reflectance of a window wall?
8. What is the recommended average illuminance on the ceiling if the task illuminance is 300lux, expressed as a range?
9. What objective display illuminance ratio is suitable for creating a 'moderate' display effect?
10. What colour temperature fluorescent lamp would you suggest and why, in an office where there is an appreciable amount of daylight in the UK?

## 4 Visual Amenity

In interiors it is not sufficient to provide good task lighting without considering the overall lit appearance of the space – the lighting aesthetics. People prefer an interior to be visually attractive and lighting can play a big part in this. An attractively lit interior will give people a greater sense of well-being and they are likely to perform better through greater satisfaction and stimulation. This approach could also contribute to a healthier environment, which could mean less absenteeism. Research has shown that people prefer a space to appear ‘visually interesting’ and ‘visually light’ particularly in the **normal field of view** which is defined as a horizontal band approximately 40° high and centred at normal eye height. (Fig 6)

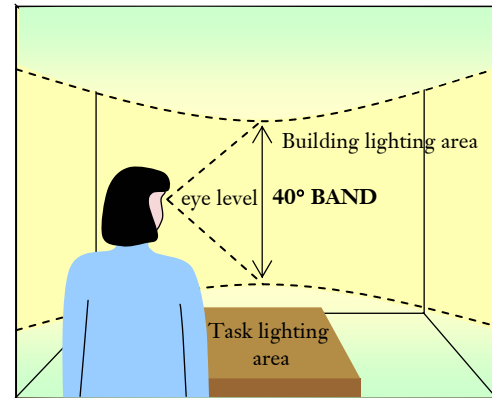


Fig 6 Normal field of view

### Visual Interest

To create ‘visual interest’ it is necessary for the light pattern to have some illuminance variation. This is to create areas of ‘light’ and ‘shade’ which people find attractive and stimulating. A very uniform light pattern, like the light from an overcast sky, is seen as dull and unappealing. Too much illuminance diversity can be equally unacceptable even uncomfortable, particularly if the change in illuminance is rapid. Hard shadows should also be avoided particularly in the work area.

### Visual Lightness

To create a feeling of ‘visual lightness’ it will be necessary to project light directly on to some room surfaces and particularly on those surfaces, which are prominent in the normal field of view. Often these will be the walls, but the ceiling may also be included, especially in large rooms. Where work-stations are employed using vertical partitions, some light on the partitions will be beneficial. Without this the room can appear gloomy and under-lit.

## 5 Lighting and Architectural Integration

Both daylighting and electric lighting are fundamental elements of the overall design of a building and must therefore be an integral part of the whole solution. In terms of the electric lighting this means the appearance of the visible lighting equipment and the way they are installed into the building. It is important that they are not an after thought to enable people to see, but an integral part of the architecture. However when choosing luminaires the lighting performance should not be compromised for the sake of their appearance, but the style needs to integrate with the architecture.

Ceiling recessed luminaires help to preserve a clear, uncluttered ceiling, whereas suspended luminaires can suggest an additional ceiling plane. Ceiling suspended luminaires are sometimes used to provide direct light up and downwards. They can be related to coffers, or barrel vaults or some other architectural feature. The lighting of walls is another important area. If a wall is lit with spotlights then the scalloped light pattern produced on the wall should be appropriate, perhaps because the wall is textured or that the pattern relates to a display of pictures. Incorporating lighting equipment with workstations or furniture is another option. This can have the advantage, that if the work-station is moved, then the lighting can move with it without the need for extensive changes to the wiring. This also applies to floor standing luminaires.



Fig 7 Lighting in barrel vaults

The lighting designer and the architect will need to pay particular attention to the detailing of the installation. This will require close co-operation between member of the design team for a good solution.

## 6 Energy Efficiency in Lighting

### Lighting Controls

A lighting system must be designed and managed to permit good control of energy use, both during the working day and outside working hours. For satisfactory control the lighting circuits must be sufficiently flexible to allow unwanted lights to be turned off, without inconvenience to others. Also control provides flexibility of use for the occupants and for the building owner. These advantages can outweigh energy considerations. Although it should be remembered that lighting in the UK consumes 16% of the total electricity. For example in offices lighting consumes about 50% of energy costs. The implementation of lighting controls can cut consumption by up to 60%. With the Building Regulations Part L1(e) since 1995 'adequate lighting control, manual or automatic shall be provided to switch off or dim lighting when adequate daylight exists or a working space is unoccupied.'

Methods of control fall into three broad categories:

- Manual control
- Automatic control (non-intelligent)
- intelligent control

#### Manual Methods

These rely upon individuals and appointed members of staff controlling the lighting system. These methods tend to be inexpensive to implement, but are less effective than automatic methods. To be effective the lighting system must be well laid out to permit flexible switching of individual luminaires or banks of luminaires. The switch panels must be sensibly located, complying with the constraints imposed by the Building Regulations Part L1(e) and clearly marked (a mimic diagram can be very helpful).

A training programme, to ensure staff awareness, is essential and this can be reinforced with posters or labels on the switch panels. One of the main disadvantages with manual methods is that whilst occupants may be aware that natural lighting is insufficient and will turn on lights, there is nothing to prompt them to turn off lights if the natural lighting becomes adequate. An imposed switch-off (particularly at lunchtime) can be effective for, if natural lighting is sufficient. In addition, a considerable amount of energy is often wasted after working hours when the lights are left on. The full lighting system may be on when cleaners are in the building, and the provision of special cleaners' circuits in which only some of the lighting is switched on can save money. Time switches provide a convenient method of ensuring that unwanted lighting is not operated outside working hours.

#### Automatic Control

These systems can use inexpensive time switches or photocells to switch or dim banks of lights. Photocells can monitor the level of useful daylight and turn off or dim luminaires (this is more effective) in rows adjacent to the windows when daylight levels are high. Whether or not the payback time for such a system

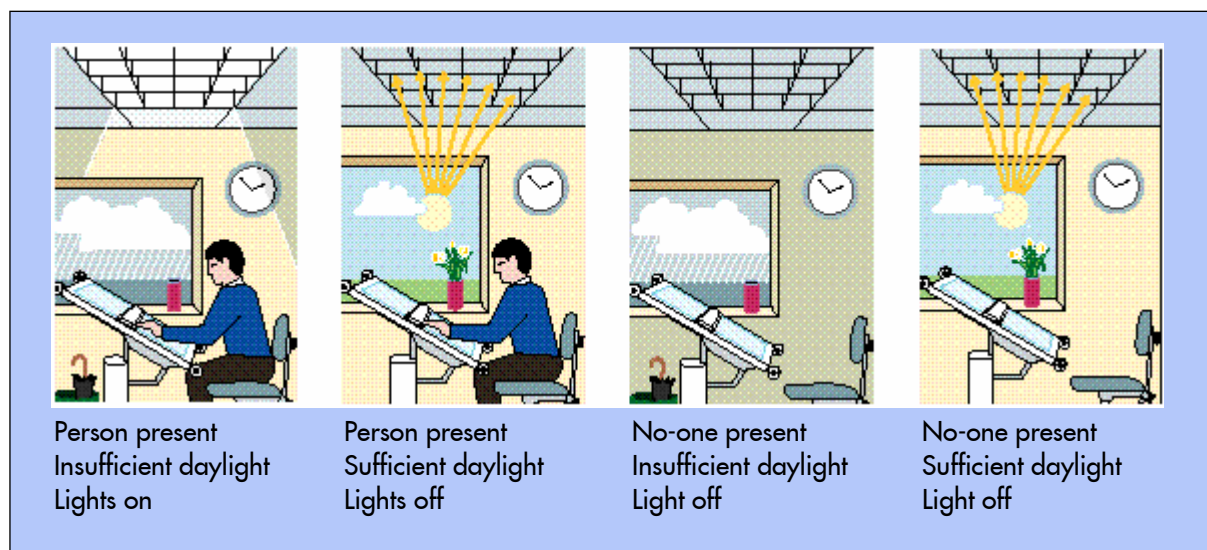


Fig 8 Lighting controlled by PIR detector and photocell



is acceptable will depend on the proportion of the working year for which the required illuminance can be provided by natural light, and hence save energy costs. Automatic systems must normally have some degree of manual override to cater for unexpected circumstances, and a time-lag must normally be built into the system to prevent premature switch-off. The presence of occupants can be detected by using passive infra-red (PIR) detectors. When combined with built-in photocell high energy savings can be expected. (Fig 8)

### Intelligent Control

There is several ways of providing intelligent control:

- Independent intelligent luminaires (eg Sensa 2)
- Intelligent luminaire controlling cluster of luminaires (eg SensaLink)
- Centralised dedicated computer control of luminaires (eg Light Sense)
- Intelligent luminaires together forming a lighting management system programmed by infra-red controller (eg SensaLink)

Intelligent lighting control responds to changing conditions in a way that is designed to be acceptable to their occupants. It responds to daylight contribution and whether there is anyone present in the space. Independent intelligent luminaires can give a simply yet powerful method of controlling energy usage, reduce the requirement for switching and allow easy reconfiguration of spaces. Systems that give more control can be time based, for example switching off at lunchtime. Some systems allow manual override by the occupants so their preferred lighting level can be selected any time.

Centralised systems rely upon dedicated computers to control either the building services or just the lighting. In the case of building services control a software program controls the various services, such as lifts, fire alarms, lighting, air conditioning and other equipment uses information from transducers and sensors in the building. Although such systems are expensive, this can be offset by the wide variety of services that can be controlled at optimum efficiency.



Fig 9 Use of remote control to set luminaire

### Flexible Visual Environment

In addition to the management of energy use, the control system can provide a very powerful means of controlling the visual environment to give flexibility of use and to improve both the working conditions and the value of the property. The main aspects to this are:

- Individual control of the visual environment
- Reconfigurable space
- Flexible buildings

#### Individual Control of the Visual Environment

The users of the space can control their visual environment to match their needs and preferences. This not only saves waste, but, has a powerful influence on morale and well being and hence efficiency. Experiments into lighting and productivity have shown that real and major improvements in performance can be achieved when worker's satisfaction is increased by better lighting. Aspects of better lighting which increase satisfaction are more potent than those that reduce costs or improve visual performance.

#### Reconfigurable Space

No matter how well-planned a business environment is now, it is likely that after a few months it will not match the business needs. It is highly probable that any office or factory layout that is appropriate today,

will need to be reconfigured to some degree within six months. In practice, this reconfiguration occurs when it must take place rather than when it should because of the restraints that are imposed by the building and its services. A controllable visual environment means that areas can be easily reconfigured to match changing requirements and new needs. The lighting can be re-defined to match the new tasks. A reconfigurable space could, for example, be defined as a filing area (with infrequent occupation and undemanding visual tasks) and then re-programmed for use as a general office when the needs change.

### Flexible Buildings

A good building is one that fully satisfies the needs of the organisation(s) that occupies it. However, at the design stage or at the refurbishment stage, the needs of the future occupants are often poorly defined. It is therefore important to design buildings that are flexible in use. This is very important to a property developer or an organisation intending to sell or lease its buildings. A flexible building is better suited to a wider range of would be occupiers; this increases the market value of the property. A second advantage of a flexible visual environment is that the design only has to allow for the range of use. With a conventional environment, each area must be designed in detail to anticipate the needs. Since these are often poorly defined, considerable time can be spent on this design stage and on checking that the final results are correct. With a flexible visual environment, this process is simplified.

### Usage of Power and Energy in Lighting

There are pressures on consumers in most developed countries of the world to reduce the amount of energy they use for environmental and economic reasons. Lighting accounts for less than 2 percent of primary fuel consumption but that usage is very visible. There is no excuse for a waste of energy in lighting, particularly when any energy savings give cost savings. One way of reducing energy usage is to design an installation to a lower quantity of light than satisfies the value recommended in the relevant code of lighting practice. This is not the right approach as it can prejudice personal safety or security or reduce productivity, since energy conservation has already been considered in the code recommendations.

There are several points during design of a lighting installation where decisions can reduce energy usage:

- Selection of the most efficient of the suitable light sources
- Selection of luminaires with high luminaire maintenance factor (LMF)
- Selection of luminaire with a high utilisation factor (UF)
- Selection of a lighting system that restricts high ambient illuminances to task areas
- The use of occupancy detectors which switch off lighting in unoccupied spaces
- The use of controls to fully use the available daylight
- The selection of a maintenance plan which minimises total annual energy consumption

For new and refurbished installations in England and Wales since July 1995 Part L of the Building Regulations places restrictions on the use of electric lighting for buildings. The regulations require that lighting systems be “designed and constructed to use no more fuel and power than is reasonable in the circumstances” and demands “reasonable provision for controlling such systems”. There is a continual debate and review of the regulations, which are likely to be revised in the future. For example, halophosphate fluorescent lamps may be excluded from the approved lamp list when assessing power compliance and the lm/W value for compliance by average lamp/gear efficacy may increase from 50 to 65. This section outlines the regulations and shows how to comply now.



Fig 10 Lighting usage is very visible

**Outline of the Building Regulations: Part L1**

Part L covers Conservation of Fuel and Power:

- L1(a) Heat loss through building
- L1(b) Control of heating and hot water systems
- L1(c) Heat loss from hot water systems
- L1(d) Heat loss from heating pipes and ducts
- L1(e) Electric lighting efficiency and control

It is part L1(e) that is of particular interest to lighting specifiers.

**Basic Provision of Part L1(e)**

The requirement is for:

- The use of energy efficient lamps and control gear
- Adequate control, manual or automatic, to give the opportunity to switch off dim electric lighting when adequate daylight exists or the space is unoccupied

**Application**

Regulations apply to:

- All new buildings of over 100 m<sup>2</sup> floor area
- Refurbished buildings over 100 m<sup>2</sup> floor area with material changes to the structure or means of fire escape

and does not apply to:

- New and refurbished building of less than 100 m<sup>2</sup> floor area
- Domestic dwellings of any size
- Refurbishment which does not involve material change to the structure or means of fire escape

**Exceptions**

Exceptions to these requirements are:

- Emergency lighting
- Lighting used to highlight displays of merchandise
- Track mounted lighting
- Lighting of museum and art gallery exhibits
- Lighting for entertainment eg theatres, concert halls
- Temporary site lighting
- All exterior lighting

**Power compliance**

Means of compliance could be by either:

- Lighting using lamps and gear with an average efficacy of 50lm/W or higher
- 95% or more of the lighting in the building measured in circuit watts using lamps and gear from **Fig 11**
- Meeting the CIBSE Lighting Code power targets (An extract is shown in **Fig 12** for commercial installations, data is also available for industrial installations in the 1994 CIBSE Interior Lighting Code)

High pressure sodium Metal halide Induction	All types, sizes, ratings and control gear
Tubular fluorescent	All 26mm T8 tubes using high frequency or low loss control gear
Compact fluorescent	All ratings above 11W with any type of control gear

Fig 11 Approved lamps

The building control surveyors may also accept:

- A design using no more energy than a complying design
- An installation that will have short running hours eg church
- That the provision was reasonable in the circumstances

Target ranges of installed power density per 100lux maintained illuminance for general lighting installations in W/m<sup>2</sup>/100lux

Lamp type	Wattage range used to calculate target ranges	Colour rendering group	Luminaire maintenance categories (LMC)	Workplane power density range (W/m <sup>2</sup> /100lux)		
				Room index		
				1	2.5	5
<b>Commercial</b> - reflectance	C, W, F = 70, 50, 20 to 50, 50, 20					
<b>Fluorescent</b>						
triposphor	32 – 100	1B	ABCDE	2.7 – 5.4	2.2 – 4.2	2.1 – 3.7
halophosphor	32 – 100	2 – 3	ABCDE	3.4 – 7.0	2.8 – 5.4	2.6 – 4.8
compact	36 - 55	1B	ABCDE	3.3 – 6.4	2.8 – 4.9	2.6 – 4.4
<b>Metal halide</b>						
clear or coated	150 – 400	2	BC	4.4 – 7.1	3.6 – 5.7	3.4 – 5.3
<b>High pressure mercury</b>						
coated	125 – 400	3	BC	6.6 – 9.9	5.4 – 7.9	5.1 – 7.3
<b>High pressure sodium</b>						
improved colour	150 – 400	3	BC	3.8 – 5.8	3.1 – 4.6	2.9 – 4.3
standard or high output	100 - 400	4	BC	2.4 – 4.9	2.0 – 3.9	1.9 – 3.6

Fig 12 CIBSE Power targets for commercial installations

**Compliance by average lamp/gear efficacy**

Worksheet 1 can be used together with power and lumen values (sourced from Thorn Lighting Power and Energy Guide, Optilume Interior or TL Vision software programs) for this compliance check.

