# Electric Lamps

Fig 1 Lamps in high bay luminaires.

This module deals with electric lamps. This is a large subject so it is divided into four sections:
- Terminology
- Tungsten filament lamps
- Fluorescent lamps
- Discharge lamps

## 1 Terminology

### Introduction

Electric lamps are made in a wide range of types for different applications such as
- lighting of buildings and places
- photography, theatre and television
- lighting of vehicles
- signals and signs
- indicators built into machinery
- navigation
- medical

Thorn Lighting is only involved with the first of these and more specifically with commercial and industrial buildings rather than domestic lighting. The electric amps described in the following modules will concentrate on the types most commonly used in conjunction with Thorn Lighting equipment. Many luminaires are designed for a single purpose such as high bay lighting, or a flameproof fitting. In contrast the same lamp may be found in a wide range of different applications. This makes it hard to optimise lamp performance as one application is concerned with durability and another colour quality. Lamp performance is thus a compromise between the various criteria.

The most up-to-date information about lamps is direct from the manufacturers, so you should try to collect current lamp catalogues. However printed catalogues are considered expensive these days and are being replaced by CD-ROMs and websites.

The main lamp manufacturers supplying the UK market are:
- GE Lighting www.gelighting.com
- OSRAM www.osram.co.uk
- Philips Lighting www.philipslampsandgear.co.uk

others whose products suit Thorn luminaires are:
- BLV Licht und Vakuumtechnik Gmbhwww.blv-licht.com
- Iwasaki Electric Co. Ltd (Eye) www.eye.co.jp
- Sylvania Lighting International
- Venture Lighting International Inc. www.venturelighting.com

Note that these are all international companies although some have production facilities in the UK.

## What is a lamp?

There is some confusion with domestic descriptions such as "table lamp" or "desk lamp" which refer to a complete lighting unit usually complete with flex and a plug. (Fig 2) In contrast lighting for commercial and industrial use is divided into luminaires and lamps. Lamps are specifically that part which converts electricity into light. Luminaires provide the optical control devices such as reflectors and louvres; they also are the mechanical housing to support and protect the lamp. Luminaires are part of the capital budget and are a permanent part of the electrical installation. Lamps are consumer durables and are part of the maintenance budget as they require regular replacement.

Fig 2 Table lamp is a misleading term.

Most lamp makers do not make luminaires for several reasons:

Firstly, lamps are made of materials such as glass, quartz, tungsten, sodium, mercury and require specialised machinery. (Fig 3) Luminaires are produced from metals and plastics and use production methods common to many other items from motor cars to office furniture. The machinery to make lighting fittings could equally well produce completely different products. Luminaires use material research and handling that is widely available. Research into lamp materials and production has little other application and thus development is more protracted, costs are higher and can only be supported by world wide sales.

Fig 3 Lamp production. *Courtesy of OSRAM*

Secondly lamp makers treat luminaire makers as an OEM market and therefore do not want to be seen as competitors by their customers.

Thirdly lamps are consumable items and require regular replacement in small numbers. This requires a different distribution and market accessibility akin to spare parts and not capital equipment.

Philips are a major exception. OSRAM and Siemens have common ownership but operate as separate organisations for the reasons mentioned above.

## Lamps and Control Gear

Many lamps require external control for starting and stable operation. There are independent control gear manufacturers but there is a current trend for lamp makers to be also involved with control gear. Commercially this can be an advantage as the consumer can avoid incompatibility between products. The following lamp manufacturers make control gear:

Osram
Philips
Venture

## Lamp terms and description

Any lamp has to fulfil four main functions:
- match the available electrical supply
- Have a lamp base which matches the luminaire lampholder
- be of the correct physical dimensions for optical control
- provide the required quantity and quality of light

# Electrical input

**Watts**
The power rating of a lamp is important as it is essential for the electrical designer to provide the correct wiring, switching and fusing. The greater the wattage the more light that is produced may seem obvious but this is only true when comparing lamps of the same type. For example 1.2m 28W T5 fluorescent tube gives the same light output as 150W linear tungsten halogen lamp.

There is a reason for the rather strange sequences of lamp wattages. The human eye does not respond to light in a linear manner and the standard steps of illumination as recommended by CIE (the international body for lighting) are shown in fig. 4.

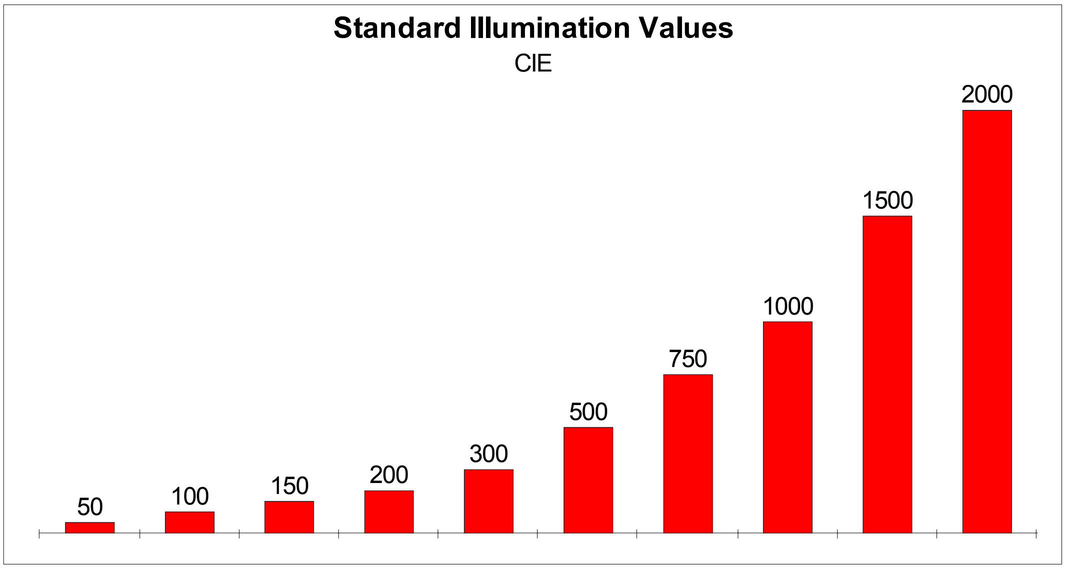



Fig 4 Standard illumination values.

These avoid awkward numbers but each step upwards is an increase of approximately 50% on the previous value.

Most lamps tend to follow the same sequence although the values vary according to the lamp type. The illumination from a given lighting layout will thus increase in a similar manner by selecting the next larger wattage.

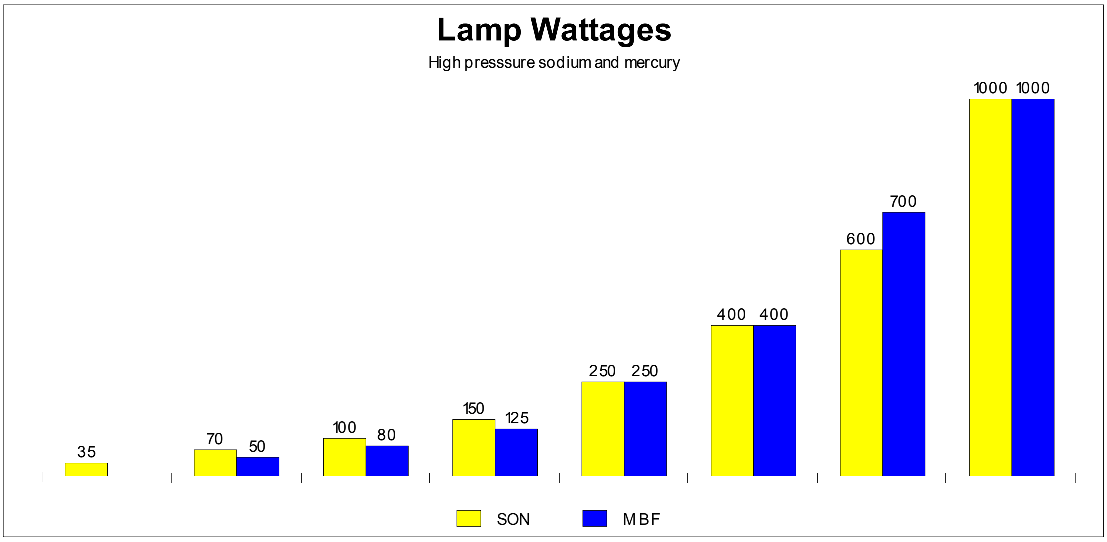



Fig 5 Lamp Wattages for high pressure sodium and high pressure mercury lamps.

Fluorescent lamps do not follow this rule as closely as there is the added complication of length to consider. The latest T5 HE fluorescent tubes produce approximately uniform light output per unit length.

**Volts**

Lamps that are connected directly to the mains supply have to be of compatible voltage. For example a 500W tungsten halogen lamp is available for

120V
130V
220/230V
240V

It is important to select the lamp which matches closely the actual supply voltage.

Discharge lamps have external electrical control equipment which provides the correct electrical supply to the lamp. For these types the control gear must be of the correct voltage rating. For example 12V 50W tungsten halogen display lamp would be operated by a transformer either as a separate component or built into the lighting fitting.

Although Europe nominally has a standard voltage of 230V, prior to harmonisation the standard for the UK was 240V and this continues to exist widely and so 240V gear is still required for many new installations.

## Lampbase or Cap

This device usually combines the mechanical support and the electrical connection to the lamp. It has to ensure the lamp is in the correct position relative to the reflector or optical control system and allows easy lamp replacement.

**Bayonet Cap**

This is limited to domestic lamps in the UK. The rest of Europe favours the Edison Screw design. Both types are available in a range of sizes to accommodate different physical sizes and electrical loads through the contacts.

For the commercial and industry market, the common bases are:

| Name | Abbreviation |
|---|---|
| Bayonet Cap | BC or B22 |
| Edison Screw | ES or E27 |
| Goliath Edison Screw | GES or E40 |

**Bi-pin bases**
These are used for fluorescent tubes and tungsten halogen lamps and have an international reference starting with G which denotes a group of pins. There can be a second letter which indicates a variation to the basic design. These letters are followed by numbers which is the distance separating the pins in millimetres.

A fluorescent tube has a G.13 base which is two pins separated by 13mm.

