

# Light Sources

## Introduction

The invention and development of light sources is a remarkable example of the progress that can be made by industrial societies when there is a sustained effort to improve a product for which there is a demand. Candles gave way to oil lamps that in turn were supplanted by gas lamps, and these in their turn were made obsolete by electric lighting. For more than two hundred years artificial lighting has been ever more available, provided with greater convenience and at reduced costs. There can be no doubt that this has materially affected peoples' lives.

There are those who argue that the easy availability of light outside daylight hours has not necessarily improved the lot of humankind. Where the coming night does not call a halt to the day's work, the working day can be expanded to fill the whole 24 hours and it might be argued that this is not necessarily good for people or society. Recent research indicates that even when people have worked on night shifts for years, they never completely adapt to the situation. Their competence at a task undertaken at night is always less than during the day. Although this line of inquiry is not going to be pursued here, it is an area of interest to designers who are responsible for designing work places where people necessarily work throughout the night.

For the moment, all that is required is a recognition of the extent of the change there has been in light sources. Improvements in efficacy have been spectacular and modern lamps are incomparably more convenient than those they have replaced. One consequence of the continuous development of light sources is that it is fruitless just to learn the characteristics of lamps currently in production. More profitable from the designer's view is to understand the significance of the properties of light sources. The consequences of developments in lamp technology may then be appreciated and the designer will be better able to choose the light source most suited to a particular circumstance.

## The Properties of Light Sources

These may be divided into two categories; those that are quantitative in nature and those that are qualitative. Given a number of light sources that satisfy the required qualitative criteria, it will always be preferable to choose a lamp that maximises the quantitative properties. Issues related to these quantitative properties are more easily decided and they will be considered first.

### Lamp Efficacy

This is a measure of how effective is a lamp at producing light. The light emitted by a lamp will be measured in Lumens and the power consumed by the lamp will be measured in Watts. Lamp efficacy is represented by the symbol  $\eta$  (*eta*), and is defined as,

$$\eta = \frac{\text{Light flux emitted by Lamp}}{\text{Power consumed by lamp}} = \frac{\Phi_v}{W} \text{ lm/w}$$

*Remember from first year ?*

Light or luminous flux is a measure of how much a source of radiation stimulates the sense of sight.

Radiation at different wavelengths varies in its ability to stimulate the sense of sight. The eye is most sensitive to radiation at a wavelength of 555nm, and on either side of this wavelength the eye's sensitivity falls to be insignificant below 400nm and beyond 700nm.

The relative effectiveness of radiation to evoke the sense of light is described as the *Luminous Efficiency of Radiation* and is represented by the symbol  $V_\lambda$ . In order to estimate the light emitted by a lamp, the effect of all the wavelengths is summed and then multiplied by a constant to convert to the absolute measure of light flux, the *Lumen*.

$$\Phi = 683 \sum_{\lambda=400nm}^{\lambda=700nm} V_\lambda P_\lambda \quad \text{lm.}$$

In addition:

- i) In the above definition of efficacy, no account is taken of the power consumed by the control gear. A fairer comparison between lamps should include the gear losses because these may vary between 0 and 20% of the lamp power.
- ii) Light output may depend upon the conditions under which the lamp is burnt.

Conditions likely to affect light output are:

- a) extremes of temperature resulting from the climate or choice of luminaire.

A too high a wattage lamp in a luminaire may result in the lamp running at too high a temperature and perhaps creating a fire risk. Also it is more than likely to result in a reduced light output from the lamp.

Appropriate lamps must be used with luminaires that have been designed for the expected environmental conditions. For example; an air handling luminaire that draws air through the luminaire in order to reduce casual heat gains passing into a room may result in a lamp running at a reduced temperature. This may in some cases this may reduce the light output. This effect is particularly noticeable with low pressure discharge lamps such as fluorescent lamps. Another example might be the use of a lamp externally in a luminaire that does not maintain the lamp temperature sufficiently.

- b) The orientation of the lamp within the luminaire should be as specified by the lamp manufacturer.

## Lamp Life

The useful life of a lamp does not necessarily mean life to extinction. A lamp that is slow to start, produces a distinct flicker or develops a pronounced hum will be considered by most users to have exceeded its useful life.

The physical characteristics of lamps will vary slightly due to the various tolerances allowed during the manufacturing process. These small differences will affect the life of the lamps. Thus the life quoted by manufacturers must necessarily be a statistic gained from observing the lives of a large number of lamps. A graph may be drawn which shows the progress of lamp failures as the hours of use increase. Depending upon the

orientation of the axes it is described as either a *Mortality Curve* or *Survival Curve*. The lamp life quoted by most manufacturers is the time taken for 50% of lamps to fail to extinction.