- Look up for each type of fitting used total circuit watts and total initial lamp lumens
- Calculate total circuit watts and lamp lumens for full quantity of each type of fitting used
- Total up circuit watts for building
- Total up initial lamp lumens for building
- Calculate average lumens per circuit watt  $\frac{d}{e}$

If e = 50 or more the building complies with the power restriction.

*Short-cut*

Look up the lm/W figure for each of the fittings being used, excluding those exempt. If every figure is 50 or above, there will be compliance with the power restriction.

**Compliance by use of approved lamps and gear**

Worksheet 2 can be used for this compliance check.

- Calculate total circuit watts for all approved lamps and gear used in the building
- Calculate total circuit watts for all non approved lamps and gear used in the building
- Percentage of approved circuit watts  $\frac{a}{(a + b)} \times 100 = \%$

If this is at least 95% the building complies with the power restriction.

Worksheets can be photocopied and used for individual projects.

**Energy Compliance**

Means of compliance could be by:

- Automatic lighting control
- Remote switching
- Manual switching

**Automatic Control**

The requirements are that lighting:

- Switches on when presence is detected
- Switches off when presence is not detected
- Responds to ambient daylight conditions
- Responds to local conditions

The Sensa range can fulfill all these requirements, as does the Lightsense & SensaLink control systems.

**Manual and Remote Control**

The requirement is that the maximum distance (in plan view) from the switch to the furthest controlled fitting is 8m or 3 times the fitting height above the floor – whichever is greater.

This particular requirement may mean that for manual switching many more switches would need to be provided than usual. An alternative approach to avoid this would be to use ‘intelligent’ fittings with automatic control.

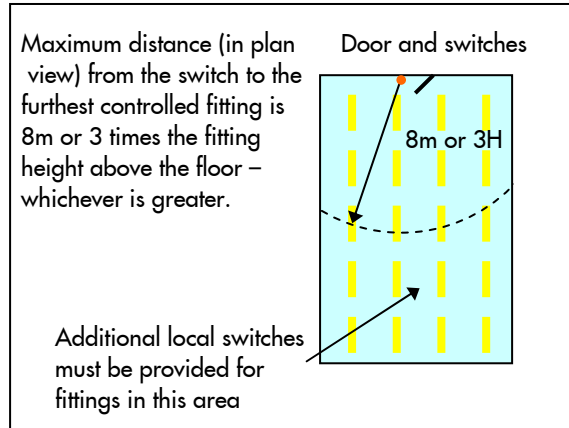


Fig 13 Manual and remote control requirements

*Questions 2*

1. In a typical office what are the energy costs for lighting as a percentage of the total?
2. In a large storeroom , where there is no daylight, that is visited infrequently, what type of lighting control do you suggest?
3. What are the three main means of demonstrating power compliance to the requirements of Part L1(e) of the Building Regulations?
4. On the basis of the CIBSE power targets show whether the following installation complies to the power requirements of Part L1(e) of the Building Regulations:  
 20×15m office with room index 4, luminaire (LMC A) with 1800mm 70W Polylux lamps providing 500lux, total lighting electrical load 3.6kW.

Worksheet 1

Compliance by average lamps and gear efficacy

Building Regulations L1

Location	Fitting Type	Circuit Watts per Fitting (W)	No. of Fittings	Total Circuit Watts (W)	Lamp Type	Lumens per Lamp (lm)	No. of Lamps	Total Lamp Lumens (lm)
<b>Total (c)</b>					<b>Total (d)</b>			

Calculation  $d/c = e$  If this is 50 or higher the building complies with the power restriction

Worksheet 2

Compliance by use of approved lamps and gear

Building Regulations L1

Approved Types

Location	Fitting Type	Circuit Watts per Fitting (W)	No. of Fittings	Total Circuit Watts
(a) Approved Total				

Non Approved Types

(b) Non Approved Total				

## 7 Lighting Installation Maintenance

The illuminance of a lighting system reduces as soon as it is switched on. There are four reasons for this:

- a reduction of lamp output with burning hours
- the failure of lamps with burning hours
- dirt on luminaires
- dirt on room surfaces

A lighting system needs to be serviced by replacing failed lamps, rectifying equipment faults, and cleaning lamps, luminaires and room surfaces. Lamp replacement may be done individually when a lamp has failed (**spot replacement**) or all the lamps in an installation may be replaced periodically (**group replacement**). The latter is

frequently the cheaper option, firstly because of the high labour cost of a multiplicity of spot replacements and secondly because the output of most lamps falls continuously with burning time, giving a low efficacy ahead of actual failure. The optimum time for group replacement can be determined from the lumen maintenance and mortality curves for the particular type of lamp, coupled with knowledge of labour, lamp, and electricity costs, but this is a complex calculation. Group replacement will be cheaper if it coincides with one of the periodic cleanings of the installation. The degree of dirtiness depends on the type of premises and the general cleanliness of its location. The effects of dirt on the transfer of light from the lamps to the work surface depend mainly on the type of luminaire used. The total influence of all this on the maintenance of lighting levels depends on the cleaning interval in the maintenance schedule.

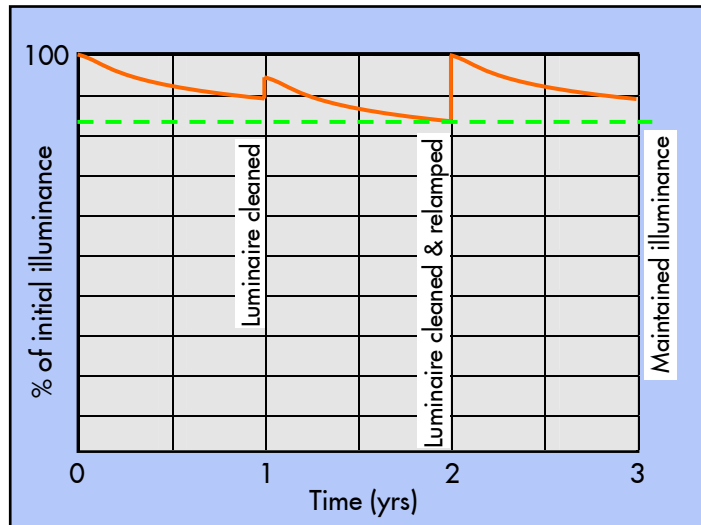


Fig 14 Typical illuminance with time & maintenance

The recommendations given in the current CIBSE Code for interior lighting include designing installations to a **maintained illuminance**. This is an average illuminance over the work surface and during the lifetime of the installation the average illuminance should not fall below the designed maintained illuminance by maintaining the installation - replacing failed lamps, cleaning the luminaires and room. The implication of this is that when the maintained illuminance is reached then maintenance need to be carried out such as lamp replacement. Fig 14 shows a typical average illuminance on the work surface of an installation with time. By implementing a maintenance schedule the illuminance does not go below the **maintained illuminance** (shown in green).

**Maintenance Factor MF** is the ratio of maintained illuminance to initial illuminance, this takes account of all losses:

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

where:

**LLMF** Lamp Lumen Maintenance Factor

**LSF** Lamp Survival Factor

**LMF** Luminaire Maintenance Factor

**RSMF** Room Surface Maintenance Factor

### Lamp Lumen Maintenance Factor, LLMF

The lumen output of all lamps reduces with time of operation. The rate of light depreciation varies for different lamp types and it is important to refer to current lamp data. From the data the Lamp Lumen Maintenance Factor for a specific number of hours of operation can be found. It is the lumen output at that time chosen divided by the initial lumen output. If the initial output is scaled to be 1.00 or 100 it makes it easy to read off the factor from a graph or table. If bulk lamp replacement is intended or assumed then the period that this happens has to be established. Guidance on typical relamping periods is given in Fig 15. The maintenance schedule is planned in terms of years, not hours, so it is necessary to know or to estimate the number of hours in a year that an installation will be operated to determine suitable intervals



of relamping. (Continuous operation will be  $365 \times 24 = 8760$  hours.) Example lamp data is shown in Fig 16 giving both Lamp Lumen Maintenance and Lamp Survival for High Pressure Sodium lamps. When it comes to fluorescent lamps a good choice is a lamp type that gives an LLMF of 0.95 through life such as GE Polylux XL lamps.

High pressure sodium (HPS)	15000h
High pressure sodium improved colour (HPSDL)	6000h
High pressure mercury (HPM)	9000h
Metal halide (MH)	6000h
Tubular fluorescent	9000h

Fig 15 Typical relamping period

Data will normally be based on test procedures that specify

the ambient temperature during testing, with a regulated voltage applied to the lamp. If any aspects of the proposed design are unusual, such as high ambient temperature, vibration, switching cycle, operating attitude, they may affect the life and/or light output of the lamps. Lamp performance under these conditions needs to be checked with the lamp manufacturer.

**Lamp Survival Factor, LSF**

This factor accounts for how many lamps are working after a time of operation. Now, if lamps are replaced when they fail, known as ‘spot replacement’, then there is not a lumen reduction due to lamp failures and **LSF can be taken as 1.00**. Another lamp replacement regime is, ‘group lamp

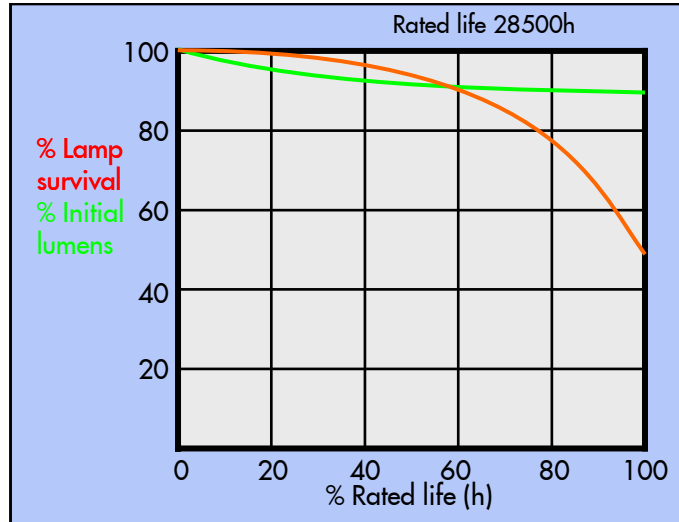


Fig 16 Lumen maintenance & lamp survival (HPS)

replacement’, that allows failed lamps to remain until the next ‘group lamp replacement’. Then a value of LSF needs to be built into the maintenance factor. LSF is obtained from lamp manufacturer’s data, either in a graph or table, often expressed as ‘% lamp survival’.

**Workplace Cleanliness Categories**

Clean, Normal and Dirty are the categories used to designate interior environments. Selection of a category is done by matching or making the closest match with one of the interiors listed against Clean, Normal or Dirty. The category of environment is needed for determining LMF and RSMF. (Fig 17)

CLEAN	Clean room, Computer centres, Electronic assembly, Hospitals
NORMAL	Offices, Shops, Schools, Laboratories, Restaurants, Warehouses
DIRTY	Steelworks, Chemical works, Foundries, Welding, Polishing, Woodwork

Fig 17 Maintenance Categories

**Luminaire Maintenance Factor, LMF**

Luminaires accumulate dust and dirt through life and different types of luminaire collect dust and dirt at different rates. A low brightness reflector luminaire in an air-conditioned office will not deteriorate as fast as an uplighter used in the same office. All Thorn Lighting luminaires have a Luminaire Maintenance Category, LMC. There are six types designated by the CIE and CIBSE that are A, B, C, D, E, and F, an additional type designated by Thorn Lighting is A+ for luminaires with very good maintenance characteristics. Broadly the categories given by CIBSE are:

- A Bare lamp batten
- B Open top reflector (ventilated self cleaning)
- C Closed top reflector (unventilated)
- D Enclosed
- E Dust proof
- F Indirect uplighter

This Luminaire Maintenance Category together with the time period between cleaning of the luminaire and the environment in which it is operated, clean, normal or dirty, is used to determine the Luminaire Maintenance Factor. (Fig 18)

**Room Surface Maintenance Factor, RSMF**

This is the last factor. It depends on the interior environment, the cleaning interval of the room and the type of luminaire. A luminaire that gives 90% or more light downwards is taken to be 'direct', one that gives 90% or more light upwards is taken to be 'indirect', and all others are 'direct/indirect'. The data shown is for room indices 1.5 to 5, covering the majority of situations. The CIBSE Interior Lighting Code also gives data for room index 0.7. It can be seen from the data that 'direct' luminaire types have a higher RSMF, this is because the light onto the workplane arrives directly with only a small contribution from inter-reflected light reliant on room surfaces.

*Worked example*

Find the maintenance factor for an office (with air-conditioning) with a room index of 3.0 using Quattro T-line luminaires having category 3 Mirrorbrite louvres and 4 × 1200mm 36W Polylux XL tubes. It is assumed that cleaning of the luminaires and the office will happen every two years. Spot lamp replacements to be made between bulk lamp replacements after 4 years, coinciding with every other cleaning of luminaires and room.