**Multi-pin bases**

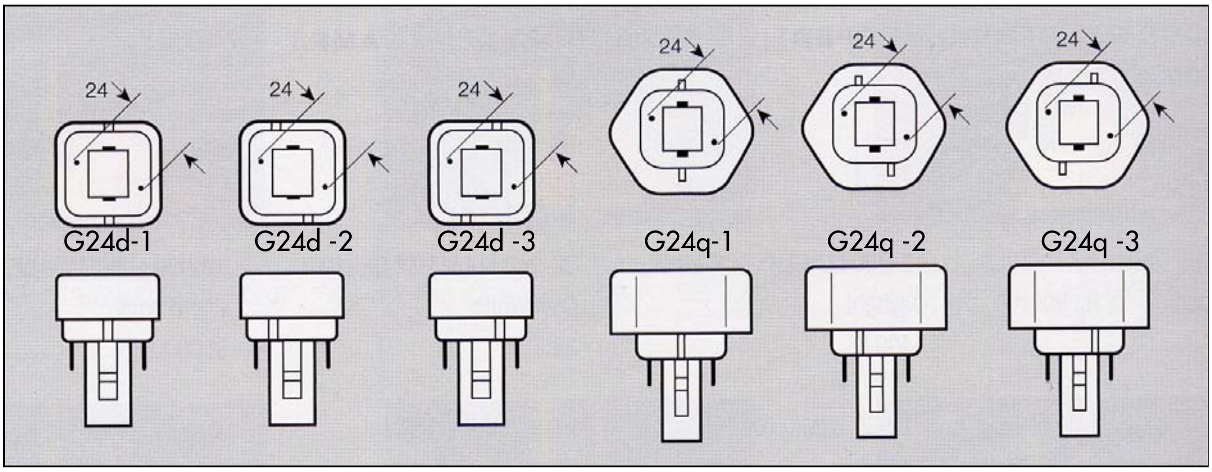



Fig 6 Selection of lampbases. *Courtesy of OSRAM*

Compact fluorescent lamps can have a base with two or four pins. For example a GE Biax™ lamp of 13W is available with either G24d-1 or G24q-1 where d stands for 2 pins and q for 4 pins. The suffix -1 is the pattern in which the pins are arranged. The 26W Biax™ lamp has G24d-3 and G24q-3. A different pattern prevents the 13W lamp from being inserted into a lampholder intended for the 26W lamp. This safety aspect does not apply to Bayonet or Edison Screw lampholders and here the luminaire must be clearly marked with the maximum safe lamp wattage.

## Physical Characteristics

### Bulb shape and finish

Bulb is another word with a different meaning domestically and commercially. At home you change a lightbulb, but this is what is called a lamp commercially. The term bulb refers only to the glass outer envelope of the lamp. The description can be general such as tubular, elliptical or reflector which is usually self-explanatory or another of the letter-number codes which the lamp making industry uses.

Fig 7 Filament lamps with different glass envelopes. *Courtesy of GE Lighting*

Note that the numbers refer to eighths of an inch and are not metric like the lampholders. Fluorescent tubes come in different diameters T.12, T.8, T.5 and T.2.

T stands for tubular shape 12 x 1/8 = 1½ inches diameter.

Another example is the low voltage reflector display lamps MR.16. Miniature Reflector 16 x 1/8 = 2 inches diameter.

Imperial dimensions apply where the product originated in US but a few bulbs have metric references because they came from Europe, such R.80 which is a reflector bulb of 80mm diameter.

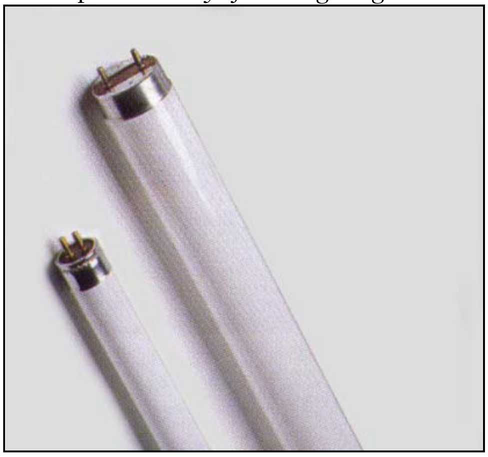


Fig 8 T.8 and T.5 fluorescent tubes. *Courtesy of GE Lighting*

Apart from the shape the surface finish can be varied from:

- clear
- diffuse (frosted)
- coated (opal or fluorescent)
- coloured
- reflective (choice of beam angles)

### Light Centre Length

This is a critical dimension from the bottom of the lamp base to the centre of the filament or arc tube. This is the point which should be at the centre of the luminaire optical system. (Fig 10)

Fig 9 Clear and coated glass envelopes. *Courtesy of GE Lighting*

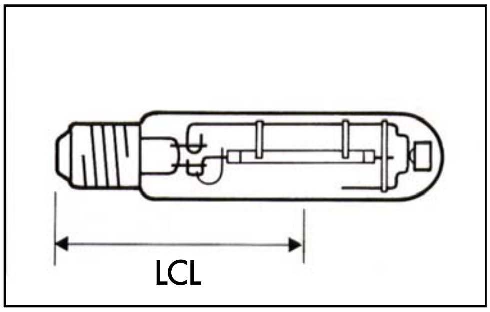



Fig 10 Light centre length.

**Light Output**
Lumen is the measure of light emitted by a lamp and can be in any direction. (Fig 11) It is the radiated power that the human eye can see. There is often radiation from a lamp at wavelengths to which the eye is not sensitive such as Ultraviolet and Infrared. Within the visible band the eye sensitivity varies as the following simple diagram shows. (Fig 12)

Lamp colour is described later in this module. Lumen output takes into consideration the colour of the light emitted by a lamp so for a given power lamps which produce mainly green and yellow light will have higher lumen output than the same power emitted as blue and red light.

In addition the ability for different types of lamp to convert electricity into light vary widely. For example:

18W Philips PL-C compact fluorescent gives 1200 lumens
100W domestic lightbulb gives 1360 lumens

Wattage is therefore not a good guide to light output. From the above example the domestic lamp gives 13% more light but uses more than five times the electrical power.

**Luminous Intensity**
This is the amount of light in a given direction and is measured in Candelas. It is often quoted in place of lumens for reflector lamps.

**Beam Angles**
Beam angles are a simple way of describing light distribution. However the normal convention for beam angle is where the light intensity has fallen to 50% of the peak value. It gives no information as to how the intensity varies within the beam , nor how much light is outside the beam. For some lamps there is a single reflector giving one beam of light. However most lamps offer a choice of beams by using either a clear or patterned glass front commonly called spot or flood. Low voltage reflector lamps have a range of moulded reflectors e.g. BLV 12V 50W Eurostar has 12°, 24°, 36° and 60°. Note these beam angles are rarely standardised between manufacturers. Where controlled lighting is important the maker should be included in the specification so the correct replacements are always obtained.

Some lamps give an elliptical beam such as:

| | |
|---|---|
| Pressed Aluminised Reflector 500W PAR 56 | |
| Narrow Spot | 13° x 8° |
| Medium Flood | 26° x 10° |
| Wide Flood | 44° x 20° |

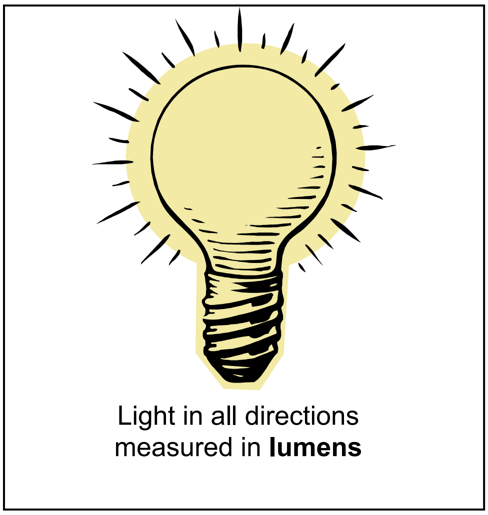



Fig 11 Lamp lumens.

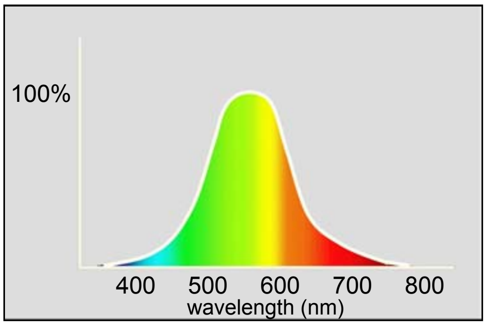



Fig 12 Visual sensitivity.

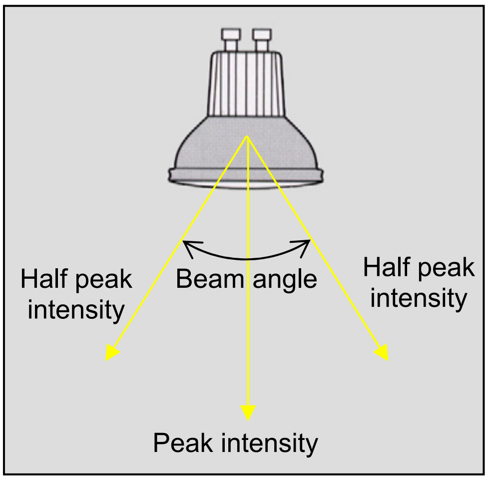



Fig 13 Beam angle.

**Efficacy**
This is a measure of the efficiency of the lamp expressed in lumens per Watt.
18W Biax™ D is 66.7 lumens per Watt
100W bulb is only 13.6 lumens per Watt

However for the same lamp type there will be a variation between low and high wattage versions with the bigger lamps normally being more efficient.

Linear tungsten halogen lamps

| Power Rating | Light Output | Efficacy |
|---|---|---|
| 100W | 1500 lumens | 15 lumens/W |
| 2000W | 44000 lumens | 22 lumens/W |

The larger lamp is 46% more efficient.

For discharge lamps including fluorescent lamps control gear is required (its purpose is explained later) and this consumes power. Lamp efficacy is expressed in two ways

1. Initial lamp lumens per nominal lamp Watt.
2. Initial lamp lumens per circuit Watt.

Version 1 is preferred by the lamp makers as it relies on information within their control.

Version 2 is preferred by those concerned with energy consumption and related green issues because it more accurately reflects use in the field. However it does require data from two separate sources (ie lamp maker and control gear manufacturer). The luminaire manufacturer may source control gear from more than one gear manufacturer.

## Colour

There are two separate colour qualities quantified by the lamp makers. **Colour appearance** is the colour that the lamp looks and **colour rendering** is how faithfully the light from the lamp displays the colour of objects. These two characteristics are independent and it is possible to have either

- two lamps with the same colour appearance but different colour rendering
- two lamps with equal colour rendering but different colour appearance.

There are three methods of describing colour appearance, by colour temperature, colour co-ordinates and correlated colour temperature.

**Colour temperature**
A solid (scientifically called a 'black body') when heated emits light if the temperature is high enough. Filament lamps are an example of this process. Initially this is seen as red light but as the temperature rises, the amount of light increases and the light includes all the other colours of the spectrum, so the light appears whiter. Because of the melting point of tungsten, filament lamps do not have colour temperatures above 3400K and domestic lamps are about 2700K. K stands for Kelvin which is the international standard for measuring temperature, which is like Celsius but starting at absolute zero.

| | Celsius | Kelvin |
|---|---|---|
| Absolute zero | -273°C | 0K |
| Freezing point (water) | 0°C | 273K |
| Boiling point (water) | 100°C | 373K |

Although Kelvin is a scale of degrees the symbol ° is not used, only the letter K.
Two filament lamps with the same colour temperature will have the same colour appearance.