The shape of the survival curve can vary between lamp types and this may influence the choice of lamp. However, for many types of lamp there are three distinct periods lamp life:

- i) There is brief initial period when there are a number of lamp failures because the various tolerances of manufacture are all on the unfavourable side,
- ii) There is a period when there is only a small but steady failure rate because manufacturing differences are mostly within tolerance.
- iii) When the lamp approaches its design life there will be a much increased failure rate which rapidly extinguishes most lamps. However, after most lamps have burnt out there may be along period when just a few lamps continue to burn because the manufacturing variations were all at the favourable end of the tolerances.

The life of some lamps depends upon the conditions of use. Particularly, the lives of discharge lamps can be reduced significantly by switching. In the case of fluorescent lamps, their lives may be reduced by 3 hours each time they are switched on. In order to take account of this fact, manufacturers quote the lives of their lamps when they are operated using particular switching patterns. In order to achieve in practice the published lamp life, it is important that the lamp should be used in a similar manner. For example, the life of fluorescent lamps is measured on lamps that are switched on and off every three hours, and therefore this life is suited to situations where on average the lamp is switched on and off 8 times every 24 hours.

The effect of switching upon lamp life may make some lamps unsuitable for certain applications. Where electric lighting is designed to respond to the available natural light, then it is to be expected that lamps will be regularly switched on and off. Under these circumstances no lamp should be used that is adversely affected by repeated switching. This indeed is why high pressure discharge lamps may be unsuitable for combined daylight and electric installations

Using lamps under conditions for which they are not designed is also likely to reduce their life. Unfavourable conditions may be the result of using the lamp inappropriately, i.e. the incorrect burning position, too small a luminaire or the wrong environment.

## Qualitative properties

Qualitative lamp characteristics are less easily chosen and may be affected by the particular approach of a designer. Rarely will there be circumstances where the desired lamp properties are so closely defined that there is only a single type of lamp that can meet requirements.

### Colour of light

The colour of natural light varies widely; from the warm cherry red embers of a glowing fire to the cool blue of a clear Winter's sky. Our eyes are able to adapt well to this range of natural light: a white sheet of paper appears reasonably white both under the light from the noon day sun to the light from a blue sky. It is therefore not essential that a particular colour of light is provided in order to see coloured surfaces as we expect to see them. However, we emotionally respond to the colour of light and for that reason it can be quite an important design consideration.

In nature warm colours are often associated with lower levels of light: the glow of a camp fire, the light from a candle and the straw and rose colours of dawn and dusk. People sometimes respond unfavourably to the use of cool light when it is used at low levels of illumination. Also bluish light can give an impression of poor lighting level and it certainly imparts a cool and solitary feeling to a scene.

Whether or not this is linked to our impression of bluish light being associated with night has not been thoroughly researched, but the effect is well used in the cinema where scenes filmed in sunlight are made to appear as night time shots by the use of a blue filter.

The rod receptors active at low levels of light have a peak sensitivity that occurs at shorter wavelengths than that of the cone receptors that are responsible for acute colour vision at higher levels of light. This means that the cones are insensitive to short wavelengths of light (Blue) that are still capable of stimulating night vision. Similarly the rods are insensitive to long wavelengths of light (Red) that stimulate daytime vision. -(Note the use of red light in submarines at night)

Where coloured light is used to convey information it must be remembered that blue light is scattered more than red light, e.g. the blue light from the sky. Therefore blue objects or light sources seen from a distance appear less distinct because the edges are blurred.

It is generally considered sensible to use warmer coloured light where illuminances are low and cooler light where illuminances are higher. Note the way in which a bluish fluorescent light used at night appears cold and clinical but is quite acceptable during the day.

The general rule that warmer coloured light sources should be used for lower illuminances should be applied cautiously and where circumstances are outside ones experience, it is worthwhile conducting a small simulation to observe what actually happens. It can be found that particular colour schemes may well affect reactions to the colour of light used. Such effects are quite independent of the colour rendering qualities of the light.

For instance, in a scale model investigation of colour in a picture gallery which was lit to conservation levels of light, it was found that an intermediate colour of light was preferred when the gallery was uniformly lit. It was anticipated that a warm colour would have been preferred, but in this

particular instance the darkish green walls appeared insipid when lit with warm light and looked more natural if lit with an intermediate colour of light.