**LLMF**

Operating hours estimated at 10h per day, 51 weeks per year, 5 days a week = 10 × 51 × 5 = 2550h  
 4 year bulk lamp replacement at 4 × 2550 = 10200h  
 from Polylux XL lamp data LLMF = 0.95

**LSF**

Spot lamp replacements means LSF = 1.00

**LMF**

2 year cleaning, Office is taken to be a Clean environment, luminaire maintenance category A+ for air-conditioned interior  
 from table LMF = 0.96

**RSMF**

2 year cleaning, Normal environment, direct luminaire, room index 3  
 from table RSMF = 0.95

MF = LLMF × LSF × LMF × RSMF

MF = 0.95 × 1.00 × 0.96 × 0.95 = 0.87

**MF = 0.87**

**Luminaire Maintenance Factor LMF**

Cleaning Interval (yrs)				Environment	LMC Type
0.5	1	2	3		
1.00	0.99	0.96	0.95	Clean	A+
0.99	0.96	0.92	0.90	Normal	
0.98	0.93	0.87	0.85	Dirty	
0.95	0.93	0.89	0.85	Clean	A
0.92	0.89	0.84	0.79	Normal	
0.88	0.83	0.78	0.73	Dirty	
0.95	0.90	0.84	0.79	Clean	B
0.91	0.86	0.80	0.74	Normal	
0.88	0.83	0.75	0.68	Dirty	
0.93	0.89	0.80	0.74	Clean	C
0.89	0.81	0.69	0.61	Normal	
0.83	0.72	0.59	0.52	Dirty	
0.92	0.88	0.83	0.79	Clean	D
0.87	0.82	0.77	0.73	Normal	
0.83	0.77	0.71	0.65	Dirty	
0.96	0.94	0.91	0.90	Clean	E
0.93	0.90	0.86	0.84	Normal	
0.91	0.86	0.81	0.79	Dirty	
0.92	0.86	0.77	0.70	Clean	F
0.89	0.81	0.66	0.55	Normal	
0.85	0.74	0.57	0.45	Dirty	

Data source CIBSE & Thorn Lighting Ltd

Fig 18 Luminaire Maintenance Factor

**Room Surface Maintenance Factor RSMF**

Cleaning Interval (yrs)				Environment	Type
0.5	1	2	3		
0.98	0.98	0.96	0.96	Clean	Direct
0.97	0.96	0.95	0.95	Normal	
0.96	0.95	0.94	0.94	Dirty	
0.95	0.92	0.89	0.86	Clean	Direct/ Indirect
0.90	0.88	0.85	0.82	Normal	
0.86	0.85	0.81	0.78	Dirty	
0.92	0.88	0.84	0.78	Clean	Indirect
0.87	0.82	0.77	0.72	Normal	
0.83	0.77	0.70	0.64	Dirty	

Room Index = 1.5 to 5 Data source CIBSE

Fig 19 Room Surface Maintenance Factor

This method of calculating maintenance factor has a sounder basis than just picking values for MF. It should be remembered that, the maintenance factor as defined for use in determining maintained illuminance is multiplied by the initial lamp lumens, that is higher than any through life lumen figure. It is common practise to do lumen method design calculations using high arbitrary values of MF, say 0.9 or 0.85, together with lamp lighting design lumens (at 2000h). This is often done in the belief that fewer fittings will be required, this is not invariably true. Commercial pressures strongly influence the method and values used in calculations when it is known that on occasions competitors sometimes use a MF = 1.0. You should seek the advice of your Chief Lighting Engineer on these matters. These difficulties can be bypassed by selecting a product such as Sensa that can 'hold' or maintain a set illuminance, when in the absence of daylight, regardless of lamp depreciation and dirt collection on the lamps, luminaires and room.

## 8 Lighting Costs – Capital and Operational

The capital cost of a lighting installation needs to be balanced against the operational costs. If only the capital costs are considered then what at first sight to be a low cost installation, may turn out to be expensive if the operational costs are excessive through high energy or maintenance costs. Therefore it is important to take a life cycle costing approach. It is particularly necessary if the people paying for the installation are different from those paying for the operational costs. This sometimes occurs in schools and some offices for example.

### Capital costs

These include the installation design, the equipment (lamps, luminaires and controls), the wiring and installation of the equipment, any necessary builder's work, as well as testing and commissioning the installation. It should be appreciated that a typical service life of a lighting installation is likely to be in excess of 20 years fully justifying payback periods of up to 5 years. A payback period is the time when the combined capital and running costs of a lighting scheme is predicted to become less than an alternative scheme for the same installation. Fig 20 shows this graphically, scheme A has a lower capital cost than scheme B but the operational or running costs of scheme B are lower than for scheme A. Therefore there comes a time, the payback period, when scheme B becomes more economical. In this example after 4 years scheme B total costs are less than scheme A.

### Operational Costs

These include the cost of energy, maintenance, repair, replacement and disposal. It is important to recognise that the cost of an electric lighting installation is a small percentage of the total building costs. Typically as an example, for an office building, it can amount to about 4%. However the electricity cost for lighting can be as much as 50% of the total electricity bill. This is a relatively small amount when compared to the cost of the office staff (fig 21), which typically amounts to 75% of the total workplace costs. The remaining 25% is divided between 15% running costs and 10% building costs. In any case the lighting operational costs should be kept to a minimum for the lighting requirement.

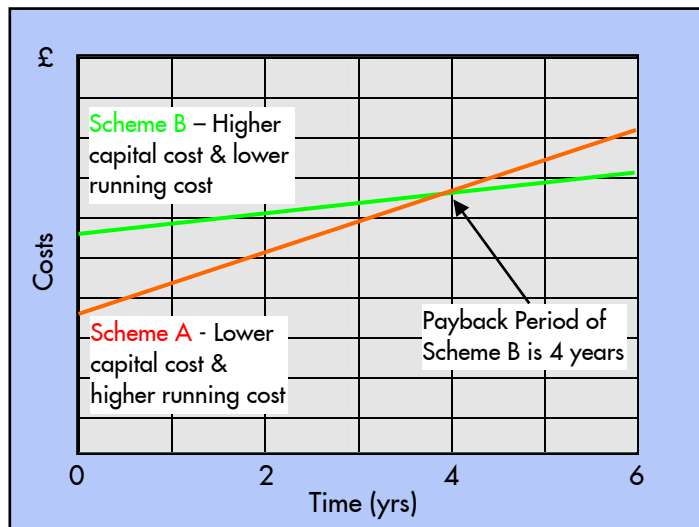


Fig 20 Payback Period of Lighting Scheme

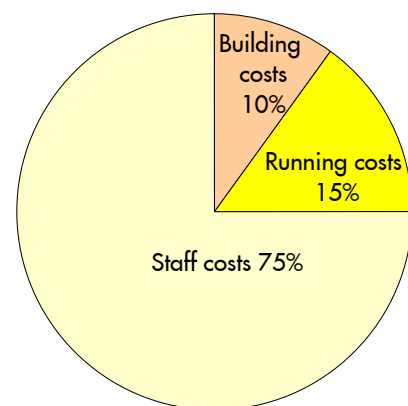


Fig 21 Typical office operation costs

## 9 Lighting Design

### Choice of Lighting System

Choosing a lighting system is distinct from choosing lamps, luminaires or other equipment. This is a strategic decision that determines the relationship between daylight and artificial light, and the degree to which the lighting system is tailored to match the local needs within the space. One basic system decision is to choose between **general**, **localised** or **local lighting**.

### Uniform or General Lighting

Lighting systems that provide an approximately uniform illuminance on the entire horizontal work plane, are called general or uniform lighting systems. The luminaires are arranged in a regular layout, giving a tidy appearance to the installation. General lighting is simple to plan and install, and requires no co-ordination with task locations, which may not be known or which may change. The greatest advantage of such a system is that it permits complete flexibility of task location. Its major disadvantage is that energy may be wasted illuminating the whole area to the level needed only for the most critical tasks.

### Localised Lighting

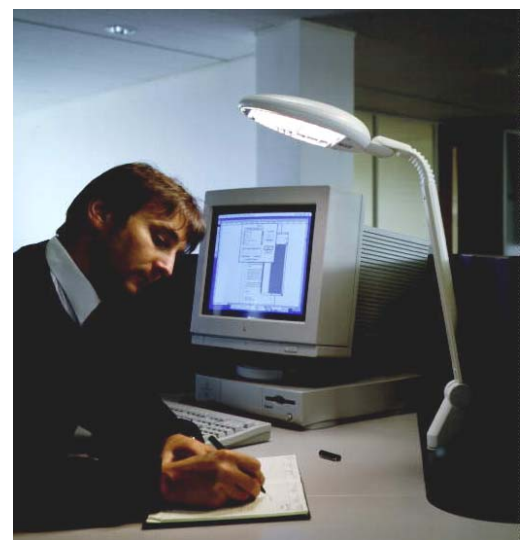
Localised lighting systems employ an arrangement of luminaires related to the position of tasks and workstations. They provide the required service illuminance on work-areas together with a lower level of general illumination for the space. By careful luminaire positioning, good light utilisation is achieved with few problems from shadows, veiling reflections, and discomfort glare. Localised systems normally consume less energy than do general systems, unless a high proportion of the area is occupied by workstations.

### Local Lighting

Local lighting provides illumination only over the small area occupied by the task and its immediate surroundings. A general lighting system is installed to provide sufficient ambient illumination for circulation and non-critical tasks, so the local lighting system simply supplements the general lighting to achieve the necessary illuminance on tasks. It is a very efficient system, particularly when high standards of task illuminance are required. Local lighting is commonly provided by luminaires mounted on the workstation, providing a very flexible room layout. Such local units must be positioned carefully to minimise shadows, veiling reflections, and glare. Fixed units are more easily able to do this.



Uniform or General Lighting



Local Lighting

Fig 22 Lighting systems

## Choice of Lamp

The choice of lamp affects the range of luminaires available, and vice versa, so one cannot be considered without reference to the other. The modules on Light Sources will help to differentiate the performance of the main lamp types. The designer can compile a list of suitable lamps by rejecting those that do not satisfy the design objectives. The availability of suitable luminaires can then be checked and the economics of the combinations assessed. Lamps must have satisfactory colour rendering properties. Visual tasks requiring accurate perception of colour are not common, but there are many merchandising situations where good **colour rendering** is desirable. The suitability of a lamp for a particular application is best decided by experimental test. Lamps must also provide the right **colour appearance**. A warm colour appearance tends to be preferred for informal situations, at lower illuminances, and in cold environments. A cool appearance tends to be preferred for formal situations, at higher illuminances, and in hot environments. It is normally undesirable to illuminate visibly adjacent areas with sources of significantly different colour appearance. **Lamp life** and **lumen maintenance** must be considered in conjunction with the **maintenance policy**, and it needs to be remembered that standardisation of lamp types and sizes within a particular site can simplify maintenance. A simple guide to choosing a suitable lamp type is as follows:

1. First decide what minimum standard of **colour rendering** is needed. Except in the case of specialist applications, the CIBSE colour rendering classes are ideal for this purpose.

Minimum Class Needed	Description
1A	Excellent colour quality. Where accurate colour matching is required (e.g. colour printing inspection)
1B	Very good colour quality. Where accurate colour judgement or good colour rendering is required for reasons of appearance (e.g. merchandising).
2	Good colour quality - Where moderate colour rendering is required, good enough for merchandising.
3	Poor colour quality - Where colour rendering is of little importance. Colours can be distorted but marked distortion is not acceptable.
4	Very poor colour quality - Colour rendering is of no importance and severe distortion of colours is acceptable.

Do not select lamps from the appropriate class. Lamps in a better class may be more efficient or a better choice for some other reason. Instead, make a note to reject any lamps that are in inferior classes.

2. Now decide which **colour appearance groups** will be unacceptable:

**Warm**  
**Intermediate**  
**Cool**  
**Cold**

Some applications that need precise colour judgement must use lamps with a specified colour appearance (often cool or cold). Make a note of what lamp appearance to reject.

3. Decide how the lighting will be controlled and how rapidly light will be required. This, when compared to the **run-up** and **re-strike times** of different lamps will determine which ones are unacceptable. (Note that auxiliary lamps can be used for rapid illumination, often a supplementary tungsten lamp with a main high intensity discharge lamp).

- By deleting lamps that have unsuitable **colour rendering** and **colour appearance** properties, and also those with unacceptable **run-up** and **re-strike** characteristics, a list of suitable lamps can be compiled. It is possible to rank this list in terms of **efficacy**, **life**, **size** and other factors that the designer considers important. A decision can then be made. The above lamp selection process deals with most situations and is usually more reliable than trying to find a lamp which ‘matches’ the needs of the design because this normally calls for very difficult compromise decisions. Size, output, the availability of suitable luminaires and other aspects will influence the choice.

### Choice of Luminaire

Obviously, the luminaire chosen have to be suitable for the application. Also luminaires have to withstand a variety of physical conditions, involving such things as moisture, dust, high or low ambient temperatures, or vandalism and be electrically safe. The related aspects of safety are covered by the European safety standard for luminaires EN 60598. Luminaires that pass the requirements of the standard are given the **ENEC Mark**. A mark which luminaires should carry is the CE mark. This mark signifies that a product conforms with the requirements of the relevant EEC directives. The prime purpose of the mark is to assist customs and market inspectors in enabling the free trading and movement of products within the EEC. Now the directives appropriate to general lighting products are the **Low Voltage Directive (LVD)** and the **Electromagnetic Compatibility (EMC) Directive**. CE marking is now compulsory to indicate LVD and EMC conformity. Luminaires that have both the ENEC and CE mark are the first choice in most situations.



Fig 23 Amigo surface mounted louvre fitting

Luminaires are classified according to the degree of protection they give to dust or moisture. This is classified by the **Ingress Protection (IP) System**. It describes a luminaire by a two digit number eg IP65, for dust-tight and protection against water jets.(Fig 24) The first digit classifies the degree of protection against the ingress of solid foreign bodies, from fingers and tools to fine dust. The second digit classifies the degree of protection against the ingress of moisture.

When equipment has to withstand hostile environmental conditions, it is important to ensure that manufacturers' claims apply throughout the life of the luminaire and not just to a new luminaire. This is the case with the **Ingress Protection (IP)** ratings when a luminaire is safety marked, since an IP rating is

First Digit	Degree of protection	Second Digit	Degree of protection
0	Non-protected	0	Non-protected
1	Protected against solid objects greater than 50mm	1	Protected against dripping water
2	Protected against solid objects greater than 12mm	2	Protected against dripping water when tilted up to 15°
3	Protected against solid objects greater than 2.5mm	3	Protected against spraying water
4	Protected against solid objects greater than 1.0mm	4	Protected against splashing water
5	Dust-protected	5	Protected against water jets
6	Dust-tight	6	Protected against heavy seas
		7	Protected against the effects of immersion
		8	Protected against submersion

Fig 24 Ingress Protection (IP) classification

then awarded to an already arduously tested luminaire. An IP rating that is not part of an accepted standard test procedure is of little value. The final decision about which luminaire to use can be based on cost, efficiency, photometric performance, glare control and other factors. This is all covered in more detail in the luminaire module.

### Photometric Performance

It is essential when selecting a luminaire that its lighting performance is understood for the purpose of comparing luminaires and that understanding is needed for carrying out lighting design calculations. The information you need to look at is photometric data. There are various formats of presenting data according to the type of luminaire. The most common type, used for the majority of luminaires will be explained. Page 24 and 25 shows the data issued by the Thorn Lighting Technology Centre at Spennymoor for a Diffusalux Type A Hospital fitting with high frequency electronic control gear for a 1800mm 70W fluorescent lamp. This is taken as an example.

**Range name:** Diffusalux

**Description:** Hospital Type A

**Luminaire maintenance category:** E. The CIE and CIBSE designate A, B, C, D, E, and F categories. An additional category is designated by Thorn Lighting, A+, for luminaires with very good maintenance characteristics. This is used in determining the maintenance factor for the installation with these luminaires.

**Conversion terms:** Set against the catalogue number and lamp type. DF for Distribution Factor, UF for Utilisation Factor, PC for Polar Curve and LD for Luminance Distribution. Currently only one luminaire is shown in the header so conversion terms that are multiplied are always 1.00 and the Glare conversion term which is added is always 0.0.

**Data code:** A unique code is given to each set of data.

**Polar curve:** (Fig 26) This gives an indication of the luminous intensity at different angles. The diagram is two diagrams in one. The left-hand side denoted by T is for one half of the **transverse plane**. (Fig 27 shows the transverse and axial planes through a luminaire.) The other half of the transverse plane, which is not shown, is a mirror image of this curve along the line OM. The right-hand side of the diagram denoted by A is again for one half of the **axial plane** of the luminaire. The other half of the axial plane is a mirror image of this curve along the line OM. The length of the line OP in the transverse plane is proportional to the luminous intensity at the **elevation angle**  $\delta$  measured from the vertical, as an example.