Lamp appearance is described by three main groups.

| Colour Appearance | Colour Temperature |
|---|---|
| Warm | below 3300K |
| Intermediate | 3300 to 5300K |
| Cool | above 5300K |

Setting out to match natural daylight is not a sensible option. The colour temperature of the sun is 5400K but that is not the full story. As the light reaches earth and enters our atmosphere it changes colour. Due to refraction more blue light reaches the earth's surface when the sun is high in the sky whereas at dusk and dawn it is predominantly red. This means that daylight varies from 10,000K to 2000K in the space of a few hours with random fluctuations according to the amount of cloud cover. Daylight is not a constant colour and the human eye is remarkably adaptable to such changes.

**Colour co-ordinates**

The CIE colour triangle is a colour map based upon three primary colours near to red, blue and green. (Fig 14) By mixing these colours in different proportions any of the colours shown can be created. Two co-ordinates, x and y enable any point on the chart to be defined.

This is a useful way of comparing the appearance of two different lamps

| | |
|---|---|
| Lamp A | x = 0.3 y = 0.3 |
| Lamp B | x = 0.2 y = 0.3 |

To move from points A to B on the chart means moving towards the blue section of the chart. Thus Lamp B will appear bluer than Lamp A.

**Correlated Colour Temperature (CCT)**

This is an attempt to use the Kelvin scale for lamps which do not act as 'black bodies', which means all discharge and fluorescent lamps. Correlated means the nearest equivalent and some lamps are closer to black body radiators than others. CCT should be used as a rough guide only and two discharge lamps with the same CCT will not necessarily appear the same or match exactly a filament lamp of the same colour temperature.

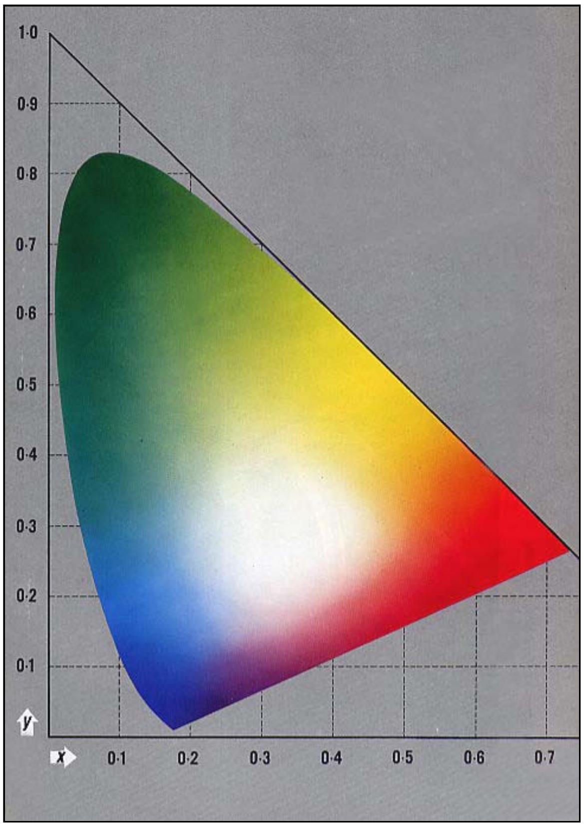



Fig 14 CIE Colour triangle. *Courtesy Lamps and Lighting.*

**Colour Rendering**

Because the human eye is most sensitive to green and yellow light many lamps concentrate their radiation in these regions so they can claim a high lumen output. This means green and yellow objects will appear much brighter than red or blue ones. This will cause poor colour rendering as the eye is unaware that some colours of the spectrum are missing.

There is no substitute for visually examining the colours of materials/products under the type of lamps intended to be used. However this not always a practical option and there is a CIE colour rendering index (CRI) which can be helpful. This grades lamps on a scale ($R_a$) of 0-100 where $R_a$ = 100 means excellent colour rendering.

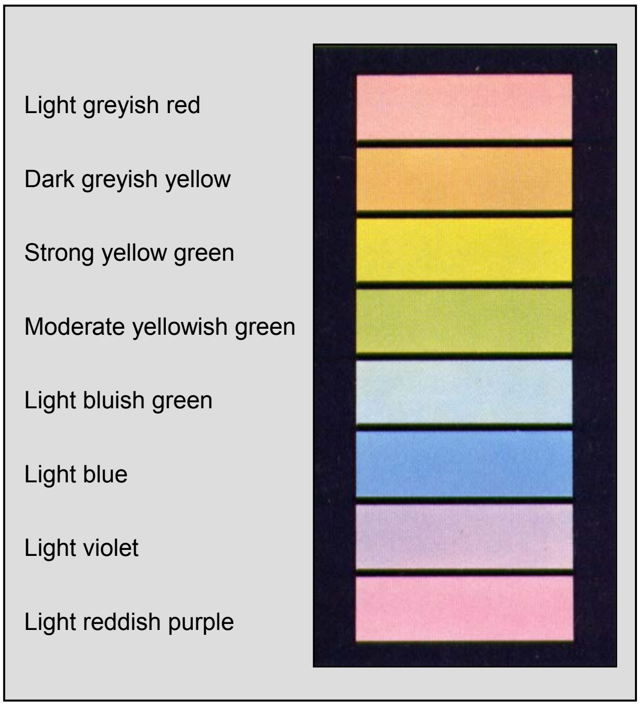



Fig 15 Colour rendering approximate test colours.
*Courtesy of Philips Lighting*

The CRI is calculated by comparing the appearance of eight colour samples against a reference source. A limitation is that the samples are all pastel shades, typically found in most normal interiors. This means the $R_a$ value may not be a good guide to saturated colours. Secondly the $R_a$ value is based upon the average closeness of the match of the eight samples. Consequently two lamps may be given the same $R_a$ value but the colour rendering of objects may not be the same, as different results from the eight samples can produce the same average figure.

The use of numerical scales is convenient but can never convey all the information about colour so often the following broad groups are sufficient.

| Colour Rendering Group* | Colour Rendering Index | Typical Application |
|---|---|---|
| 1A | 90 and above | Where accurate colour matching is required |
| 1B | 80 - 89 | Where accurate colour judgements are necessary |
| 2 | 60 - 79 | Where moderate colour rendering is required |
| 3 | 40 - 59 | Colour rendering is of little significance but marked distortion is unacceptable |
| 4 | 20 - 39 | Where colour rendering is of no importance and colour distortion is acceptable |

*CIE colour groups have been discontinued but reference can still be found in current lamp literature.

The final draft (March 2001) of a new European Standard pr EN 12464 ‘Lighting of indoor work places’ has been submitted for formal voting. Within this Standard is a schedule of lighting for different task and applications. In addition to recommended maintained illuminance values there is minimum $R_a$ for each situation. A minimum of $R_a$80 for normally occupied interiors is proposed with only few exceptions. Colour rendering is likely to become a more important part of the lighting specification than at present and the choice of lamp will no longer be solely at the discretion of the lighting designer. The Standard calls for the recognition of safety colours to be considered in addition to the requirements of the visual task.

Although this European Standard has yet to be approved (March 2002) it has been incorporated into the new Lighting Code* issued by the Society of Light and Lighting in February 2002, replacing the CIBSE Code for Interior Lighting last published in 1994. Recommended good lighting practice in the UK now calls for the use of light sources with a minimum $R_a$80 for interior lighting. The future use of high pressure mercury lamps, halophosphate fluorescent tubes, high pressure sodium lamps and some metal halide lamps will be severely restricted for lighting of interiors.

* Full version only available as CD-ROM from CIBSE Publications (Tel 020 8675 6554) at £166.88.

## Non visible radiation

Lamps can emit unwanted radiation which does not affect the visual performance but is important for the health and comfort of the occupants.

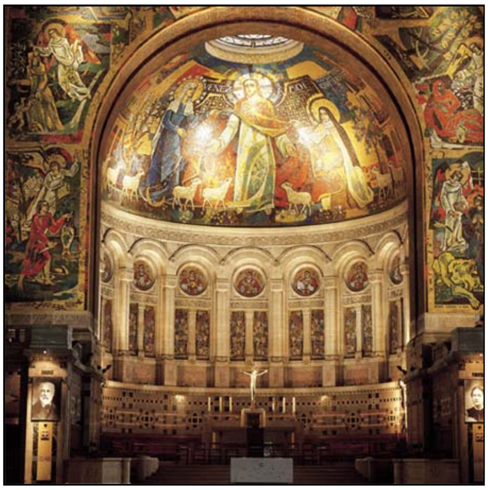


Fig 16 Limit non visible radiation on works of art.

**Ultraviolet**
Lamps which use quartz rather than glass can emit UV radiation. Such lamps should be used in suitable glass fronted luminaires. Extra precautions should be taken where materials as fabrics or works of art are being lit. (Fig 16) Here greater control of UV radiation is required to prevent fading.

Normally the amount of UV from artificial lighting is less than experienced outdoors from natural light so there is no health hazard.

**Infrared**
This is recognised as heat and occurs with all lamps. As IR is reflected in a similar way to light it is important not to over light displays as the merchandise can suffer from becoming too hot.

Lighting contributes to the heat gain of a building which in summer can require extra air conditioning or ventilation to be provided.

Radiated Energy from lamps

| Lamp type | Light | Infrared | Ultraviolet |
|---|---|---|---|
| Filament | 5% | 83% | 0 |
| Fluorescent tube | 28% | 38% | 0.6% |
| H P Mercury | 17% | 65% | 3.7% |
| Metal Halide | 24% | 59% | 1.3% |
| H P Sodium | 30% | 55% | 0.3% |

## Flicker

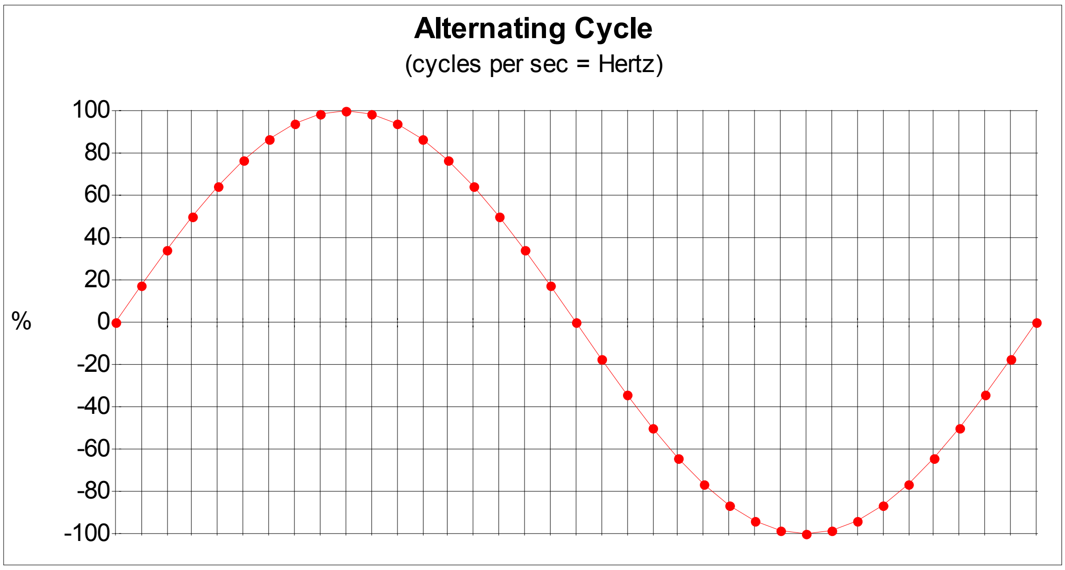



Fig 17 Waveform of mains voltage supply.