Where a number of light sources are to be seen together it is important to consider the effect of any differences in their colour. Electric lighting used to supplement daylight should be of a similar colour to the daylight so that the two light sources blend together. This may be especially necessary if the designer is trying to maintain a day lit character to a room.

There may be occasions when there is a need to use contrast in colour to emphasise the fact that an exhibit is on display, or that one is moving into a different type of room. Moving from a day lit gallery perhaps to a rest room, perhaps could be indicated by a change in the colour of the light. Within a single room it may be that one wishes to pick out a particular feature or display by emphasising it with a change in the colour of light. It is perhaps more usual to have a cooler overall light with spotlighted areas lit with warmer light, as this follows the experience of natural lighting. But there is no reason why it should not be the other way around.

If a number of distinct light sources of different colours are used they will cast coloured shadows. This may be distracting and can be avoided if the two light sources can be housed within the same luminaire, or the light from the two sources is well diffused so that there are no distinct shadows.

## Colour Rendering

The appearance of coloured surfaces depends upon the spectrum of the light that illuminates them. Generally the narrower the band of wavelengths lighting a surface, the more distorted the colour appearance of the surface. There are occasions when it is necessary to accurately render the colours of a surface e.g. a museum or an artist's studio, and there are other times when it is not that important, e.g. an iron foundry or even a general office.

The ability of a light source to render colours faithfully is given by the lamps CIE general Colour Rendering Index,  $R_A$ . The maximum value of  $R_A$  is 100 and represents an ability of the light to render colours identically to the light from a full radiator of the same colour as the lamp.

Although the colour rendering of a lamp is generally considered independently of illuminance, it has been shown that people will accept a lower illuminance if the lamp has a high  $R_A$ . The term *visual clarity* was coined to describe this effect, whereby the improved ability to discriminate between colours, provided by good colour rendering lamps, was seen to be equivalent to the improved discrimination of contrast provided by higher illuminances.

## Physical Size

The physical size of a lamp primarily affects its ease of handling. Some fluorescent lamps are 2.4m long and these can be difficult for a single person to carry through doors and no one can safely re-lamp a 2.4m luminaire on their own.

Some discharge lamps are small enough to be safely handled using long poles fitted with grippers. This allows installations up to 6m in height to be re-lamped without resorting to either access towers or gantries.

Where lamps absorb substantial amounts of power their ability to dissipate heat will be affected by their physical size. The smaller the lamp the higher

is the temperature needed to rid the lamp of unwanted heat. Clearly high temperatures may stress not only the lamp but also the luminaire housing the lamp. However, if a lamp is running at a high temperature, it is less likely to be affected by small changes in environmental conditions.

Large lamps will have a high surface area and therefore be more affected by the environmental conditions. Thus the longer sized fluorescent lamps can be adversely affected by the cold when used externally.

### **Optical Size**

This need not be the same as the physical size of the lamp. If the incandescent lamp is considered, the light producing filament is quite small compared to the size of the bulb within which it is housed.

There are three main optical effects of size that need to be considered:

- i) The smaller the source of light the more it can be closely controlled either by reflection or refraction. The light source must be small if its light is to be projected in tight beams.
- ii) For a given light output, the larger the source of light the lower will be its surface brightness and the less dazzle there will be. Chinese paper lanterns exploit this to good effect and it is quite popular to use paper globes in Bath because the high ceilings of Georgian rooms require lamps of quite high wattage to light the large room surfaces.
- iii) The larger the source of light, the softer will be the edge of cast shadows. Generally sharp edged shadows will give a rather stark appearance to a room and softening the edges of shadows can make a space appear more homely.

### **Starting Characteristics**

Some lamps provide their maximum light output and intended colour almost immediately after being switched on. Other lamps may take time to reach their normal colour or their full light output. The time needed to attain full light output may exclude the use of particular lamps from some applications. Where light is required instantly for short periods then clearly it would be inappropriate to choose a lamp with a noticeable run up time.

However, where a lamp may be left running for long periods of time and there is prior knowledge of when the lamp needs switching on, then even a quite substantial run up time may be acceptable e.g. floodlighting a football stadium with metal halide lamps.

### **Change in Output**

Changes in output may be considered under two broad categories; short term and long term variations.

#### **Short term changes**

After changes that occur on starting, the most significant variation is that which causes the sensation of flicker. Sensitivity to flicker changes substantially between individuals and depends upon such factors as the luminance of the source, its position in the field of view, the size of the source, the waveform of the variation in light and its frequency.

The frequency at which flicker is no longer observed is known as the Critical Fusion Frequency(CFF).