Fig 25 Diffusalux Hospital Type A

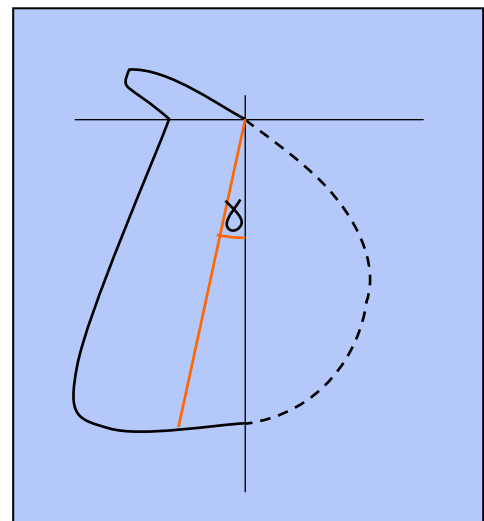


Fig 26 Polar curve

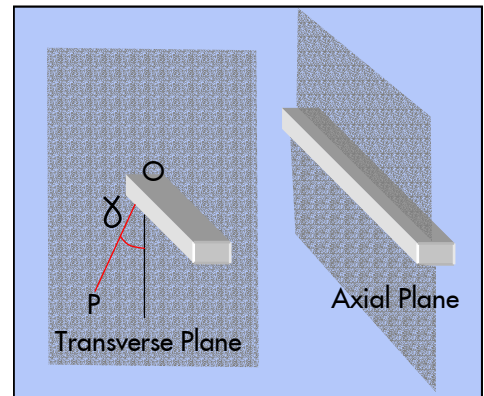


Fig 27 Planes of luminous intensity through luminaire.

# Thorn Lighting Technology Centre

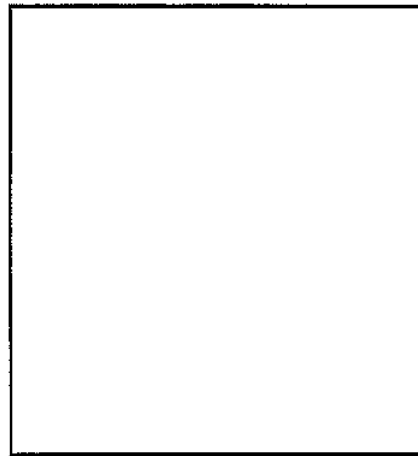
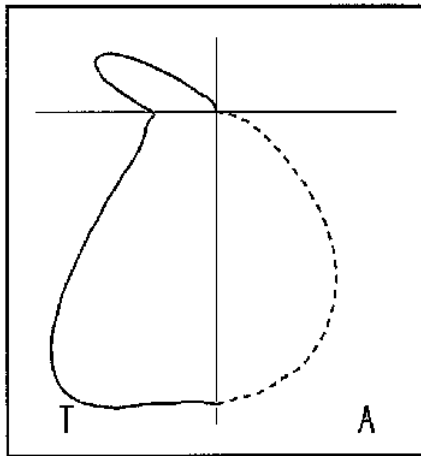
A BSI Registered Photometric Laboratory

## DIFFUSALUX

**Description:** Hospital Type A  
**Luminaire maintenance category** E

**Conversion terms**

Catalogue number	Lamp	DF,UF,PC	Glare	LD	Data code
DLUX AZ 170	1800mm 70W 26Ø	1.00	0.0	1.00	R0001603 *



**Light output ratio** Up 0.16 Down 0.61 Total 0.77  
**Max. spacing to height ratio** SHR MAX 1.73

**Utilisation factors UF[F]** SHR NOM 1.70

**Uncorrected glare indices**

Reflectances			Room index				
C	W	F	1	2	3	4	5
0.8	0.6	0.2	0.56	0.69	0.74	0.77	0.79
	0.5		0.52	0.66	0.72	0.75	0.78
	0.3		0.47	0.61	0.68	0.72	0.75
0.7	0.6	0.2	0.54	0.66	0.71	0.74	0.76
	0.5		0.51	0.63	0.69	0.72	0.74
	0.3		0.45	0.59	0.65	0.69	0.72
0.5	0.6	0.2	0.50	0.61	0.65	0.68	0.69
	0.5		0.47	0.59	0.63	0.66	0.68
	0.3		0.43	0.55	0.61	0.64	0.66
0.0	0.0	0.0	0.34	0.43	0.48	0.50	0.52
<b>DF[F]</b>			0.34	0.43	0.48	0.50	0.52
<b>DF[W]</b>			0.27	0.18	0.13	0.11	0.09
<b>DF[C]</b>			0.16	0.16	0.16	0.16	0.16

Room size		Viewed crosswise					ECT
X	Y						
2H	2H	5.1	5.8	5.5	6.2	7.0	+0.1
	3H	7.4	8.1	7.8	8.5	9.4	-0.4
	4H	8.8	9.4	9.2	9.8	10.7	-0.9
	6H	10.3	10.9	10.7	11.3	12.2	-1.7
	8H	11.1	11.6	11.5	12.0	12.9	-2.1
12H	11.9	12.5	12.3	12.9	13.8	-2.7	
4H	2H	6.1	6.7	6.5	7.1	8.0	+0.1
	3H	8.8	9.3	9.2	9.7	10.6	-0.4
	4H	10.4	10.9	10.8	11.3	12.2	-0.8
	6H	12.1	12.5	12.5	13.0	13.9	-1.6
	8H	13.0	13.5	13.5	13.9	14.8	-2.1
12H	14.1	14.5	14.5	14.9	15.8	-2.7	
8H	4H	11.1	11.6	11.6	12.0	12.9	-0.7
	6H	13.1	13.6	13.6	13.9	14.9	-1.4
	8H	14.4	14.9	14.8	15.1	16.1	-1.8
	12H	15.6	16.0	16.0	16.3	17.3	-2.5
12H	4H	11.3	11.7	11.8	12.2	13.1	-0.5
	6H	13.5	14.1	13.9	14.3	15.2	-1.2
	8H	14.7	15.2	15.2	15.5	16.4	-1.6

LAL0117.0 Issue 2



# Thorn Lighting Technology Centre

A BSI Registered Photometric Laboratory

## DIFFUSALUX

**Description:** Hospital Type A  
**Luminaire maintenance category:** E  
**Conversion terms**

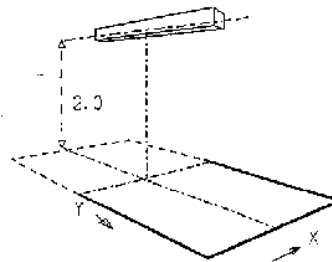
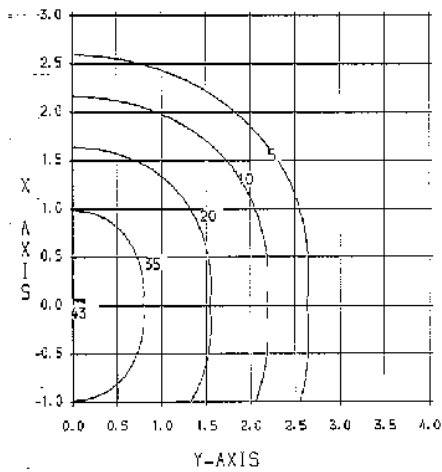
Catalogue number DLUX AZ 170      Lamp 1800mm 70W 26Ø      DF,UF,PC Glare LD Data code 1.00 0.0 1.00 R0001603 \*

### Luminous intensity in cd / 1000 lm

Elevation angle	Azimuth angle			
	0	30	60	90
0	199	199	199	199
5	197	196	195	195
10	200	198	195	193
15	204	201	193	188
20	212	205	192	184
25	218	210	190	176
30	220	209	184	166
35	211	200	173	153
40	187	183	158	138
45	151	155	140	119
50	118	123	121	97
55	94	96	94	73
60	76	77	74	55
65	64	63	57	40
70	58	55	47	30
75	54	50	38	21
80	52	44	30	13
85	48	39	23	6
90	46	36	17	0
95	55	37	17	0
100	66	41	16	0
105	83	54	16	0
110	93	69	17	0
115	92	74	22	0
120	75	64	27	0
125	49	42	21	0
130	31	28	14	0
135	19	17	9	0
140	15	13	5	0
145	13	10	5	0
150	10	8	3	0
155	8	6	3	0
160	5	4	2	0
165	3	3	1	0
170	1	1	0	0
175	0	0	0	0
180	0	0	0	0

### Isolux diagram for horizontal plane

in lux / 1000 lm. All distances are in metres



### Luminance distribution in cd/m<sup>2</sup>/1000 lm

Elevation angle	Azimuth angle			
	0	30	60	90
45	520	554	555	555
50	426	462	513	498
55	359	384	431	420
60	311	332	374	363
65	284	297	322	312
70	284	288	305	289
75	297	297	292	267
80	329	305	284	247
85	360	328	288	227
90	429	388	317	0

**Light output ratio:** The light from the lamp is controlled by the luminaire, to direct light to where it is most useful, avoiding waste and glare, but in doing so, the light controller absorbs some of the light emitted by the lamp. There are three light output ratios.

Upward light output ratio (ULOR)

$$ULOR = \frac{\text{Flux emitted above the horizontal}}{\text{Total bare lamp flux}}$$

Downward light output ratio (DLOR)

$$DLOR = \frac{\text{Flux emitted below the horizontal}}{\text{Total bare lamp flux}}$$

Light output ratio (LOR)

$$LOR = \frac{\text{Flux emitted}}{\text{Total bare lamp flux}}$$

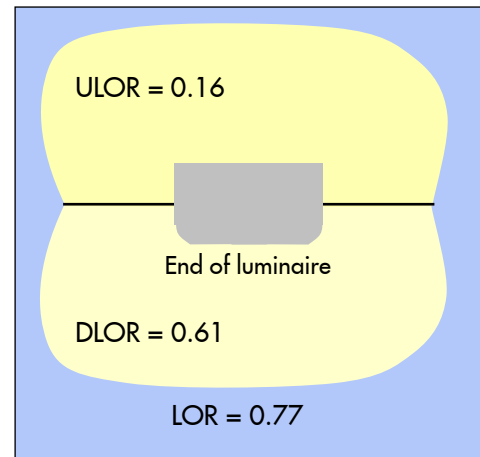


Fig 28 Light output ratio of Diffusalux Type A Hospital fitting

**Max. spacing to height ratio:** The maximum spacing to height ratio or SHR MAX indicates how far apart fitting in a regular arrangement should be spaced before the uniformity becomes unacceptable for general lighting. The spacing to height ratio is important when planning an installation and it will be covered in detail later in this section.

**Utilisation factor UF[F]:** For particular proportions of room size and room reflectances this table gives factors for how well a regular arrangement of fittings gets light onto the horizontal work plane. The total lamp lumens multiplied by the UF[F] gives the total amount of light flux (lumens) falling on the work plane, that imaginary surface at the level of the task, or the UF[F] can be expressed as:

$$UF[F] = \frac{\text{Total flux received by the work plane}}{\text{Total flux emitted by the bare lamps}}$$

This table is best explained during the calculation of average illuminance that follows. It can be noted though that the data is generated for a luminaire layout with a nominal spacing to height ratio (SHR NOM) of 1.70 in the example chosen. Also the data at the bottom for DF[F], DF[W] and DF[C] is not part of the **utilisation factor** table but **distribution factors** that can be used with **transfer factors** to find the average illuminance on the walls and ceiling.

**Uncorrected glare indices:** This table enables the calculation of a discomfort glare index for a wide range of room sizes and reflectances. Later a worked example will explain the use of this data.

**Luminous Intensity:** One the second page luminous intensity data is shown expressed in candelas per 1000 lamp lumens.

The actual intensity is:

$$I = \frac{\text{Intensity value in table} \times \text{lamp lumens of luminaire}}{1000}$$

The angles of elevation are measured from the downward vertical passing through the centre of the fitting, so 0° corresponds to directly below the fitting and 180° to directly above the fitting. The angles of **azimuth** are shown in the plan view of a fitting in fig 29. A vertical plane passing through 0° and 180° is the **axial plane**. A vertical plane passing through 90° and 270° is the **transverse plane**.

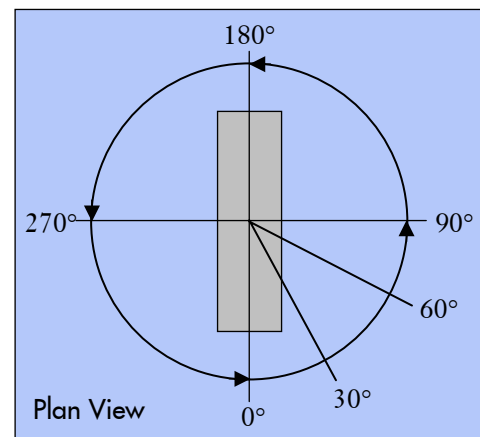


Fig 29 Measurement of azimuth angles

**Luminance distribution:** This table enables the luminance of the luminaire to be calculated at elevation angles 45° to 90° for the azimuth angles 0°, 30°, 60° and 90°. There are recommendations on limiting luminance of luminaires that give direct downward light when in areas where display screens are used, like computer screens. Luminance is measured in cd/m<sup>2</sup> but the table is expressed in cd/m<sup>2</sup>/1000lm to be independent of the lamp used. To calculate luminance, L:

$$L = \frac{\text{Luminance value in table} \times \text{lamp lumens of luminaire}}{1000}$$

**Isolux diagram for horizontal plane:** It was explained in the Lighting Theory module that the Inverse Square Law works with a fair degree of accuracy for small light sources or luminaires where the distance between the luminaire and the point of measurement is at least 5 times the maximum dimension of the luminaire. For shorter distances other calculations are necessary for accuracy. The isolux diagram gives pre-calculated values of illuminance that are valid. The grid is a plan view with the luminaire centrally placed at 0.0, 0.0. Each contour is for a unique illuminance value when the luminaire is 2.0m above the surface. The illuminance at points that are not on contours can be estimated by looking at adjacent values. It should be appreciated that the illuminance values are in lux/1000lm, so that to calculate illuminance, E:

$$E = \frac{\text{Illuminance value in diagram} \times \text{lamp lumens of luminaire}}{1000}$$

The **Comprehensive Product Catalogue 1999** shows isolux diagrams in a perspective view. Other than that the data format is essentially the same.