The standard alternating supply in Europe is 50 Hertz i.e. 50 cycles per second. (Fig 17) Each cycle contains a positive and negative peak. Light is generated when the current flows through the lamp regardless of its direction so lamps produce two pulses of light for each cycle. The flicker is therefore at 100 Hz which is too rapid for the eye to consciously detect but can still cause discomfort to some people as headaches or eye strain.

## Starting run-up and hot restrike

Some lamps provide instant light whereas others take several minutes to "warm-up" and initially give little or no light. Often these lamps when hot cannot be immediately restarted and the lamps have to cool down when before starting becomes possible. It is important that areas are not illuminated solely by lamps which could be accidentally switched off and deprive the occupants of all illumination, such as public areas and spaces with moving machinery, hot surfaces, corrosive chemicals etc. (Fig 18)

Fig 18 Make provision for instant light after switch on.

## Lumen depreciation

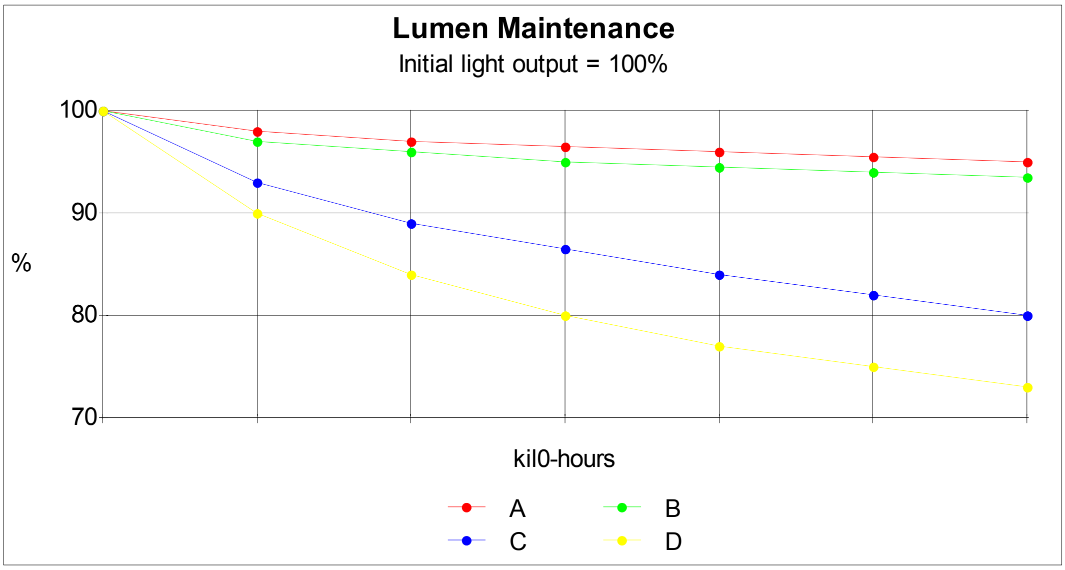



Fig 19 Lumen maintenance.

The above graph show four different types of lamps.

A - New Generation Triphosphor fluorescent tube
B - High Pressure sodium lamp
C - Standard White fluorescent tube
D - Metal halide lamp

Most lamps emit reduced light with age. This can be associated with a change in colour for some types. The electrical consumption remains roughly constant so the value-for-money declines and it is possible to calculate the point where it is better to replace a lamp even if it has not physically failed. More important, although rarely considered is the loss in efficiency, not of the lamps, but of the operatives working under a reduced illuminance and thus making more errors, working slower and suffering visual fatigue and possibly causing accidents or injury.

The light output of lamps is quoted as initial lumens after 100 hours burning. Some lamps take a few hours to stabilise; 100 hours covers this "bedding down" period. Part of the lighting design process to predict the loss of light from the lamps, as well as from dirt on luminaires and room surfaces and thus determine the maintained illuminance. The lighting design has to assume some form of regular cleaning and lamp replacement. A comprehensive maintenance schedule should be given to the user by the lighting designer.

## Colour shift

High pressure discharge lamps are prone to colour shift through life, particularly metal halide versions. In cases where colour appearance is very important the lamp replacement will be more frequent to minimise any colour difference. Lamps used for colour inspection similarly should be changed as the colour rendering may affected.

Fig 20 Metal halide lamps are prone to colour shift through life.

## Lamp life and failure

Lamp life is often defined as the period that the lamp continues to function correctly. End of life can be the physical failure as is the normal condition for filament lamps. However the end of "effective life" can be when the light output falls to such an extent that it is no longer economic or safe. 30 % loss in initial light output can represent end of lamp life. A colour shift may occur and a new replacement lamp may not match the rest of the aged installation. The manufacturer may specify a lamp life as that where consistent colour can be expected.

Whatever criteria are used, the performance quoted is the average from a batch of lamps all operating at the correct conditions of voltage, current, temperature, position etc. In practice lamp may not be operated at the optimum conditions. Supply voltage can vary, the control gear may not match exactly the electrical characteristics of the lamp. The luminaire may position the lamp incorrectly or cause the wrong operating temperature. The lamp may be switched on a more frequent cycle than normal or there may be excessive external vibration.

## Standards

In most cases the Standards for lamps are written long after the lamp has been invented. Consequently most lamp standards set out physical dimensions, electrical characteristics with tolerances that accept the lamps already in production. The standards provide some guidance for compatibility but little regarding performance or durability. If maker "A" and maker "B" both claim to conform to meet a particular lamp standard then lamps from either will fit and operate in a luminaire requiring a lamp to the same standard. However there is no guarantee, and a strong likelihood that lamps "A" and "B" will be different colours, with different light output and of different durability. It is important that lamps are purchased from one supplier, and this applies to replacements as well as for the original installation.

## Product Disposal

The UK Government has announced a national lamp recycling initiative to help meet the requirements of the forthcoming Waste Electrical and electronic Equipment (WEEE) Directive. This will be managed by SustainaLite, a not-for-profit company founded by the Lighting Industry Federation and the Environmental Services Association. This scheme covers all types of discharge lamp including linear and compact fluorescent lamps.

It is likely that future legislation will involve controlled disposal of luminaires as well as lamps and therefore Thorn Lighting policy is a wider issue than can be adequately covered in these notes.

Fig 21 SustainaLite logo.

## Lamp Codes

In 1994 IEC 1231 was published which provides a method of identifying different lamp types by an internationally agreed coding system. This is called ILCOS (International Lamp Code System). Eventually this will enable lamp makers, luminaire manufacturers, control gear producers to specify any lamp and ensure electrical and mechanical compatibility, but will not prevent the differences between individual products as mentioned earlier.

This system is like a new language and thus not yet well understood by the lighting industry, and conflicts with branding policies by the marketing experts who do not want to reveal that their product is in no way different to the competition.

Previously there were various national codes but with the globalisation of the lamp industry a single code has many advantages. Here are a few examples

| | ILCOS | GE | OSRAM | Philips |
|---|---|---|---|---|
| Metal Halide | M | MBI | HQI | HPI |
| High Pressure Sodium | S | LU | NAV | SON |

The ILCOS reference can be used in a short form when describing a type of lamp but the reference can be extended to include colour, lampholder and many other details.

Its use is to be encouraged even though initially its value will be limited. Certainly luminaires should be marked with ILCOS references listing suitable lamps. It will also identify the correct replacement lamps for the maintenance schedule.

*Questions 1*

1. Who are the three major lamp makers supplying the UK market?

2. Name three materials used in lamp manufacture.

3. What would the next appropriate wattage rating in this sequence?
   10W, 15W, 25W, ..........W.

4. What do the letters G E S stand for?

5. What is the difference between G24d and G24q lampbases?

6. To which colour is the human eye most sensitive?

7. For which lamps is the performance often quoted in candelas?

8. For what colour temperature are lamps described as having a ‘cool’ appearance.

9. The Colour rendering index (CRI) is determined by comparing the appearance of
   a) three primary colours or
   b) eight pastel shades?

10. ILCOS is
    a) European Trade Association or
    b) Manufacturer’s brand name or
    c) International lamp coding system?

# 2 Tungsten Filament lamps

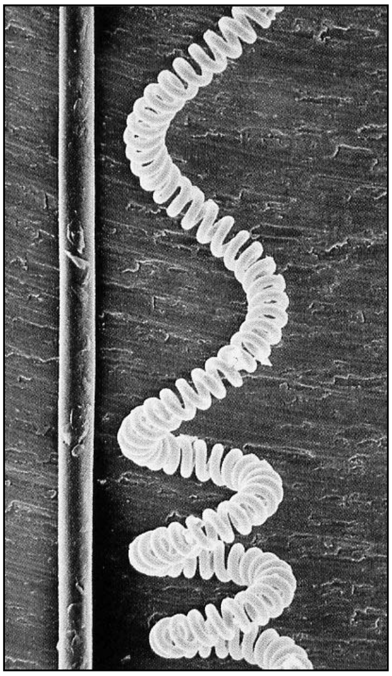


Fig 22 Human hair against filament.

## History

Filament lamps became available from the end of the 19th century when vacuum pumps were capable of creating a sufficiently "hard" vacuum. Various materials were tried for the filament but the electric lamp adopted tungsten in the early 1900s when it became possible to draw a fine tungsten wire. Tungsten has proved the most suitable filament material because it has a high melting point (3410°C) together with a low rate of evaporation. By the 1930s the lamp design had developed to a form very similar to the lamps manufactured today.

## How light is generated

Passing electricity through a wire (filament) generates heat and all solid materials will emit electromagnetic radiation when heated to a sufficiently high temperature. (Fig 22) The atoms become excited by numerous interactions and energy is radiated in a continuous spectrum. The radiation is over a wide waveband and the quantity increases as the temperature rises. Also the peak emission shifts and its wavelength becomes shorter as the temperature increases. Look at a domestic lamp when operated on a dimmer switch. At full power the colour is yellowish white but as the power is reduced not only does the amount of light lessen but the colour becomes orange and eventually red.

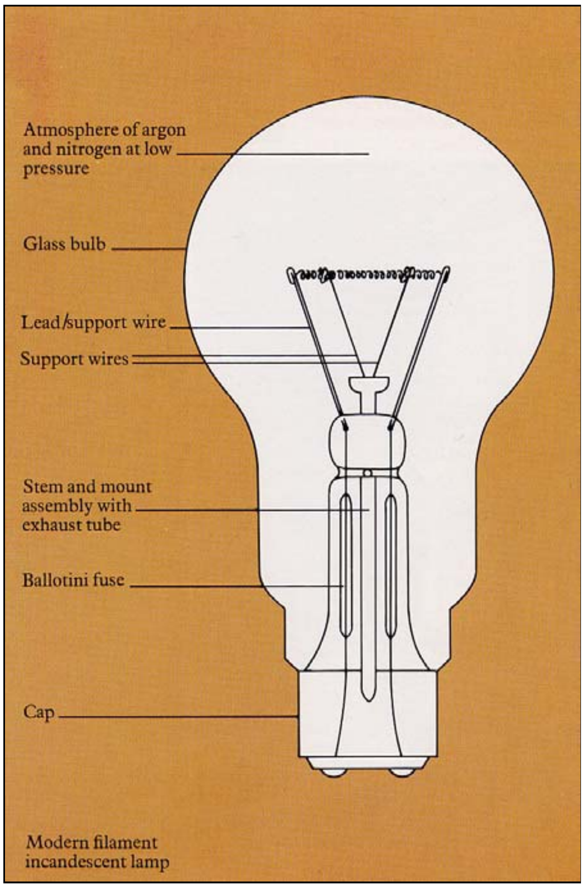



Fig 23 Filament lamp construction.