Light is emitted from a discharge lamp in proportion to the current flowing in the lamp and this varies 100 times a second. This is above the Critical Fusion Frequency and therefore this is not the cause of flicker seen by most people.

There are two main causes of flicker:

- i) that caused by the cathode and Faraday dark spaces moving from one end to the other end of a fluorescent lamp at a frequency of 50hz, and
- ii) that caused by the instabilities of arcs in some high pressure discharge lamps.

One way to eliminate flicker is therefore to shield the ends of the fluorescent lamps so that the dark spaces are hidden from view. A better way is to specify the use of electronic control gear which run the lamps at a frequency well above the CFF .

Arc instabilities are becoming less common and should be checked by inspecting the appearance of the light from different manufacturer's lamps.

Sometimes new fluorescent lamps will appear to produce spirals of light along their length and these are termed striations. They can occur with dimmed lamps and usually disappear after the lamp has been in use for some hours.

#### **Long term variations**

The two long term variations of significance to the designer are the changes in light output that occur with most lamps and colour differences that develop over time with some high pressure discharge lamps.

The lumen maintenance curve shows how the light output changes over time. If a lighting installation is to provide a given illuminance then a drop in light output must be allowed for at the time of design. In the past the drop in light output from lamps has been countered by installing extra luminaires. But with the introduction of dimmable high frequency luminaires there is also the opportunity to install fewer luminaires of greater power which are initially dimmed down to provide the design illuminance.

Changes in the colour of lamps will be particularly noticeable where numbers of lamps are seen together. It may well be that where critical comparisons can be made, then the useful life of the lamp may be determined by the acceptable level of colour difference between lamps in the installation.

### **Control Gear**

Some lamps require control gear to run the lamp. With discharge lamps there are generally three components that are essential;

A mechanism or circuit device for initiating the discharge in the lamp. This will normally involve either creating a voltage surge which is sufficient to break down the electrical resistance across the discharge tube, or using a small secondary discharge to heat the discharge gas in order to facilitate a discharge across the main electrodes.

A current limiting device that restricts the current flowing through the discharge tube. A simple electrical resistance would limit the current but it would also consume power without directly adding to light production. A coiled wire may be used to limit an alternating current without incurring a loss of power and this item is called either a *choke* or a *ballast*.

A current flowing through a coil produces a magnetic field. When the current is increased the strength of the magnetic field is increased and electrical power is drawn by the circuit. However the energy put into the magnetic field is not dissipated and when the current flowing in the circuit is reduced the power stored in the magnetic field is fed back into the electrical circuit leaving no net loss of energy. Although the choke dissipates little power it does change the electrical characteristic of the circuit and the current and voltage waveforms are displaced from one another. This displacement is characterised by the Phase angle between the waveforms and a circuit with a large phase angle will be described as having a low power factor. A circuit in which the voltage and current waveforms are exactly in phase will have a power factor of unity.

Circuits with low power factors cause problems in the generation and transmission of electrical power and therefore capacitors are included in the circuit in order to bring the power factor of the circuit back to near unity.

An electrical charge is stored between two parallel plates that are at different voltages. As the voltage difference is increased so the stored electric charge is increased and power is drawn from the electrical circuit. When the voltage between the plates is reduced, the energy stored in the electric field is returned back to the electrical circuit resulting in no net loss of energy. Again however the characteristics of the electrical circuit are changed and the current and voltage waveforms are displaced.

A capacitor added to a lamp circuit is designed to change the circuit characteristics in exactly the opposite way to the choke and the two combined limit the current but have no overall affect upon the circuit power factor.

Additionally capacitors may be added to reduce the emission of radio interference.

Where high frequency circuits are used there are additional circuit elements. The alternating current from the mains is first changed to a direct current that is then modified into one of high frequency. Both of these operations can introduce unwanted interference to the mains and radio frequencies. It is important that both are prevented introducing a buffer filter between the mains and the active part of the circuitry.

## **Range of Light Output**

Lamps of different types will provide different magnitudes of light. Floodlighting a football pitch requires a lot of light flux that is not available from an incandescent source, and therefore other sources are more appropriate. Within a living room, only small amounts of light can be usefully used and therefore sources that are only available in high powers can not be considered.

## **Costs**

The two types of costs to be considered are capital and running costs. Within capital costs there will need to be considered the electrical installation and its control as well as the luminaires and lamps themselves.

Included in the running costs will be the cost of electricity, the cost of replacement of lamps that have burnt out and the cost of the labour needed to fit them. The cost of cleaning luminaires in an installation may also need to be considered. With high cost labour it might well be cheaper in the long run to buy expensive luminaires that require little attention over the years.