**Another Example of photometric data**

Luminaires that have nearly the same luminous intensities at different azimuth angles have **radially symmetrical** light distributions. The photometric data for these is simpler. The main difference occurs in the **polar curve** and **luminous intensity** table. For comparison the main differences of this data is shown with a Radbay fitting using a high pressure sodium lamp. The polar curve in the transverse and axial planes are the same so it is not necessary to identify the curve with a T or A. (Fig 31) Also there is only a need to show one column of intensity values that are averaged over several vertical planes of measurement. (Fig 32)

Luminous intensity in cd/1000lm	
Elevation angle	Mean vertical
0	284
5	286
10	293
15	291
20	293
25	294
30	302
35	330
40	364
45	337
50	248
55	114
60	33
65	15
70	8
75	4
80	2
85	1
90	0
95	0
100	0
105	0
110	0
115	0
120	0
125	0
130	0
135	0
140	0
145	0
150	0
155	0
160	0
165	0
170	0
175	0
180	0

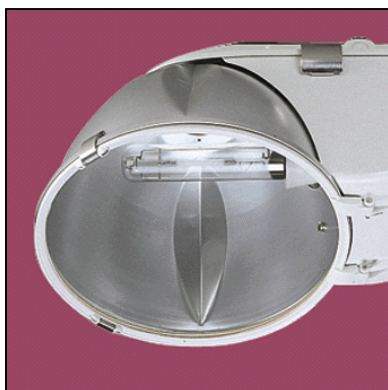


Fig 30 Radbay with HPS lamp

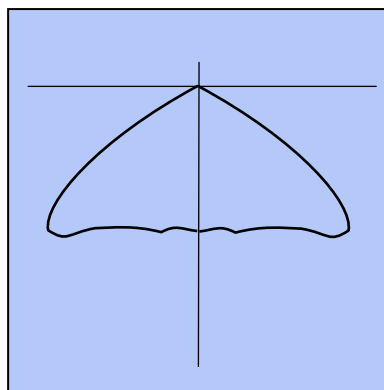


Fig 31 Polar curve for Radbay

Fig 32 Intensity data for Radbay

**Beam diagram**

A beam diagram or illuminance cone, as it is sometimes called, (Fig 33) is a useful way of showing spotlight and downlighter photometric performance. The diagram gives the maximum illuminance,  $E_{max}$ , in lux over a range of distances  $h$ , usually 1 to 4 metres away from the luminaire. The angle given is the beam angle over which the luminous intensity drops to half the peak value. The diameter of the beam to the half peak intensity is denoted by  $d$  in metres. The majority of spotlights and downlighters contribute significant quantities of light beyond the beam angle as well as spill light.

Using the **inverse square law**,  $E = \frac{I}{d^2}$  in the form  $I = E \times d^2$  it can be deduced that the maximum luminous intensity is  $3290 \times 1^2 = 3290cd$ .

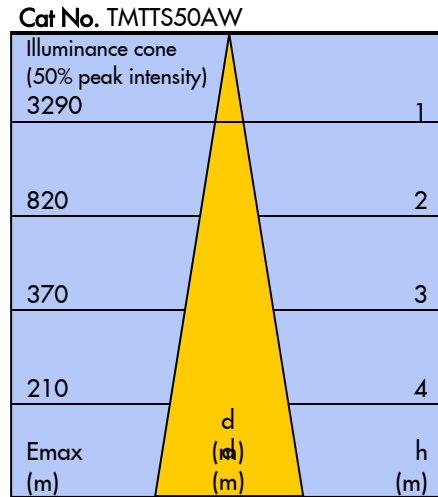


Fig 33 Beam diagram

*Questions 3*

1. A large warehouse with a room index of 4.0 uses Radbay RBSO250 fittings with 250W high pressure sodium tubular lamps. The fitting has a maintenance category of A. Assume that relamping occurs at 18000 hours and operation is during 12 hours per day, 51 weeks per year and 5 days a week and that spot lamp replacement happens. Recommend a maintenance policy and calculate the maintenance factor. (Use data in fig 16)
2. Give a percentage of operational costs for staff in a typical office.
3. A luminaire with an ENEC mark has IP23 classification, what does this mean in terms of the degree of protection provided by the luminaire?
4. What does a polar curve indicate?
5. What is the light output ratio of a fitting a measure of?
6. What is likely to result in a lighting installation if the maximum spacing to height ratio is exceeded?

**Spacing to Height Ratio**

The **Spacing to Height Ratio** (SHR) is the spacing between luminaires divided by their height of luminaires above the horizontal work plane. This distance, the mounting height, is known as  $H_m$ , see fig 37. It affects the uniformity of illuminance on the work plane. When the UF[F] tables are determined, for a nominal spacing to height ratio SHR NOM, the maximum spacing to height ratio SHR MAX of the luminaire is also calculated, and is a value which should not be exceeded if the uniformity is to be acceptable for general lighting. The maximum spacing applies for both the axial and transverse spacing of luminaires measured from centre to centre of adjacent luminaires in a regular arrangement. It is usual to space luminaires that are adjacent to the walls at about half the spacing to the walls (Fig 34).

It is very important to realise that spacing to height data is only calculated for unobstructed areas. Objects such as screens, filing cabinets, bulky equipment, and so on, cause obstructions and shadows. As a result the lighting may become unacceptable in parts of the space. This must be dealt with separately by under-spacing the luminaires. Similar consideration must be given to the problems caused by lamp failures. In practice this means that wide spacings can be undesirable, especially in industrial lighting with high pressure discharge lamps. A common approach in industrial lighting is to calculate the minimum number of luminaires needed to achieve acceptable uniformity, and use about twice this number in practice (by selecting a suitable lamp rating).

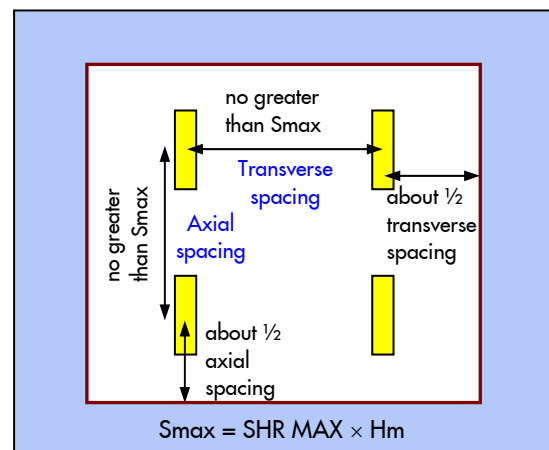


Fig 34 Maximum spacing for uniformity

### Average Illuminance

The average illuminance produced by a lighting installation, or the number of luminaires required to achieve a specific average illuminance, can be calculated by means of utilisation factors, a UF being the ratio of the total flux received by a particular surface to the total lamp flux of the installation. The average illuminance E over a horizontal work plane, for example at desk height or on the floor, can be calculated from the "lumen method" formula. In which case the UF used is UF[F] from standard photometric data.

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

where :

E is the maintained illuminance

n is the number of lamps per luminaire

N is the number of luminaires

F is the initial bare lamp flux (when maintained illuminance is required)

UF is the utilisation factor of the installation

MF is the maintenance factor

A is the area of the work plane

Utilisation factors can be determined for any surface or layout of luminaires. The UF symbol can be shown followed by an extra letter in brackets, to denote the surface. As explained, UF[F] is the utilisation factor for the floor cavity, additionally UF[W] is the utilisation factor for the walls and UF[C] is the utilisation factor for the ceiling cavity. Utilisation factors are, in practice, only calculated for general lighting systems with regular arrays of luminaires and for three main room surfaces. The highest of these surfaces, the C surface (for ceiling cavity), is an imaginary horizontal plane at the level of the luminaires having a reflectance equal to that of the ceiling cavity. The lowest surface, the F surface (for floor cavity), is a horizontal plane at normal working height (ie table height) which is often assumed to be 0.85m above the floor. The middle surface, the W surface (for walls), consists of all the walls between the C and F planes. The method of calculating utilisation factors is detailed in CIBSE technical memorandum No 5 (CIBSE TM5). Thorn Lighting publishes utilisation factors for standard conditions for its luminaires. The standard method of presentation is shown in Fig 35. To use this table, it is only necessary to know the **Room Index** and the **effective reflectances** of the three standard surfaces (ceiling cavity C, walls W and floor cavity F). The data is given for room indices 1 to 5 in steps of 1. For values of room index between these values an estimate can be made.

#### Worked example

Find the UF at a room index of 2.5 at reflectances for the ceiling cavity, walls and floor cavity of 0.8, 0.6 and 0.2 respectively.

Take the difference between the values of UF at 2 and 3 and add half (0.5) of this onto the UF at 2. The UF at room index (RI) 2.5 is:

$$0.77 + \frac{0.84 - 0.77}{2} = 0.805 \approx 0.80$$

This is called **interpolation**.

Find the UF at RI of 1.7 for reflectances 0.7/0.5/0.2 for ceiling cavity, walls and floor cavity respectively.

$$UF_{1.7} = UF_{1.0} + 0.7(UF_{2.0} - UF_{1.0})$$

$$UF_{1.7} = 0.52 + 0.7(0.68 - 0.52) \approx 0.63$$

<b>Light output ratio</b>		Up 0.27	Down 0.67	Total 0.94			
<b>Max. spacing to height ratio</b>		SHR MAX 2.14					
<b>Utilisation factors UF[F]</b>		SHR NOM 2.10					
<b>Reflectances</b>			<b>Room Index</b>				
C	W	F	1	2	3	4	5
0.8	0.6	0.2	0.60	0.77	0.84	0.88	0.91
	0.5		0.55	0.72	0.81	0.85	0.89
	0.3		0.46	0.65	0.74	0.80	0.84
0.7	0.6	0.2	0.57	0.72	0.79	0.83	0.86
	0.5		0.52	0.68	0.76	0.81	0.84
	0.3		0.45	0.62	0.71	0.76	0.80
0.5	0.6	0.2	0.51	0.64	0.71	0.74	0.77
	0.5		0.47	0.61	0.68	0.72	0.75
	0.3		0.41	0.56	0.64	0.68	0.71
0.0	0.0	0.0	0.28	0.39	0.45	0.49	0.51
<b>DF[F]</b>			0.28	0.39	0.45	0.49	0.51
<b>DF[W]</b>			0.39	0.28	0.22	0.18	0.16
<b>DF[C]</b>			0.27	0.27	0.27	0.27	0.27

Fig 35 Utilisation Factor Table and Distribution Factors

**Interpolation** can also be carried out for reflectance values that fall between those given in the UF table. For example, if the reflectances are 60/60/20 for the ceiling cavity, walls and floor cavity respectively. Take two UFs at the RI required at reflectances 70/60/20 and 50/60/20. Then find the mean of the two UFs, to approximate to a 0.6 ceiling cavity reflectance.

When the floor cavity has a reflectance different to 0.2 the correction factors should be applied shown in [fig 36](#). These factors are multiplied with the utilisation factor.

If a room index is calculated to be greater than 5 it is usually sufficiently accurate to take the value of UF at a room index of 5 because generally only small changes in UF occur above this room index.

Calculation of floor cavity reflectance, ceiling cavity reflectance and room index is covered in the next sections.

**Room Index**

Utilisation factors are determined by the effective reflectance of the room surfaces and the room index. The Room Index is for rectangular rooms given by:

$$RI = \frac{L \times W}{Hm(L + W)}$$

where:

L is the length of the room  
 W is the width of the room  
 Hm is the height of the luminaire plane above the horizontal work surface or plane

If the room is re-entrant in shape, for example L-shaped, then it must be divided into two or more non-re-entrant sections which can be treated separately.

R[F] = 0.0							
C	Reflectances		Room Index				
	W	F	1	2	3	4	5
0.8	0.6	0.0	0.918	0.889	0.875	0.867	0.863
	0.5		0.931	0.898	0.883	0.874	0.868
	0.3		0.951	0.915	0.896	0.885	0.877
0.7	0.6	0.0	0.926	0.901	0.890	0.883	0.879
	0.5		0.937	0.910	0.896	0.889	0.888
	0.3		0.955	0.925	0.909	0.899	0.892
0.5	0.6	0.0	0.940	0.925	0.918	0.914	0.912
	0.5		0.950	0.932	0.923	0.918	0.915
	0.3		0.965	0.944	0.934	0.927	0.923
R[F] = 0.1							
C	Reflectances		Room Index				
	W	F	1	2	3	4	5
0.8	0.6	0.1	0.957	0.941	0.933	0.929	0.926
	0.5		0.964	0.946	0.938	0.933	0.929
	0.3		0.975	0.956	0.945	0.939	0.935
0.7	0.6	0.1	0.961	0.948	0.942	0.938	0.936
	0.5		0.968	0.953	0.945	0.941	0.938
	0.3		0.977	0.961	0.953	0.947	0.943
0.5	0.6	0.1	0.969	0.961	0.957	0.955	0.954
	0.5		0.974	0.965	0.960	0.957	0.955
	0.3		0.983	0.972	0.965	0.962	0.960
R[F] = 0.3							
C	Reflectances		Room Index				
	W	F	1	2	3	4	5
0.8	0.6	0.3	1.047	1.067	1.077	1.083	1.087
	0.5		1.039	1.060	1.071	1.078	1.083
	0.3		1.027	1.048	1.061	1.069	1.075
0.7	0.6	0.3	1.042	1.058	1.066	1.071	1.074
	0.5		1.038	1.053	1.061	1.067	1.070
	0.3		1.024	1.043	1.053	1.060	1.063
0.5	0.6	0.3	1.033	1.042	1.047	1.049	1.051
	0.5		1.028	1.038	1.043	1.046	1.048
	0.3		1.018	1.030	1.037	1.042	1.044

Fig 36 Correction Factors to convert UF[F] values for 0.2 floor cavity reflectance to other values of floor cavity reflectance.

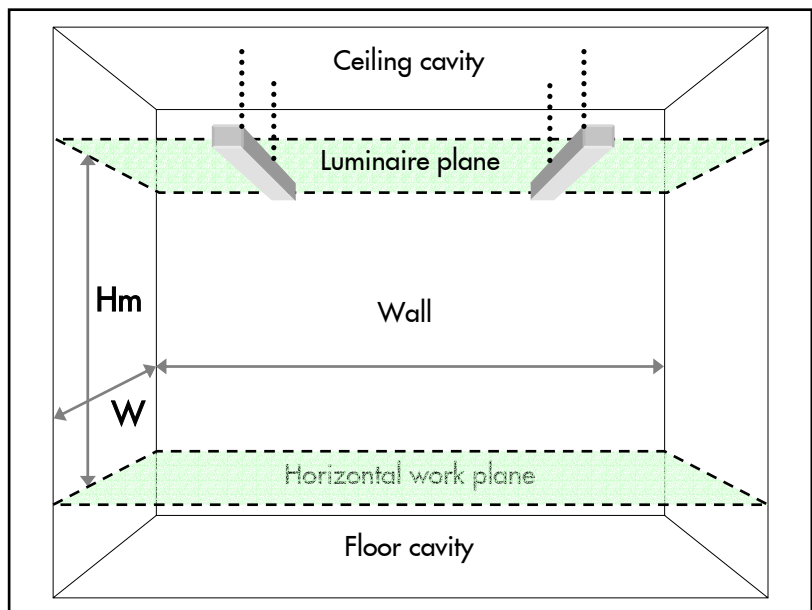


Fig 37 Calculation of Room Index

### Effective reflectance of room surfaces

The effective reflectances are needed for the wall surface, the ceiling cavity, and the floor cavity. The wall surface will generally consist of a series of areas  $A_1$  to  $A_n$  of different reflectances  $R_1$  to  $R_n$  respectively. The effective reflectance of a composite surface is the area-weighted average  $R_a$ , given by:-

$$R_a = \frac{R_1A_1 + R_2A_2 + \dots + R_nA_n}{A_1 + A_2 + \dots + A_n}$$

In the case of either the floor cavity or the ceiling cavity (or any other cavity) the effective reflectance depends on both the reflectance of the cavity surfaces and the relative depth of the cavity. The

approximate value is given by:-  $R_c = \frac{CI \times R_a}{CI + 2(1 + R_a)}$

where  $R_a$  is the area-weighted average reflectance of the surfaces of the cavity as described above and CI is the Cavity Index, a similar measure to the Room Index, defined as

$CI = \frac{l \times w}{d(l + w)}$  where  $d$  is the depth of the cavity and  $l$  and  $w$  are its length and width.