## Lamp construction

The thin filament requires supports and electrical connections. (Fig 23) If the filament was exposed to the atmosphere it would oxidise immediately so it is contained in a glass bulb with a vacuum or inert gas filling. The wires connected to the filament have to pass through the glass bulb and there must be no air leaks. The bulb and electrical connections are terminated externally with a lampholder which provides both mechanical and electrical connection to the lighting fitting.

### Filament

The tungsten wire for a 240V 100W lamp is thinner than human hair and about 1.2m in length. Filaments are coiled and arranged in a circular or cage formation in order to keep the lamp size as compact as possible. The coiling helps to retain the heat generated and so the light output is improved. Many domestic lamps use coiled-coil filaments where the double coiling process reduces the heat losses in two ways. Apart from the more compact filament shape, fewer filament supports are required. Each support conducts heat away from the filament.

**Bulb**
In addition to containing the vacuum or gas filling, the glass bulb can be used to control the light emitted. Coloured bulbs, diffusing bulbs and reflector shapes all modify the light generated from the filament. The bulb can also have a decorative shape such as the large globes or candle lamps. (Fig 24)

Fig 24 Assortment of filament lamps. *Courtesy of GE Lighting*

**Vacuum or gasfilling**
Although a vacuum will prevent oxidation of the tungsten, it will not stop evaporation. The darkening of bulbs is due to evaporated tungsten which has condensed on the relatively cool bulb surface. With an inert gas filling this evaporation will be suppressed and the heavier the molecular weight of the gas the more effective it will be. For normal lamps an Argon/Nitrogen mixture (9:1) is used because of its low cost. Krypton or Xenon is only used in specialised applications such as cycle lamps where the small bulb size helps to offset the increased cost of the gases, and where performance is critical and extra cost is justifiable.

Gasfilling can conduct the heat away from the filament so low conductivity is important. Gas filled lamps normally incorporate fuses in the lead wires. A small break in the filament can cause an electrical gas discharge to occur which can draw very high currents. As filament fracture is the normal end of lamp life it would not be convenient for sub-circuits fuses to fail and so the internal fuse contains the problem within each lamp.

**Lampholder**
There are a wide variety of lampholders for filament lamps which are given reference codes based upon international standards. The lampholder will combine the requirements of the lamp and its luminaire. The more common domestic types have generic names but usually the code reference is more specific. (Fig 25)

| | | |
|---|---|---|
| Bayonet Cap | | |
| BC | Bayonet Cap | B22d |
| 3 pin BC | 3 pin Bayonet Cap | B22d-3 |
| SBC | Small Bayonet Cap | B15d |
| Edison Screw | | |
| SES | Small Edison Screw | E14s |
| ES | Edison Screw | E27s |
| GES | Goliath Edison Screw | E40s |

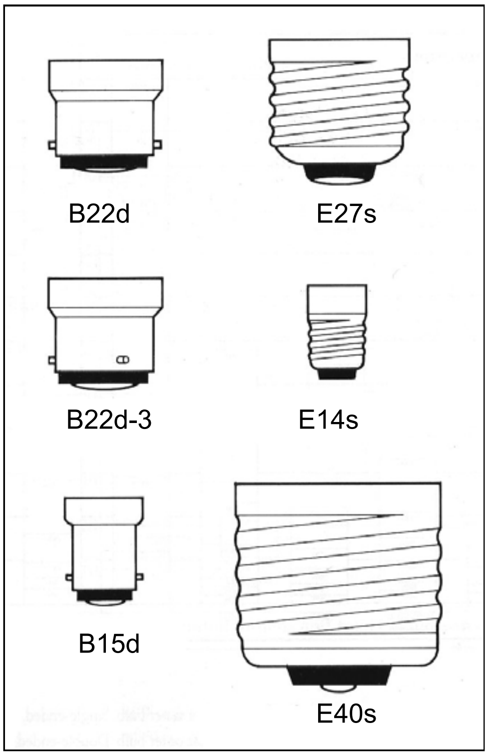



Fig 25 Common lamp caps.

**Efficacy**
Filament lamps are mediocre producers of light, typically 12 lumens/Watt, but this low performance is offset by their low cost and convenience. 95% of the radiated energy is as heat and not light.

**Colour**
The light generated is a continuous spectrum and so will give good colour rendering. The colour appearance is "warm" (2500 - 2700K) - which is not normally comfortable for illuminances of more than 500 lux.

**Life**
There is a trade-off between life and light output . Standard domestic lamps have a average rated life of 1000 hours although there are long life options which will last for 2000, 3000, or even 16,000 hours. Extended lamp life should only be considered where maintenance is difficult or access is limited. Tungsten filament lamps are very inefficient and there should be clear justification for reducing performance still further.

Fig 26 Domestic application.

**Voltage sensitivity**
Filament lamps are particularly sensitive to voltage variation and it is most important that all lamps match the supply conditions.

For example:

| Supply Voltage | lumens | power | life |
|---|---|---|---|
| -10% | -33% | -15% | +400% |
| -5% | -20% | -6% | +100% |
| +5% | +20% | +8% | -60% |
| +10% | +40% | +15% | -75% |

It is important to remember that this applies equally to all supply voltages. Running 12V lamps at 12.6V represents a 5% increase and will have the same effect as running 240V lamps at 252V.

**Market Demand**
The use of tungsten filament lamps is mainly for the domestic market where cost is important and burning hours are low. As the domestic market is about 40% of the total lighting market this is sufficient to sustain its use. (Fig 26)

## Tungsten Halogen Lamps

**History**
These lamps first appeared until 1960s and initially were only in high wattage ratings for floodlighting. The principle was extended to specialised lamps for the theatre, projection equipment and automotive industry where the extra performance was important.

Fig 27 Tungsten halogen collection.
*Courtesy of GE Lighting*

The low voltage (6-24V) versions with integral reflectors were modified for display lighting in 1980s and now dominate this market sector. Below 50V is more accurately defined as Extra Low Voltage (ELV).

**How the light is generated**
Tungsten halogen lamps employ a tungsten filament in exactly the same manner as conventional filament lamps and thus rely on thermal radiation. The addition of halogen gas enables the filament to operate satisfactorily at higher temperatures and thus increases the visible radiation.

**Lamp construction**
The halogen cycle described below requires a minimum bulb wall temperature of 250°C. This affects the bulb shape which is much smaller, and the material used is quartz. The first lamps were of linear construction with a slim quartz tube surrounding a straight coiled filament. Hence the name Quartz Halogen. (Fig 28)

Fig 28 Linear quartz halogen lamps.
*Courtesy of GE Lighting*

**Filament**
The filaments are similar to conventional tungsten lamps. Where low voltage lamps are now available there are added advantages. The filament is shorter and thicker. This means less supports and a even more compact design with increased light output.

**Bulb**
There are many shapes of tungsten halogen lamp and in some cases these are intended as direct replacement for the filament lamp. Quartz melts at a high temperature and oxy-gas firing is necessary which makes manufacture more complex. Quartz has almost no thermal expansion and at the seal where the lead wires enter the bulb there is a problem as metallic wires will expand and break the seals. The solution is to use a very thin molybdenum foil but this is only effective up to 350°C. There is thus only a narrow margin between the minimum bulb wall and maximum seal temperatures.

**Gas filling**
Either Iodine or Bromine are the halogen gases used and these are frequently at a positive pressure. Tungsten halogen lamps should be housed so that should a lamp fracture occur, the pieces will be safely contained within the luminaire. Quartz fragments can contain sufficient thermal inertia to be a fire hazard. All luminaires used for interior lighting should be suitably enclosed.
(Note that low pressure tungsten halogen lamps are available for use in open luminaires)

The main purpose of the halogen gas is to enable the filament temperature to be increased without excessive evaporation. The "halogen cycle" uses the thermo-chemical reaction of the gases with the tungsten vapour. As the tungsten vapour moves away from the filament the temperature falls and at about 1000°C it combines with the iodine vapour to form tungsten iodide. This compound will remain as a vapour above 250°C. Provided the minimum bulb temperature is above this there will be no blackening (condensation). As the gaseous compound circulates within the lamp it will separate into the two original elements when its temperature rises above 1000°C. The tendency is therefore to contain the tungsten evaporation to the space immediately surrounding the filament.

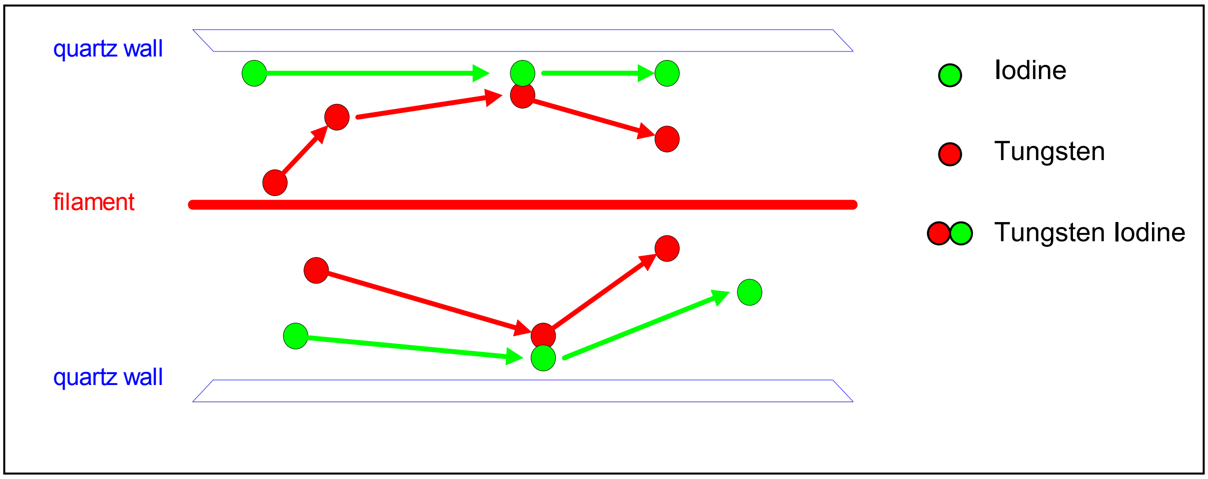



Fig 29 Tungsten halogen cycle.