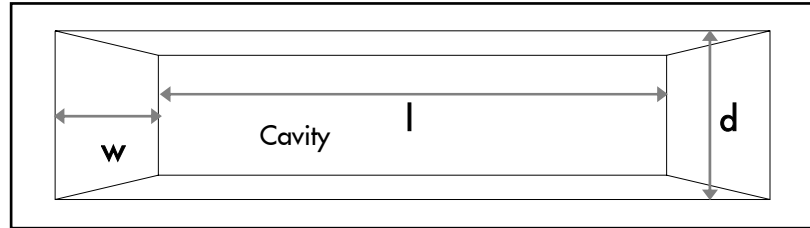


Fig 38 Calculation of Cavity Index

#### Worked example

Calculate the effective average reflectance of a ceiling cavity where luminaires are suspended 1.0m below the ceiling. The reflectance of the ceiling is 80% and walls 50%. The room is 20 by 10m.

$R_a = \frac{R_1A_1 + R_2A_2}{A_1 + A_2}$  where:  $R_1 = 0.8$ ,  $R_2 = 0.5$ ,  $A_1 = l \times w = 20 \times 10 = 200$ ,  $A_2 = 2d(l + w) = 60$

$$R_a = \frac{(0.8 \times 200) + (0.5 \times 60)}{200 + 60} = 0.73$$

$$CI = \frac{l \times w}{d(l + w)} = \frac{20 \times 10}{1(20 + 10)} = 6.7$$

$$R_c = \frac{CI \times R_a}{CI + 2(1 + R_a)} = \frac{6.7 \times 0.73}{6.7 + 2(1 + 0.73)} = 0.48$$

Note the large difference between the ceiling reflectance of 0.8 and the effective reflectance of only 0.48!

### Calculation Procedure for General Lighting

The following calculation procedure is recommended when calculating the number of luminaires needed to achieve a given average illuminance:

1. Calculate the Room Index RI, the Floor Cavity Index CI, and the Ceiling Cavity Index CI
2. Calculate the effective reflectances of the ceiling cavity, walls, and floor cavity. Remember to include the effect of desks or machines in the latter. (For surface or recessed luminaires with a flat ceiling there is no ceiling cavity)
3. Determine the UF value from the table for the luminaire selected, using the Room Index from (1) and the effective reflectances from (2).
4. Apply any necessary correction to the UF value for floor cavity reflectances other than 0.2.
5. Determine LLMF and LSF from the lamp lumen maintenance and lamp survival curves or tables respectively, based upon the expected re-lamping policy. (LSF is 1.0 if there is to be 'spot' lamp replacement.)
6. Determine the LMF and RSMF from the tables in [fig 18](#) and [fig 19](#).
7. Calculate the maintenance factor (MF) by multiplying together the four factors from (5 and 6).
8. Calculate the maximum spacing of luminaires from  $SHR_{MAX} \times H_m$ .
9. Calculate the total number of luminaires at or just below the maximum spacing for uniformity. (Particular care should be taken if the layout of luminaires is constrained by the module of the ceiling, eg a  $600 \times 600$ mm ceiling system module with recessed luminaires.)

10. Use this number in the 'lumen method' formula:  $E = \frac{n \times N \times F \times UF(F) \times MF}{A}$

11. Check illuminance (E) against your target illuminance, (E<sub>T</sub>):

Much higher than target	Select another luminaire with lower lamp lumens	Go to 3
Same or just lower than target		Go to 12
Lower than target	Increase luminaire number by about E <sub>T</sub> /E	Go to 10
Much lower than target	Select another luminaire with higher lamp lumens	Go to 3

12. Determine practical layout and check spacing. The proposed layout should not exceed the maximum spacing.

13. If not done already calculate the illuminance that will be achieved by the final layout.

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

*Worked example*

Calculate the number of luminaires needed for a school workshop 20 × 10 × 3m using ceiling mounted Diffusalux College Range luminaires with electronic control gear. The reflectance of the ceiling, walls and work plane is 80%, 50% and 20% respectively. The work benches are 800mm high. Assume the luminaires and room are cleaned each year with 'spot' lamp replacement. The maintained illuminance recommended is 300lux.



L = 20m, W = 10m, Hm = 3 – 0.8 = 2.2m

**Room Index**

$$RI = \frac{L \times W}{Hm(L + W)} = \frac{20 \times 10}{2.2(20 + 10)} = 3.0$$

Selection of luminaire: DLUXCZ 158 with single 1500mm 58W Polylux XL lamp

**Utilisation Factor**

UF = 0.77 at RI 3.0 reflectances 80/50/20% (See fig 39)

**Maintenance Factor**

LLMF = 0.95  
 by using Polylux XL lamps  
 LSF = 1.0  
 because of 'spot' lamp replacement  
 LMF = 0.90  
 LMC is E, Environment is Normal and yearly cleaning  
 RSMF = 0.88  
 Environment is Normal, Direct/Indirect yearly cleaning  
 MF = LLMF × LSF × LMC × RSMF  
 MF = 0.95 × 1.0 × 0.90 × 0.88 = 0.75  
 (Data from fig 17, 18 and 19)

<b>Light output ratio</b>	Up 0.18	Down 0.64	Total 0.81				
<b>Max. spacing to height ratio</b>	SHR MAX 2.03						
<b>Utilisation factors UF[F] SHR NOM 2.00</b>							
<b>Reflectances</b>			<b>Room Index</b>				
C	W	F	1	2	3	4	5
0.8	0.6	0.2	0.62	0.74	0.79	0.82	0.84
	0.5		0.58	0.71	0.77	0.80	0.82
	0.3		0.52	0.66	0.72	0.76	0.79
0.7	0.6	0.2	0.60	0.71	0.76	0.78	0.80
	0.5		0.56	0.68	0.73	0.77	0.78
	0.3		0.51	0.64	0.70	0.73	0.76
0.5	0.6	0.2	0.55	0.65	0.69	0.72	0.73
	0.5		0.53	0.63	0.68	0.70	0.72
	0.3		0.48	0.59	0.65	0.68	0.70
0.0	0.0	0.0	0.39	0.47	0.51	0.54	0.55

Fig 39 Utilisation Factor Table for DLUXCZ 158

**Total number of luminaires for uniformity**

Maximum spacing  
 Smax = SHR MAX × Hm  
 Smax = 2.03 × 2.2 = 4.47m



Min. no. of luminaires along length,  $L = \frac{20}{4.47} = 4.47 \approx 5$  (number must be rounded up)

Min. no. of luminaires along width,  $W = \frac{10}{4.47} = 2.24 \approx 3$  (number must be rounded up)

Min. no. of luminaires =  $5 \times 3 = 15$  (less than this uniformity will be below 0.8)

**‘Lumen method’ formula**

$$E = \frac{n \times N \times F \times UF(F) \times MF}{A} = E = \frac{1 \times 15 \times 5400 \times 0.77 \times 0.75}{20 \times 10} = 234\text{lux}$$

Using initial lamp lumens of 5400lm

Illuminance is lower than target therefore increase luminaire number by about  $E_T/E = 300/234 = 1.28$

No. of luminaires =  $15 \times 1.28 = 19$  (increase to 20 for regular layout of 5 along length by 4 along width)

This layout will conform to spacing requirements.

Re-calculating:

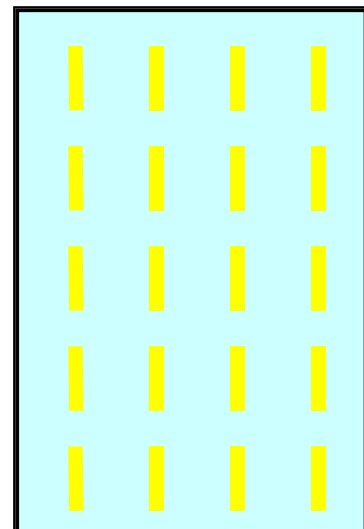
$$E = \frac{n \times N \times F \times UF(F) \times MF}{A} = E = \frac{1 \times 20 \times 5400 \times 0.77 \times 0.75}{20 \times 10} =$$

312lux  $\approx$  **300lux**

Could calculate this by multiplying first illuminance by the fractional increase in the no. of luminaires:

$$E = \frac{20}{15} \times 234 = 312 \text{ lux} \text{ Giving the same result.}$$

20 Diffusalux luminaires (DLUXCZ 158) with single 1500mm 58W Polylux XL lamps in a regular layout of 5 along the length at 4m spacing by 4 along the width at 2.5m spacing is design to provide a maintained illuminance of 300lux. The length of the luminaire parallel with the length of the room (20m).



**Calculation Procedure for Local and Localised Systems**

When local or localised systems are used or when unusual layouts or unconventional light distributions are used, calculations of average illuminance can be inappropriate. In such circumstances, it is necessary to calculate the illuminance at all points of interest with one of three methods:

- Basic photometric data and the Inverse Square and Cosine Law.
- Pre-calculated aids, such as isolux diagrams.
- A computer programs.

**Illuminance at a Point**

The use of basic photometric data is helpful when comparing luminaire performance and making luminaire selection. Then hand calculations, when used with discretion, can give much information about the required solution, but become tedious when large numbers of points are involved when applying the Inverse Square and Cosine Law.

Refer to the Lighting Theory module for the **Inverse Square and Cosine Law** that enables calculation at a point:

$$E = \frac{I \cos A}{d^2} \times MF \quad E = \frac{I \cos^3 A}{h^2} \times MF \quad \text{including the maintenance factor.}$$

For multiple small luminaires the results can be summed at a point.

**Isolux Diagrams**

Isolux diagrams give a ‘picture’ of what illuminance pattern results from a single or several luminaires. They give line contours of equal illuminance on a specified plane, offering a faster method of carrying out the same calculations. They can provide considerable guidance on the location of luminaires. Frequently

there is a plan view grid with the luminaire centrally placed at 0.0, 0.0. Each contour is for a unique illuminance value when the luminaire is 2.0m above, or away from a vertical surface. The illuminance at points that do not cross any contour can be estimated by looking at adjacent values. It should be appreciated that the illuminance values are in lux/1000lm, so that to calculate illuminance, E:

$$E = \frac{\text{Illuminance value in diagram} \times \text{lamp lumens of luminaire}}{1000}$$

### Computer Programs

Computer programs are a powerful tool but the results need to be well understood and interpreted. Illuminance values and other parameters can be calculated easily with a computer with a suitable program, such as **Optilume Interior** or **TL Vision**, for any type of lighting system, general, local or localised. A general caution needs to be given that the quality of the results is only as good as the quality of the thought that went into the design. The accuracy of the final result is no greater than the accuracy of the data supplied (photometric and installation data), despite the impression of precision given by the printout. Some computer software uses poor calculation methods and inadequate data. At the planning stage it is often better to obtain illuminance plots for individual luminaires or groups of luminaires than to attempt to simulate the complete installation. Tabulated illuminance values (**luxplots**) provide lots of detail, but are difficult for the inexperienced designer to assess. Graphic presentations such as **shading diagrams** are much easier to understand. Too much importance should not be placed on variations of illuminance, which although shown on the printout, will not be noticeable to the occupants. At the same time, the printout can give false confidence in the lighting solution and can prevent adequate consideration being given to the way in which other criteria are satisfied. In any event, attention should be given to satisfying the original design objectives.

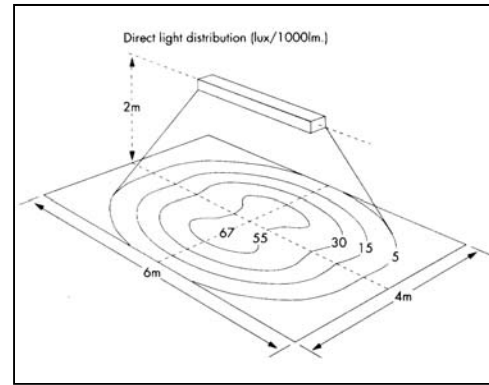


Fig 40 Isolux diagram

One very useful area of computer simulation is three dimensional graphics. 3D graphics systems are a very useful aid to the architect and consultant, in the form of CAD (Computer Aided Design), when used as part of a structural design and drafting system. This enables the inter-relationship of objects in space to be seen and dimensional clashes to be identified. The use of computer programs that 'merge' illuminance plots into CAD drawings of spaces is a valuable development to some engineering consultants.

Good quality and mathematically accurate visual representations of rooms and objects within it can now be achieved with 'rendering' techniques. **Lightscape** is a software program that enables near to photo-realistic images. Direct and inter-reflected light is calculated using accurate photometry of luminaires accounting for the colour and reflective properties of all surfaces. Images from different viewing positions are fairly easy to process because everything is stored as a surface with co-ordinates and properties. Images of this type always look computer generated partly because they are too 'clean' and lack clutter that most occupied spaces have, that lived in feeling. Make a point of seeing for yourself examples of these techniques. The generation of such images is generally very time consuming and hence costly but can be beneficial for the right project. Outdoor installations are amenable to this technique as much as indoor ones.

Another approach is to use a photographic image of an installation and scan it. This stored scanned image is then changed with a Photo Editor software program, such as **Adobe Paintbrush**. To make changes to the image that gives a good representation of expected light patterns from luminaires is a skilled task requiring considerable lighting engineering experience. In this process in effect a flat 2D image of a 3D scene is being changed discreetly by colour, brightness and contrast over entire image or small areas of chosen shapes. With all computer visual simulations it is important to convey to the client that they are an 'impression' of the appearance, not a guarantee, 'this is how it will look'. Judgements based upon the images are often very different from those based upon the real interior.