**Lampholder**
Most lampholders are of ceramic construction because of the heat associated with these lamps. It is most important that the luminaire/lampholder design controls the maximum foil temperature within safe limits. (Fig 30)

**Efficacy**
The higher operating temperature will provide about 20 lumens/Watt. With no blackening the light output remains nearly constant through life.

Infra red reflecting films are being introduced that reflect heat back onto the filament with significant increases in efficacy up to 35 lumens/Watt.

GE Lighting Tungsten Halogen Double ended Linear

| Standard | lumens | |
|---|---|---|
| 300W | 4800 | 2000 |
| 500W | 9500 | 2000 |
| 1500W | 33000 | 2000 |

| Halogen-IR | lumens | life(h) |
|---|---|---|
| 225W | 4800 | |
| 375W | 9000 | 2000 |
| 900W | 32000 | 2000 |

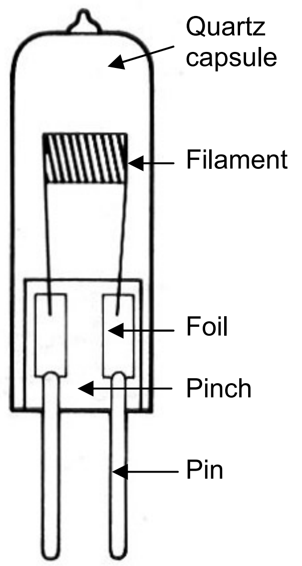



Fig 30 Linear quartz halogen lamps.

Potential power saving

| | |
|---|---|
| 300W by 225W | **25%** |
| 500W by 375W | **25%** |
| 1500W by 900W | **40%** |

**UV Radiation**
Because tungsten halogen lamps operate the tungsten filament at a higher temperature more Ultraviolet radiation is produced. In addition quartz is a good transmitter of UV whereas glass is not. The amount is small and less than is commonly experienced from natural daylight. However the following warning should be heeded when using tungsten halogen lamps.

**"If the average lighting level on the skin or eyes exceeds 4,000* lux for continuous exposure then appropriate UV filters should be used.**

| | | |
|---|---|---|
| *** for** | **6 hours** | **5,500 lux** |
| | **4 hours** | **8,000 lux** |
| | **2 hours** | **16,000 lux** |
| | **1 hour** | **32,000 lux** |
| | **½ hour** | **64,000 lux"** |

It is now possible to obtain some quartz lamps with a special version of the material which will reduce UV transmission. These lamps are called UV blocking lamps. Most ELV reflector lamps are available with glass fronts. This physically encloses the tungsten halogen capsule and prevent handling and at the same time provides UV protection.

Where valuable works of art are concerned additional protective means are recommended and lighting levels should be carefully controlled so in this situation always seek expert advice.

## Dichroic Filters

These are used with the ELV reflector lamps as an alternative to the conventional metal reflective coating. Dichroic films have the ability to selectively reflect specific radiated wavelengths of energy. Those used for lamps reflect the visible spectrum but transmit infrared radiation. Consequently the white light is directed forwards and the IR radiated heat is largely emitted out of the back of the lamp. This is advantageous for display purposes where excessive heat could cause damage or fading. However it does put additional thermal stress on the luminaire and lampholder. Always check that the luminaire will accept dichroic lamps. (Fig 31)

Fig 31 Tungsten halogen dichroic lamp.

## Colour

The colour rendering is the same as filament lamps as there is a continuous spectrum. The colour appearance is whiter and the colour temperature is normally 3000-3200K compared with 2500-2700K for conventional filament lamps.

## Life

It is normally possible to combine increased light output with extended life and tungsten halogen lamps are rated at 2000 hours. ELV lamps are 2000 - 5000 hours and some up to 10,000 hours.

## Voltage Sensitivity

The same comments as for tungsten filament lamps apply with the added problem that under-running can cause the temperatures to fall and the halogen cycle will not operate. This is encountered with high wattage lamps run on dimmers for long periods, when blackening can be experienced. Operating the lamps at full output will clear this in a few minutes.

Although not of major importance for general commercial and industry lighting, filament lamps are available to operate at low voltages such as emergency supplies or safer low voltages (120V) for construction sites. Filament lamps will operate equally well from alternating (AC) or direct (DC) current.

## UK Supply Voltage

This was "harmonised" at 230V in 1995 with 'mainland Europe, but the UK electricity generators have maintained 240V as it is well within the tolerances allowed. Lamps should be specified to match the actual voltage supplied and not the nominal value. Over-running lamps will give short lamp life. Overheating of luminaires could also become a risk. Note also that the current tolerances of +10% to -6% will be increased further to ±10% in 2003.

| | | Nominal V | Tolerance | Max V | Min V |
|---|---|---|---|---|---|
| pre 1995 | UK | 240 | ±6% | 254 | 226 |
| pre 1995 | Europe | 220 | ±10% | 242 | 198 |
| 1995-2002 | UK | 230 | +10% -6% | 253 | 216 |
| 1995-2002 | Europe | 230 | +6%-10% | 244 | 207 |
| 2003 | UK | 230 | ±10% | 253 | 207 |
| 2003 | Europe | 230 | ±10% | 253 | 207 |

Adopting the wider tolerances from mainland Europe will allow mains voltage variations which will cause major problems for users of incandescent filament lamps unless they check the actual supply voltage.

**Building Regulations Part L**
The current regulations do not include tungsten or tungsten halogen lamps in the Table of approved types. The average performance of the installed load has to 50 lumens/circuit Watt or higher (CIBSE recommends 65 lumens/circuit Watt as an achievable energy target). If tungsten lamps are used they must be in conjunction with more efficient lamp types.

ELV reflector lamps can be efficient lighting where only specific areas or objects require illumination. The variety of beam widths available mean that the correct lamp can be selected with no wasted spill light. Remember that display lighting is not included in Part L of the Building Regulations. However it is totally inappropriate to use these lamps for general lighting of corridors, lift lobbies, toilets etc. Because of their attractive small size many examples of this bad practice can be seen.

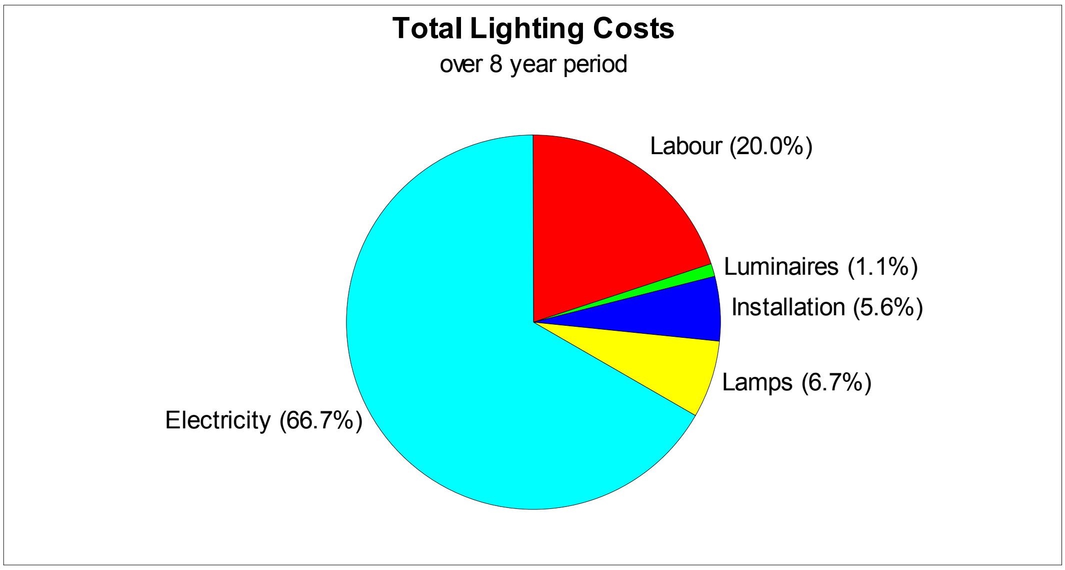
**Safe handling**
It is easy for quartz to pick up salt from your fingers (rather like a wine glass after a meal). If the lamp is switched on the salt will burn permanently into the quartz and the lamp will be permanently damaged. If any lamp has been handled always clean it with a cloth and a small amount of spirits such as methylated spirits or industrial alcohol. Never wash or immerse lamp in water. Some lamps have a extra outer glass bulb so that can be safely handled. Touching quartz will not harm you except when it is HOT. Never handle any lamp until it has been switched off AND allowed to cool down.

**Control**
Tungsten filament and tungsten halogen lamps provide instant light at full power immediately upon switching on. They can be easily dimmed but the reduction in light output is not matched by an equal reduction in power consumed. Dimming should therefore be for effect and not as an attempt to save energy. Dimming will prolong lamp life if used for a considerable amount of the total operating time.

**Lighting Costs**
This example demonstrates the relative costs associated with lighting. Rounded values have been used to make the arithmetic simple to follow.

Two 500W tungsten halogen floodlights are used to illuminate a shop front. The lighting is operated for 3000 hours per year and the installation has an anticipated life of 8 years. Lamp life is 2000 hours and cost of electricity is 5p per kilowatt-hour.

| *Component Costs* | | TOTAL |
|---|---|---|
| Luminaires | 2 floodlights at £10 each | £20 |
| Installation | Wiring and fixing 2 luminaires at £50 each | £100 |
| Lamps | Total burning hours is 2 x 3000 x 8 = 48000 hours<br>number of lamps used 48000/2000 = 24<br>24 lamps at £ 5 each | £120 |
| Labour | Labour cost to change one failed lamp £15<br>24 lamps will cost | £360 |
| Electricity | Electrical load is 2 x 500W = 1kW<br>electricity consumed 1 x 3000 x 8 = 24000 kWh<br>cost 0.05p x 24000 | £1200 |
| | GRAND TOTAL | £1800 |




The major costs to the user are the electricity consumed and the labour for changing the lamps. These factors are usually ignored because the prices are presented in a way that hides the true costs.

*Capital cost*

| | | | |
|---|---|---|---|
| Luminaires | £20 | | |
| Installation | £100 | | |
| Initial set of lamps | £10 | Total | £130 |

*Maintenance*

| | | | |
|---|---|---|---|
| Cost to change one lamp | | | |
| Labour | £15 | | |
| Lamps | £5 | Total | £20 |

(lamps fail one at a time so will be billed separately)

*Electrical consumption*

| | | | |
|---|---|---|---|
| 750 kWh used per quarter | | | |
| 750 x 0.05p | £37.50 | Total | not available |

(energy costs are charged either monthly or quarterly and no breakdown is provided as what was used by the lighting)

From these figures it is easy to assume that the capital costs are most important and electrical costs are simply not known. From the pie chart it can be seen that the electricity is by far the largest cost and also the cost of lamps and labour is four times that of the luminaires and their installation.

Later it will be possible to see the effect of using other light sources for basically the same situation.

*Questions 2*

1. What material is used for making lamp filaments?

2. Name three different shapes of light bulb.

3. What terms are used to describe lamp efficiency?

4. What is the typical luminous efficiency of a tungsten halogen lamp?

5. Which lamp has the higher colour temperature?
   a) domestic lightbulb or b) tungsten halogen lamp

6. When a filament lamp is dimmed does
   a) the colour temperature go up or
   b) go down?

7. What is the nominal electrical supply voltage for the UK?

8. What two precautions must always be taken before removing a lamp?

9. What is the colour rendering index (CRI or Ra) for tungsten halogen lamps?

10. In total through life costs for a lighting installation what is the major contributing factor?

# 3 Fluorescent Lamps

## History of Fluorescent lamps

There were experimental gas discharge tubular lamps from the beginning of the 20th century. The fluorescent tube was announced just before the 2nd World War but did not become readily available until hostilities ceased in 1945. The industrial and commercial post war recovery adopted fluorescent tubes widely as a means of lighting the complete occupied space within buildings evenly and without shadows.

The compact versions of the fluorescent tube did not appear until the 1980s and were primarily intended as a low energy replacements for the GLS filament lamps. Since then the range of CFLs has increased to make more compact commercial luminaires such as recessed downlights. (Fig 33)

Fig 32 Linear fluorescent lamps.

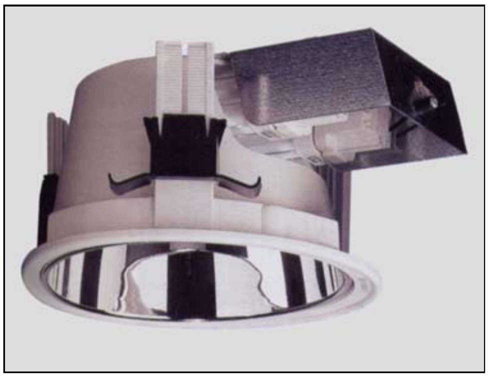


Fig 33 Compact fluorescent lamps used in downlight.

## General characteristics

### How light is generated

Passing electricity through a gas or metallic vapour will cause electromagnetic radiation at specific wavelengths according to the chemical constitution and the gas pressure. The fluorescent tube has a low pressure of mercury vapour and this will emit a small amount of blue/green light (2%), but the majority of the radiation (60%) will be as UV radiation at 253.7 and 185.0 nm.

Inside the glass tube wall is a thin phosphor powder coating, selected to absorb the UV radiation and transmit it in the visible region. This process is approx. 50% efficient.

The glass tube is a poor transmitter of UV radiation and therefore only a insignificant proportion is radiated by the lamp.

It is possible for fluorescent lamps to emit radio interference although only for a short distance so ceiling mounted lamps are unlikely to cause problems for radios at table height.

When new some lamps can appear to have a swirling discharge. This is due to minute traces of impurities in the gas and normally disappear after the first few hours burning.

When operated from normal 50 Hz alternating electrical supply there will be flicker at 100 cycles per second with light generated for the positive and negative parts of the cycle (see p 12). The modulation of the flicker depends upon the 'afterglow' of the phosphors. A long 'afterglow' minimises the effect of flicker. However the practical solution to lamp flicker is to use high frequency electronic control gear which operates the lamps at 30 kHz and higher and thus overcomes any visual discomfort.

### Lamp construction

Although the manner of generating light is complex the physical construction is relatively simple. (Fig 34) The gas pressure is chosen to provide the maximum UV radiation at a bulb temperature of approx. 40°C which occurs in an ambient temperature of 25°C. (See comments about T5 lamps later in this module)

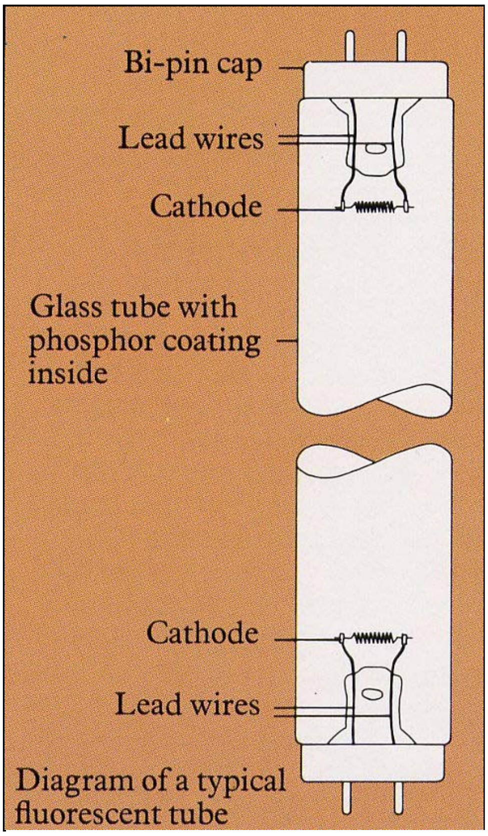



Fig 34 Lamp construction.

### Efficacy

Fluorescent lamps are considerable more efficient than filament lamps. The considerable improvements are due to the phosphors that are now available. Halophosphate coated lamps reach 80 lumens/Watt and the tri-phosphor versions over 90 lumens/Watt.

When used with high frequency electronic control gear the lamp efficacy is increased by up to about 10% so fluorescent tubes are now reaching 100+ lumens/Watt.

## Colour

The colour is determined by the phosphor used and there are many different "white" fluorescent tubes available. The colour attributes are divided into two separate aspects.

Colour appearance is how the lamp looks. Those lamps with a red bias are described as "warm" and those with a high blue content are called "cool". The Kelvin scale of colour temperature defines the colour emitted from a solid body when heated to a high temperature. A higher colour temperature means a "cooler" colour appearance.

Strictly this scale cannot be applied to fluorescent tubes with a discontinuous spectral radiation, but it does provide a convenient rough approximation. This is why it is called Correlated Colour Temperature (CCT). Two lamps may have the same CCT but may still appear as different colours.

### Colour rendering

You will remember that colour rendering is how the illuminated objects look. Where the colours are accurately portrayed then the light source has a good colour rendering. There is a relative scale called CRI (colour rendering index) or Ra from 0 - 100. The higher the value the better the colour rendering. With halophosphates colour rendering could only be improved with a marked loss in efficacy. Tri-phosphor lamps combine better colour rendering with greater efficacy.

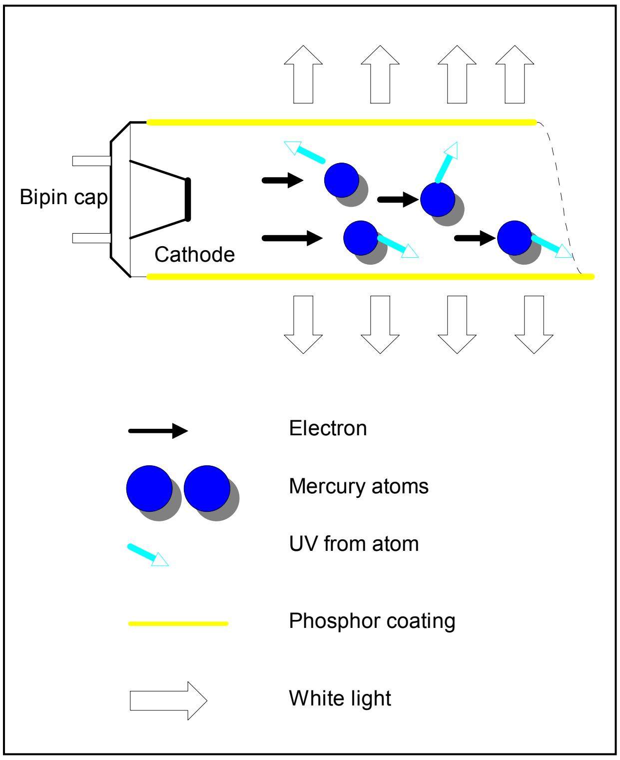



Fig 35 Fluorescent light production.

## Phosphor coating

The first phosphors used were zinc and beryllium silicates but by the 1950s they had been replaced by alkaline-earth halophosphates which are still used today in White, Warm White and Cool White lamp types. The halophosphates give a wide emission across the visible spectrum but peak in the yellow/green as does the human eye response. In contrast the reds and blues tend to be muted colours when illuminated by these lamps.

Typical products:

| CCT (K) | Efficacy(l/W) * | CRI (Ra) | GE | OSRAM | Philips |
|---|---|---|---|---|---|
| 2900 | 79 | 51 | Warm White | Warm White | Colour 29 |
| 3500 | 83 | 54 | White | White | Colour 35 |
| 4000 | 79 | 67 | Cool White | Cool White | Colour 33 |

* based on OSRAM T8 58W

### Triphosphors

In the 1980s narrow band phosphors became available and a combination of three phosphors give a good white colour with approx. 10% more light than the halophosphates. There is an improvement in the red and blue rendering, but the lamps cost is higher.

Typical products:

| CCT (K) | Efficacy(l/W) * | CRI (Ra) | GE | OSRAM | Philips |
|---|---|---|---|---|---|
| 3000 | 93 | 85 | Polylux 830 | Lumilux Warm White | Colour 83 |
| 3500 | 93 | 85 | Polylux 835 | Lumilux White | Colour 835 |
| 4000 | 93 | 85 | Polylux 840 | Lumilux Cool White | Colour 84 |

*based on GE T8 58W

### Second Generation Triphosphors

These use the same triphosphors but with an extra coating which prevents mercury contamination of the tube glass wall, which otherwise would darken the glass and reduce the mercury pressure reducing light output.

Typical products:

| CCT (K) | Efficacy(l/W) * | CRI (Ra) | GE | OSRAM | Philips |
|---|---|---|---|---|---|
| 3000 | 90 | 85 | Polylux XL 830 | Lumilux Plus Warm White | Super Colour 830 |
| 3500 | 90 | 85 | Polylux XL 835 | Lumilux Plus White | |
| 4000 | 90 | 85 | Polylux XL 840 | Lumilux Plus Cool White | Super Colour 840 |

*based on OSRAM T8 58W

The second generation triphosphor lamps have the same light output and colour rendering but improved lumen maintenance through life.