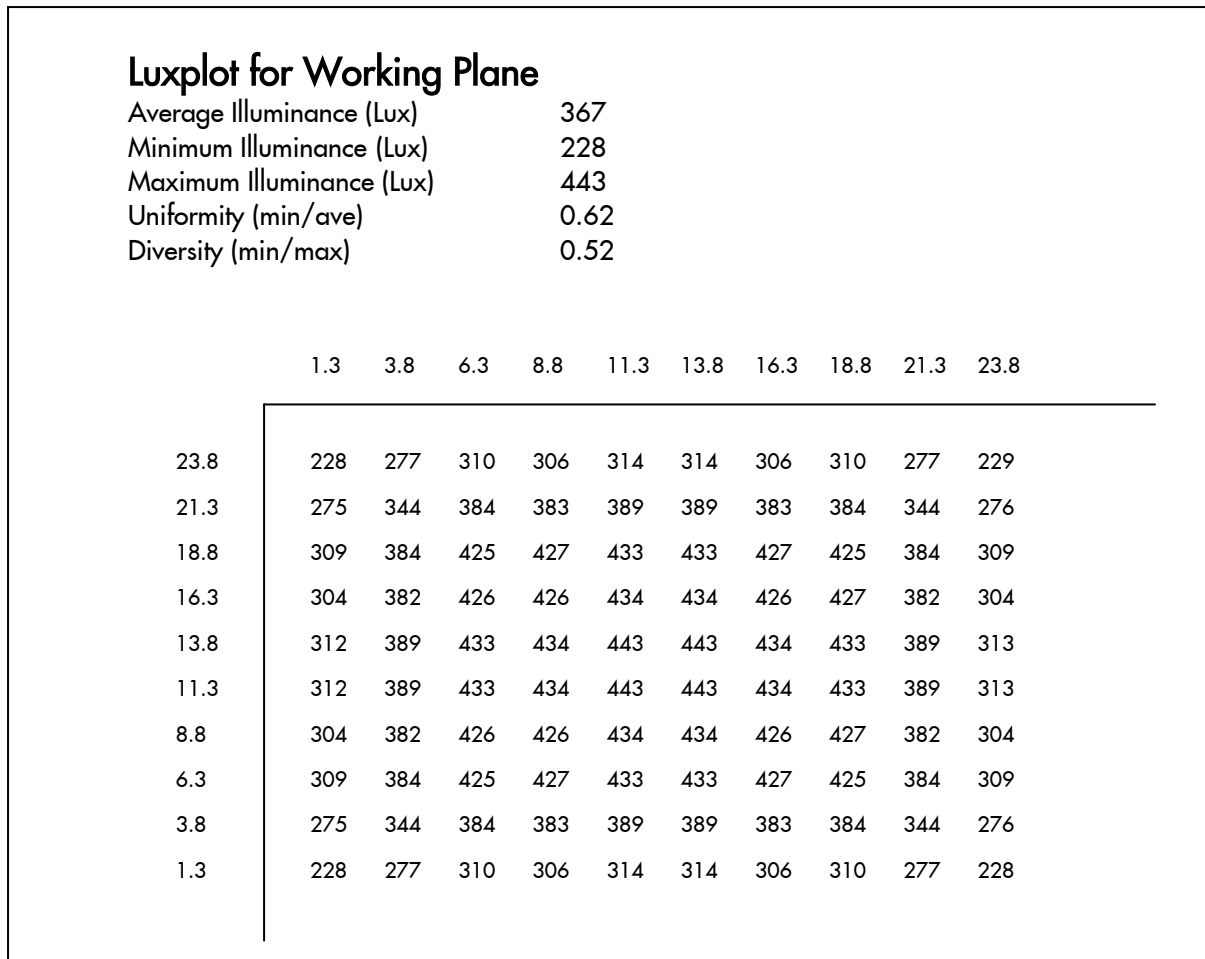


Fig 41 Example of Luxplot for working plane

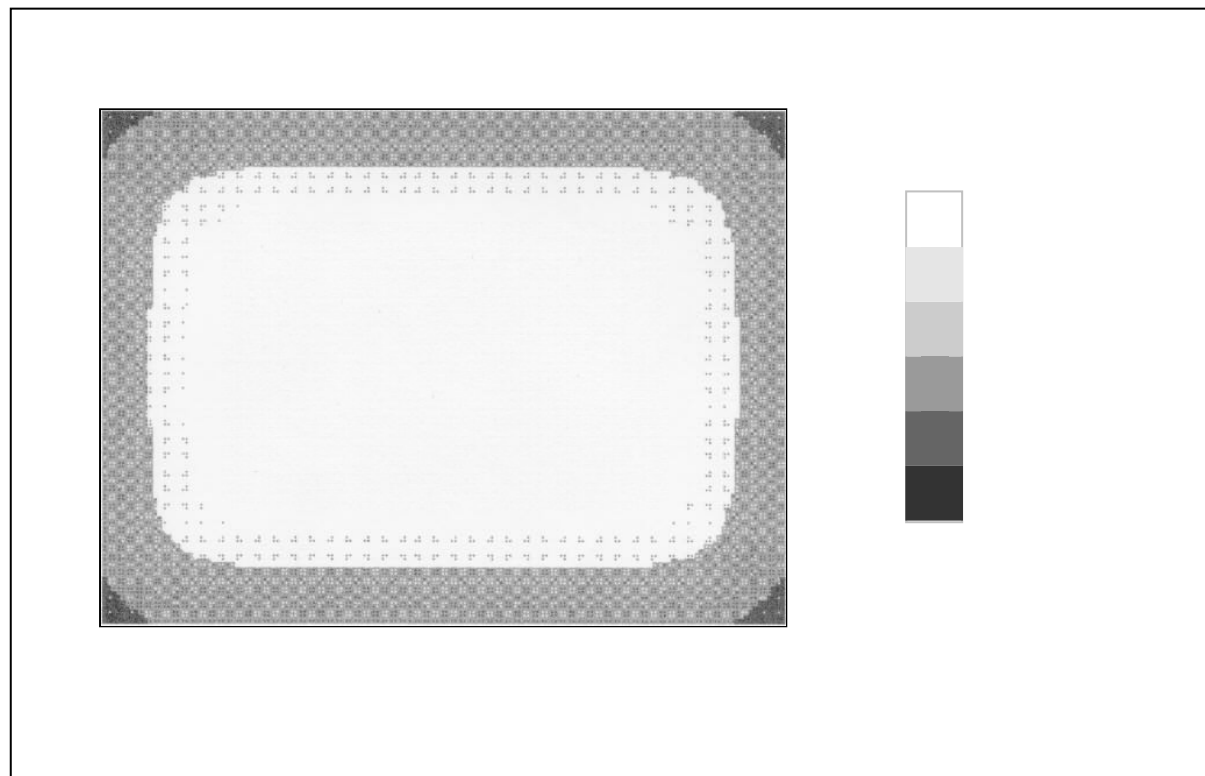


Fig 42 Example of Shading Diagram

## Discomfort Glare – UK Glare Index System

The UK Glare Index system for predicting the degree of discomfort glare in an installation is based upon the Building Research Establishment (BRE) **Glare Index formula**. The CIBSE recommends that the calculation of Glare Index for a lighting installation is done either by a computer program, using accurate data and the BRE **Glare Index formula** or by means of **Uncorrected Glare Index tables** published by the luminaire manufacturer. The designer does not have to be involved with the complex formula. Thorn Lighting's **Optilume Interior** and **TL Vision** software programs calculate the glare indices for a lighting installation. Even so you should be able to

understand and calculate glare index using uncorrected glare index tables. Without this understanding the result of computer programs may be unclear and you should be able to check the glare index values given.

The **Glare Index formula** contains a paradox. If one luminaire, 2m in length, is treated as two luminaires, each 1m long, the calculated glare index is changed though the degree of discomfort glare remains the same. This paradox is removed by the **Unified Glare Rating formula** put forward by the CIE. It is likely that CIBSE will adopt the UGR System in due course.

## BRE Glare Index Calculation using Tables

An example of an **Uncorrected Glare Indices** table is shown in [fig 43](#). The reflectances C, W and F are for the ceiling cavity, walls and floor cavity respectively. The indices in it must be corrected to allow for differences between the real installation and the standard installation on which the tables are based. The size of different installations are, for the purpose of glare, expressed in terms of one dimension H, the height of the luminaires above seated eye level (this is taken to be 1.2m above the floor). The room dimensions in the glare table are expressed as multiples of this quantity H. Normally the dimensions of the room are expressed as length and width, but this is not done in the case of a glare calculation. Instead the horizontal dimensions X and Y are used and refer to the lengths of the walls that are opposite (X) and parallel (Y) to the observer in the room. The main part of the table gives glare indices for luminaires viewed crosswise for values of room reflectance and room size. If an index is required for luminaires viewed endwise then the **ECT, Endwise Correction Term**, is added to the index read off the table using the ECT in the same row as the index in the 'viewed crosswise' part of the table. In calculating glare we are interested in the worst case to ensure satisfactory conditions for every occupant. The worst viewing positions will be when a person is seated at the rear of the room, halfway along the wall, with their back to the wall. Sometimes the worst case occurs halfway along the length, sometimes halfway along the width. Therefore the calculation has to be repeated with the length and width exchanged. That is why X is taken to be the room dimension perpendicular to the observer's line of sight and Y is taken to be the dimension parallel to the line of sight. The table is calculated with the observer located in the worst possible glare position, in the middle of one wall. [Fig 44](#) shows this arrangement.

In the standard installation (on which the table is based), the height above eye level, H = 3.05m, the spacing to height ratio of the luminaires is 1.0, and the total bare lamp flux for each luminaire is 1000 lm. **Correction terms** are usually needed for the total lamp lumens per luminaire and for the H value of the installation. The corrections are given in a table in [fig 45](#) and [fig 46](#) but can be expressed mathematically as values to be added to the uncorrected glare index.

### Glare Index formula

$$\text{Glare Index} = 10 \text{Log}_{10} \left\{ \frac{0.239}{L_b} (g[1]+g[2]+.....+g[n]) \right\}$$

Where:

g[1], g[2], etc are glare constants for each luminaire in the field of view, and are calculated from:

$$g[n] = \frac{L_s^{1.6} \omega^{0.8}}{p^{1.6}}$$

Where as seen by the observer:

$L_s$  is the luminance of luminaire n

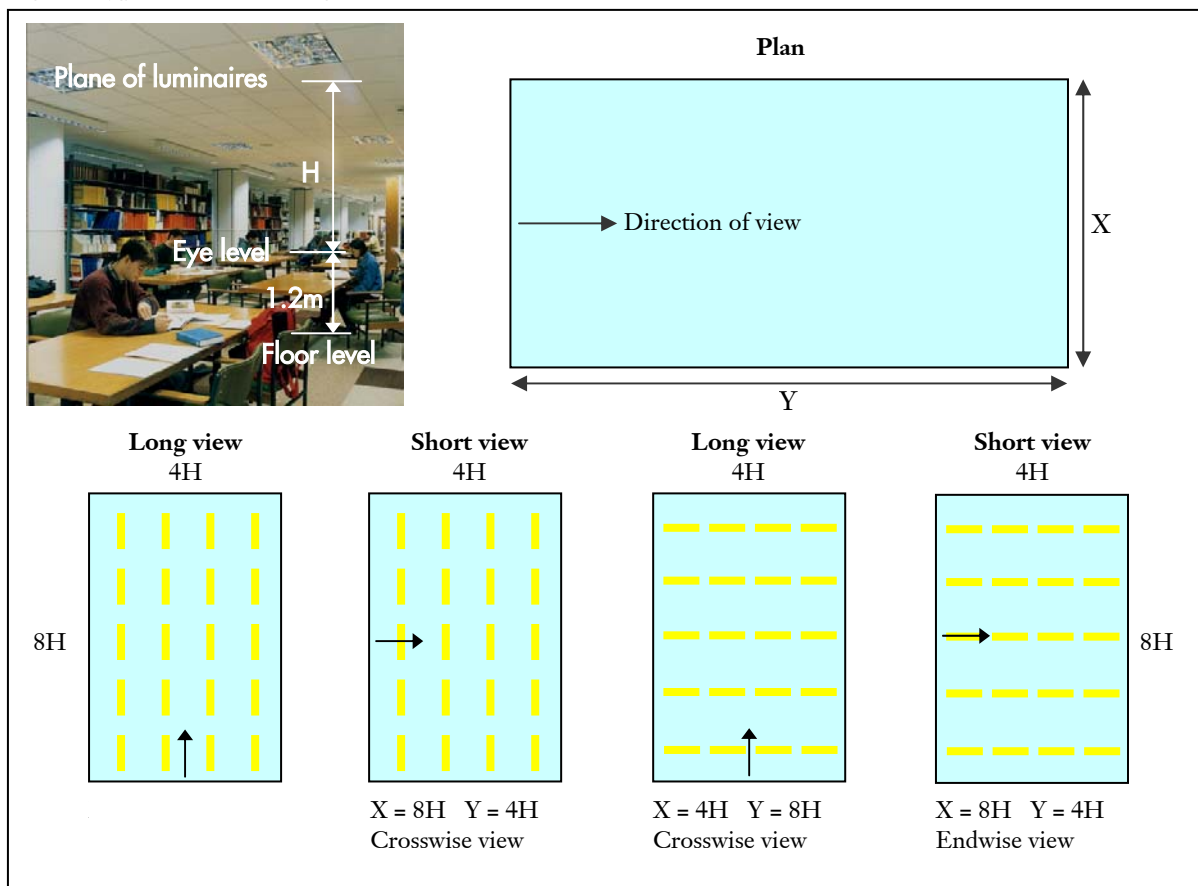
$L_b$  is the luminance of the background

$\omega$  is the solid angle of luminaire n

p is the position index of luminaire n

Uncorrected glare indices							
Reflectances							
C		0.8	0.8	0.7	0.7	0.5	
W		0.6	0.5	0.6	0.5	0.5	
F		0.2	0.2	0.2	0.2	0.2	
Room size							
X	Y	Viewed crosswise					ECT
2H	2H	-12.4	-11.7	-12.2	-11.5	-11.0	+21.7
	3H	-12.6	-11.9	-12.3	-11.6	-11.2	+22.2
	4H	-12.6	-12.0	-12.3	-11.7	-11.2	+22.4
	6H	-12.6	-12.0	-12.3	-11.8	-11.2	+22.4
	8H	-12.6	-12.0	-12.3	-11.8	-11.2	+22.4
	12H	-12.6	-12.0	-12.3	-11.8	-11.3	+22.3
4H	2H	-6.9	-6.3	-6.6	-6.0	-5.5	+16.0
	3H	-7.1	-6.5	-6.8	-6.3	-5.7	+16.6
	4H	-7.1	-6.6	-6.8	-6.3	-5.8	+16.8
	6H	-7.1	-6.7	-6.8	-6.4	-5.9	+17.0
	8H	-7.1	-6.8	-6.8	-6.5	-5.9	+17.0
	12H	-7.1	-6.8	-6.8	-6.5	-5.9	+16.9
8H	4H	-5.8	-5.4	-5.5	-5.1	-4.6	+15.5
	6H	-5.9	-5.5	-5.6	-5.3	-4.7	+15.6
	8H	-5.8	-5.4	-5.5	-5.3	-4.6	+15.6
	12H	-5.8	-5.5	-5.5	-5.3	-4.6	+15.5
12H	4H	-5.5	-5.2	-5.2	-4.9	-4.3	+15.2
	6H	-5.6	-5.1	-5.2	-5.0	-4.4	+15.3
	8H	-5.6	-5.3	-5.3	-5.1	-4.4	+15.3

Fig 43 Typical uncorrected glare indices table



Lamp flux (per luminaire) correction =  $6 \log (F/1000)$

Where F is the actual luminaire total **initial** lamp lumens

Height above eye level correction =  $4 \log H - 1.94$

Where H is the actual luminaire height above a 1.2m eye level.

Correction terms for luminaire lengths no longer appear in the header of the photometric data since only the data for one luminaire is shown.

The worked example given in below is for the same room and luminaire used in the ‘lumen method’ example, where different indices are shown for luminaires viewed crosswise and endwise. A sensible lighting design procedure is to examine the effect of running the luminaires in two different directions and selects the one which minimises the higher of two glare indices, one with X as the shorter wall and one with X as the longer wall.

*Worked example*

Calculate the glare index for a school workshop  $20 \times 10 \times 3\text{m}$  using Diffusalux College Range DLUXCZ 158 with single 1500mm 58W Polylux XL lamp. The reflectance of the ceiling, walls and work plane is 80%, 50% and 20% respectively. The limiting glare index specified is 19.

**Room Dimensions**

$L = 20\text{m}, W = 10\text{m},$

Luminaire height above eye level,  $H = 3 - 1.2 = 1.8\text{m}$

Room Width =  $5.6H \approx 6H$  Room Length =  $11.1H \approx 12H$

**Correction Terms**

For lamp flux per luminaire,  $5400\text{lm} = 6 \times \log(5400/1000) = 4.4$   
 [on calculator press:  $5.4 \log \times 6 =$ ]

For height above eye level,  $1.8\text{m} = 4 \times \log H - 1.94 = (4 \times 0.255) - 1.94 = -0.9$

Total correction terms =  $4.4 - 0.9 = 3.5$

**Uncorrected glare indices**

See [fig 47](#)

Total bare lamp flux (Initial) for each luminaire lumens	Conversion Term
500	-1.8
700	-0.9
1000	0.0
1500	+1.1
2000	+1.8
3000	+2.9
5000	+4.2
7000	+5.1
10000	+6.0
15000	+7.1
20000	+7.8
30000	+8.9
50000	+10.2
70000	+11.1
100000	+12.0
150000	+13.1
200000	+13.8

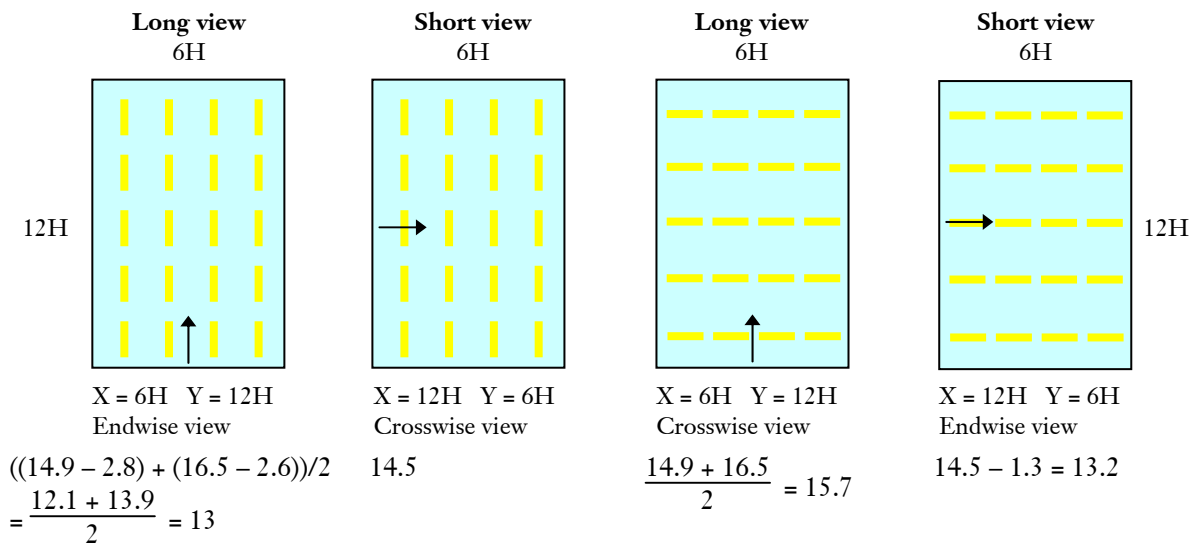
Fig 45 Glare Index correction for lamp flux per luminaire

Mounting height H above 1.2m horizontal work plane metres	Conversion Term
1.0	-1.2
1.5	-0.5
2.0	0.0
2.5	+0.4
3.0	+0.7
3.5	+1.0
4.0	+1.2
5.0	+1.6
6.0	+1.9
7.0	+2.2
8.0	+2.4
9.0	+2.6
10.0	+2.8
11.0	+3.0
12.0	+3.1

Fig 46 Glare Index correction for height above eye level

Uncorrected glare indices							
Reflectances							
C		0.8	0.8	0.7	0.7	0.5	
W		0.6	0.5	0.6	0.5	0.5	
F		0.2	0.2	0.2	0.2	0.2	
Room size							
X	Y	Viewed crosswise					ECT
2H	2H	5.0	5.8	5.4	6.2	7.0	-0.1
	3H	7.7	8.3	8.1	8.7	9.6	-0.7
	4H	9.1	9.8	9.5	10.2	11.0	-1.2
	6H	10.7	11.3	11.1	11.7	12.6	-1.9
	8H	11.5	12.0	11.9	12.4	13.3	-2.3
	12H	12.3	12.9	12.7	13.3	14.2	-2.9
4H	2H	6.0	6.7	6.4	7.1	7.9	-0.1
	3H	9.0	9.6	9.4	10.0	10.9	-0.7
	4H	10.8	11.3	11.2	11.7	12.6	-1.1
	6H	12.5	13.0	13.0	13.4	14.3	-1.8
	8H	13.5	13.9	13.9	14.3	15.3	-2.2
	12H	14.5	14.9	14.9	15.3	16.3	-2.8
8H	4H	11.5	12.0	12.0	12.4	13.3	-0.9
	6H	13.6	14.0	14.0	14.4	15.4	-1.5
	8H	14.8	15.4	15.3	15.6	16.6	-2.0
	12H	16.0	16.5	16.5	16.7	17.7	-2.6
12H	4H	11.8	12.1	12.2	12.6	13.5	-0.7
	6H	14.0	14.5	14.4	14.7	15.7	-1.3
	8H	15.2	15.6	15.7	15.9	16.9	-1.7

Fig 47 Uncorrected glare indices table of DLUXCZ 158



**Glare indices**

$13 + 3.5 = 16.5 \approx 17$

$14.5 + 3.5 = 18.0 = 18$

$15.7 + 3.5 = 19.2 \approx 19$

$13.2 + 3.5 = 16.7 \approx 17$

Both arrangement of luminaires do not exceed the limiting glare index of 19

The glare index for the installation with the length of luminaires parallel with the length of the room is **18**

## **Uplighting and Luminous Ceilings**

The BRE Glare Index formula does not apply to certain conditions. Two special ones are uplighting and luminous ceilings. In the first case, uplighting, the formula is quite meaningless. The light source is not visible and the  $L_s$  term is therefore zero. As a simple guide, the average luminance of the ceiling should not exceed  $500\text{cd/m}^2$ . It is also important that the rate of change of ceiling luminance is gradual with no 'sharp' changes. If this condition is met then small areas can have a ceiling luminance of  $1500\text{cd/m}^2$ . As a guide, the average luminance of a luminous ceiling should not exceed  $500\text{cd/m}^2$ . This recommendation is, however, based upon ceilings of diffusing panels and there is considerable reason to believe that louvre ceilings can have higher luminances in the downward direction if the shielding angle is satisfactory.



## 10 Answers to Questions

### Questions 1

1. Safety and Health, Performance, Appearance & Comfort
2. 200, 300, 500, 750, 1000, 1500 lux
3. 400lux
4. The task
5. The ratio of the minimum illuminance to the average illuminance
6. 16
7. 60%
8. 90 to 270lux
9. 15:1
10. 4000K

### Questions 2

1. 50%
2. PIR control, presence detection
3. Means of compliance could be by either:
  - Lighting using lamps and gear with an average efficacy of 50lm/W or higher
  - 95% or more of the lighting in the building measured in circuit watts using approved lamps and gear
  - Meeting the CIBSE Lighting Code power targets
4.  $3.6\text{kW} = 3600\text{W}$   $\text{W/m}^2 = \frac{3600}{20 \times 15} = 12$   $\text{W/m}^2/100\text{lux} = \frac{12}{5} = 2.4$  This complies with target range of 2.1 – 3.7

### Questions 3

1. Operating hours per year:  $12 \times 51 \times 5 = 3060\text{h}$   
 No. of years between bulk relamping:  $\frac{18000}{3060} \approx 6$  years

#### LLMF:

18000h is 63% of rated life of 28500h in fig 16

LLMF = 0.91

#### LSF:

With spot replacement

LSF = 1.0

#### LMF:

Normal environment, type A, taking 2 year fitting cleaning

LMF = 0.84

#### RSMF:

Normal environment, direct fitting, taking 3 years room cleaning (room index 4.0)

RSMF = 0.95

$\text{MF} = \text{LLMF} \times \text{LSF} \times \text{LMF} \times \text{RSMF}$

$\text{MF} = 0.91 \times 1.00 \times 0.84 \times 0.95 = \mathbf{0.73}$

Maintenance Factor is 0.73    2 year fitting cleaning

3 years room cleaning            6 year bulk lamp change

2. 75%.
3. IP23 means protection against solid objects greater than 12mm and spraying water.
4. A polar curve indicates the luminous intensity of a luminaire at various angles.
5. Light output ratio is a measure of:  $\frac{\text{Flux emitted by fitting}}{\text{Total bare lamp flux}}$
6. Low uniformity of illuminance.

## 11 Summary

### Lighting Objectives

The lighting objectives can be considered under three broad headings:

- Safety and health.
- Performance.
- Appearance and comfort.

### Integrated Approach to Lighting Design

To create a good lighting installation an integrated design approach or **holistic approach** is necessary.

The entirety of the lighting objectives and the means to a lighting solution are considered. All the requirements and constraints are balancing one against another to ensure that the best possible solution is determined. This is made easier using the **Lighting Design Framework**.

### Visual Function

This includes:

- Illuminance
- Uniformity of illuminance
- Discomfort Glare
- Surface Colour
- Reflectance of room surfaces
- Task reflectance
- Luminance and illuminance distributions
- Modelling
- Colour rendering and appearance

### Visual Amenity

People prefer a space to appear 'visually interesting' and 'visually light' particularly in the **normal field of view**, which is defined as a horizontal band approximately 40° high and centred at normal eye height.

To create '**visual interest**' it is necessary for the light pattern to have some illuminance variation. This is to create areas of 'light' and 'shade' which people find attractive and stimulating. To create a feeling of '**visual lightness**' it will be necessary to project light directly on to some room surfaces and particularly on those surfaces, which are prominent in the **normal field of view**.

### Lighting and Architectural Integration

Both daylighting and electric lighting are fundamental elements of the overall design of a building and must therefore be an integral part of the whole solution. In terms of the electric lighting this means the appearance of the visible lighting equipment and the way they are installed into the building. The lighting designer and the architect will need to pay particular attention to the detailing of the installation. This will require close co-operation between member of the design team for a good solution.

### Energy Efficiency in Lighting

Methods of control fall into three broad categories:

- Manual control
- Automatic control (non-intelligent)
- intelligent control

There is several ways of providing intelligent control:

- Independent intelligent luminaires (eg Sensa 2)
- Intelligent luminaire controlling cluster of luminaires (eg Sensa 2)

- Centralised dedicated computer control of luminaires (eg Light Sense)
- Intelligent luminaires together forming a lighting management system programmed by infra-red controller (eg SensaLink)

In addition to the management of energy use, the control system can provide a very powerful means of controlling the visual environment to give flexibility of use and to improve both the working conditions and the value of the property. The main aspects to this are:

- Individual control of the visual environment
- Reconfigurable space
- Flexible buildings

Usage of Power and Energy in Lighting - for new and refurbished installations in England and Wales since July 1995 Part L of the Building Regulations places restrictions on the use of electric lighting for buildings.

### Lighting Installation Maintenance

The illuminance of a lighting system reduces as soon as it is switched on. There are four reasons for this:

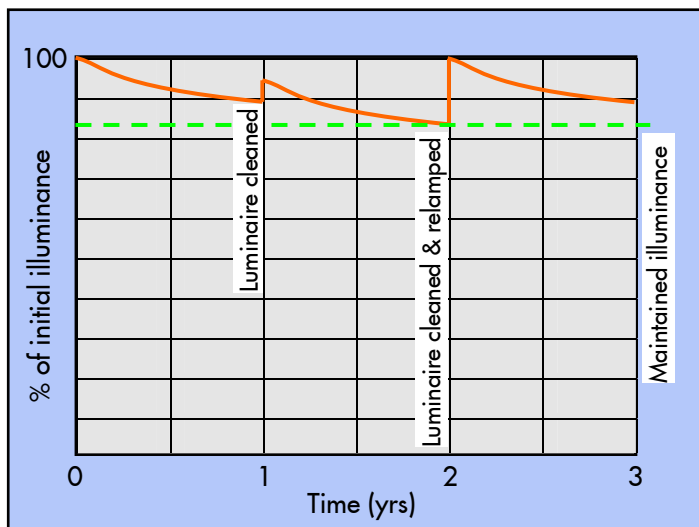
- a reduction of lamp output with burning hours
- the failure of lamps with burning hours
- dirt on luminaires
- dirt on room surfaces

A lighting system needs to be serviced by replacing failed lamps, rectifying equipment faults, and cleaning lamps, luminaires and room surfaces.

Current CIBSE Code for interior lighting include designing installations to a **maintained illuminance**.

**Maintenance Factor MF:**

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



Typical illuminance with time & maintenance

### Lighting Costs – Capital and Operational

The capital cost of a lighting installation needs to be balanced against the operational costs. If only the capital costs are considered then what at first sight to be a low cost installation, may turn out to be expensive if the operational costs are excessive through high energy or maintenance costs.

### Lighting Design

Choosing a lighting system is distinct from choosing lamps, luminaires or other equipment. A basic system decision is to choose between **general, localised** or **local lighting**.

### Choice of Lamp

The designer can compile a list of suitable lamps by rejecting those that do not satisfy the design objectives on the following basis:

- colour rendering
- colour appearance
- run-up and re-strike times
- efficacy
- life
- size

## Choice of Luminaire

Luminaires have to withstand a variety of physical conditions and be electrically safe. The related aspects of safety are covered by the European safety standard for luminaires EN 60598. Luminaires that pass the standard are given the **ENEC Mark**. The **CE** mark signifies that a product conforms with the requirements of the relevant EEC directives. Now the directives appropriate to general lighting products are the **Low Voltage Directive (LVD)** and the **Electromagnetic Compatibility (EMC) Directive**. Luminaires are classified according to the degree of protection they give to dust or moisture. This is classified by the **Ingress Protection (IP) System**.

## Photometric Performance

This generally is presented as:

Range name

Description

Luminaire maintenance category

Polar curve

Light output ratio

Maximum spacing to height ratio

Utilisation factor

Uncorrected glare indices

Luminous intensity

Luminance distribution

Isolux diagram for horizontal plane

## Spacing to Height Ratio

The **Spacing to Height Ratio (SHR)** is the spacing between luminaires divided by their height of luminaires above the horizontal work plane. SHR MAX is a value that should not be exceeded if the uniformity is to be acceptable for general lighting.

## Average Illuminance

The average illuminance  $E$  over a horizontal work plane, for example at desk height or on the floor, can be calculated from the "**lumen method**" formula:

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

## Room Index

The Room Index is for rectangular rooms given by:

$$RI = \frac{L \times W}{H_m(L + W)}$$

## Effective reflectance of room surfaces

The effective reflectance of a composite surface is the area-weighted average  $R_a$ , given by:-

$$R_a = \frac{R_1A_1 + R_2A_2 + \dots + R_nA_n}{A_1 + A_2 + \dots + A_n}$$

In the case of either the floor cavity or the ceiling cavity (or any other cavity) the effective reflectance depends on both the reflectance of the cavity surfaces and the relative depth of the cavity. The

approximate value is given by:-  $R_e = \frac{CI \times R_a}{CI + 2(1 + R_a)}$

### **Calculation Procedure for Local and Localised Systems**

When local or localised systems are used or when unusual layouts or unconventional light distributions are used, calculations of average illuminance can be inappropriate. In such circumstances, it is necessary to calculate the illuminance at all points of interest with one of three methods:

- Basic photometric data and the Inverse Square and Cosine Law.
- Pre-calculated aids, such as isolux diagrams.
- A computer programs.

### **Discomfort Glare – UK Glare Index System**

The UK Glare Index system predicts the degree of discomfort glare in a lighting installation. The glare index can be calculated by means of **Uncorrected Glare Index tables** and **correction terms** for Endwise orientation, bare lamp lumens and height, The Glare Index formula does not apply to uplighting and luminous ceilings.