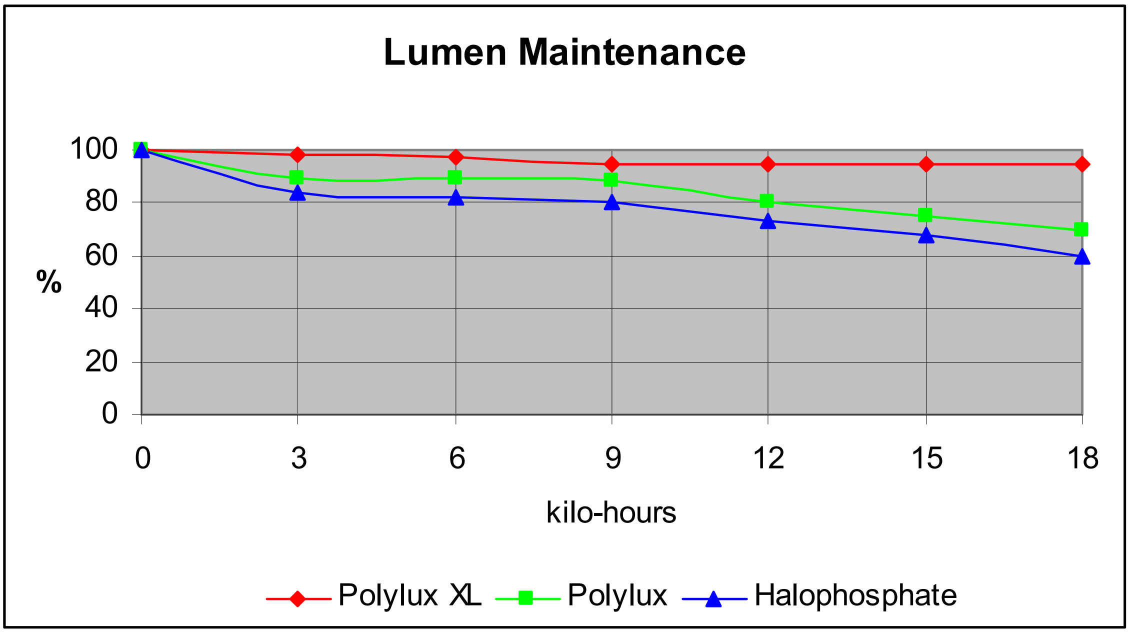



Fig 36 Fluorescent lamp lumen maintenance factor. (LLMF)

The second generation lamps are gradually replacing the earlier types. One significant advantage is with only 5% loss in light output spot replacement of lamps can be continued for as long as is economical as the difference between new and old lamps will not be noticeable.

Fig 37 CRI of 80+ recommended.

The recent (February 2002) publication of the New Lighting Code by the Society of Light and Lighting calls for a minimum CRI of 80 for interior lighting with very few exceptions. This means the use of halophosphates is no longer recommended as good lighting practice. All new installations and the group replacement for existing installations should be with tri-phosphor fluorescent tubes.

Tri-phosphor tubes are also specified in the Building Standards for Scotland, but strangely not in the Building Regulations for England and Wales.

## Cathodes

Fluorescent tubes are properly called "hot cathode tubular fluorescent lamps" because the cathodes are heated as part of the starting process. The cathodes are tungsten filaments with a coating of barium carbonate. When heated this coating will provide additional electrons to help start the discharge. This emissive coating must not be over-heated as lamp life will be reduced.


Fig 38 Red cold cathode installation.

Not normally used for general lighting, there are "cold cathode" lamps which do not require this pre-heating but rely upon a much higher voltage to establish the discharge. (Fig 38) Such lamps are widely used for exterior commercial signage commonly called neon lighting because some have a neon gas filling to give a strong red colour.

## Glass tube

The lamps use soda lime glass as the operating temperature is not high. This glass is a poor transmitter of UV, so little harmful radiation is emitted outside the lamp. The low surface temperature of the lamp enables plastic materials to be used in the construction of luminaires. (Fig 39)

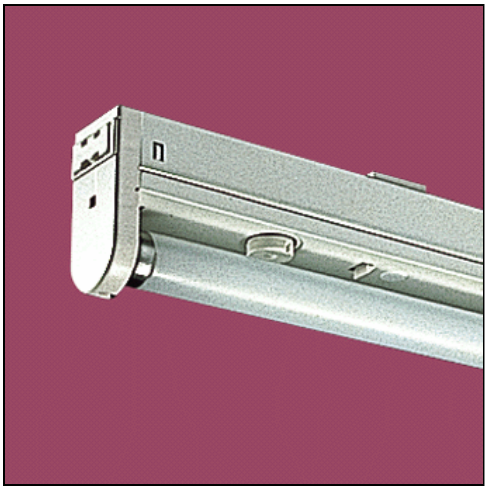


Fig 39 Plastic end cap for fluorescent fitting.

The diameter of the fluorescent tube is measured in eighths of an inch like many other bulb shapes. Over the years lamps have become slimmer and wattage for a given length reduced.

## Mercury dose

The amount of mercury required is small, typically 12mg. The latest lamps are using a mercury amalgam which enables closer dosing control using only 5mg. Reduction of the mercury content is important as there is future legislation which will limit the disposal of fluorescent lamps to designated landfill sites and transported only by registered carriers.

The amalgam enables the optimum mercury pressure to be sustained over a wider temperature range. This is useful for exterior lighting and also for compact recessed luminaires.

Amalgam lamps are not compatible with all emergency lighting circuits and this aspect should always be checked with the control gear manufacturer. Clear instructions about replacement lamps must be given to those maintaining the emergency lighting system.

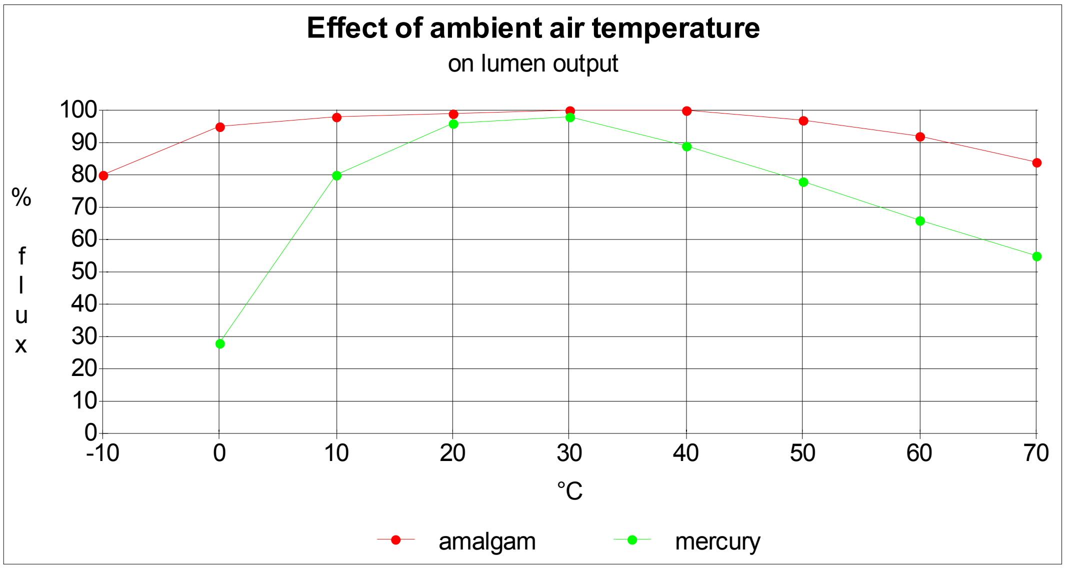



Fig 40 Typical performance of compact fluorescent with different dosing.

Note that fluorescent tubes give their maximum performance in ambient temperatures of approx. 25°C. The exception is T.5 lamps which because of the anticipated reduced luminaire size give optimum performance at 35°C.

## Temperature sensitivity

Because the fluorescent tube has a low gas pressure this will change with slight variations in temperature. Both hot and cold conditions will cause the light output to decrease and below about -10°C it will be difficult to start fluorescent lamps. Luminaire design should ensure that the lamps operate as close to the bulb temperature of 40°C.

Argon or Krypton gas in the lamp helps to establish the discharge before the warmth of the lamp provides the full mercury pressure. Although the fluorescent lamps gives a useful amount of light as soon as it is switched on, it will take up to 20 minutes before full light output is produced. When taking light meter readings always allow sufficient time for the tubes to reach full light output.

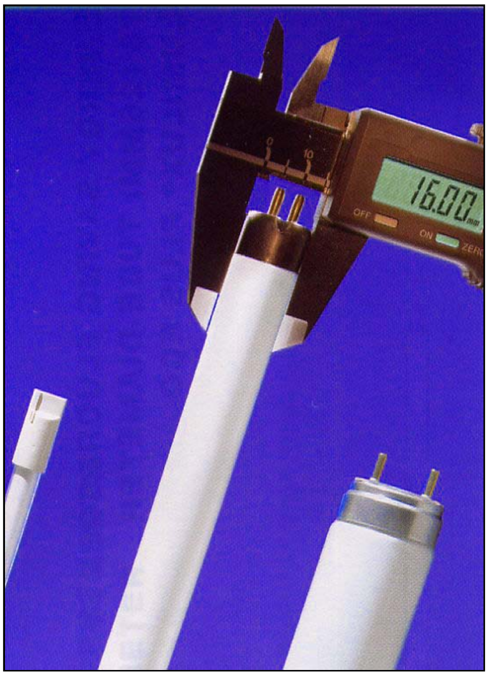


Fig 41 T.2, T.5 and T.8 fluorescent tubes. *Courtesy of Osram*

## Tube Diameter

The first lamps were 1½ inches in diameter. More recently the tube diameter has been reduced to 1 inch. The accepted convention in the lamp industry is to describe the diameter in eighths of an inch and this is used world wide. Tubes are thus T.12 or T.8

The T.8 tubes were deliberately made the same length as their T.12 predecessors and the bi-pin caps had the same pin spacing. This was to allow T.8 lamps to be used in luminaires originally designed for T.12 lamps. Note that 8ft lamps are only available in T.12.

In 1995 a range of even slimmer tubes T.5 was introduced, with three major changes.
Shorter length to fit within metric modules of 600, 900, 1200 and 1500mm.
Designed to operate only with electronic high frequency control gear.
To operate at a higher ambient temperature without loss of light output.

These lamps cannot be retro-fitted and require dedicated luminaires and control gear. The slimmer lamps work best at a higher voltage than can be provided by conventional switch start circuits and this is one reason why electronic control gear is needed. These are all the existing electronic benefits:

- higher efficacy,
- no discernible flicker,
- reliable starting,
- prolonged lamp life
- quiet operation.

T.2 fluorescent tubes have also been introduced. These changes are part of the continuous development and increased efficacy of fluorescent tubes.

**Changes to 1500mm (5ft) fluorescent tube**

| year | Dia | Power | Colour | lumens | efficacy |
|---|---|---|---|---|---|
| 1961 | T.12 | 80W | White | 4500 | 56 l/W |
| 1966 | T.12 | 65W | White | 4900 | 75 l/W |
| 1983 | T.8 | 58W | White | 5100 | 88 l/W |
| 1983 | T.8 | 58W | Tri-phosphor | 5400 | 93 l/W |
| 1995 | T.5 | 49W HO | Tri-phosphor | 4900 | 100 l/W |
| 1995 | T.5 | 35W HE | Tri-phosphor | 3650 | 104 l/W |

In just over 30 years the efficacy has almost doubled. Note that two versions of the T.5 lamp range are included in the above table. This is because there are two ranges of wattages for this new lamp.

HO stands for high output and the aim is the maximum light output for a given physical lamp size, whereas HE is for high efficiency and the maximum lumens per Watt have been achieved.

New T.5 power ratings

| | HO | HE |
|---|---|---|
| 550mm | 24W | 14W |
| 850mm | 39W | 28W |
| 1150mm | 54W | 28W |
| 1450mm | 49W | 35W |

In some cases maximum light output per luminaire can have a significant effect on the capital cost, whereas in other situations the lowest possible operating costs are more important. The optimum length for the T.5 lamp is 1200mm or less which is why the 1450mm HO lamp is a lower wattage than the 1150mm size.

## Lamp disposal

Fluorescent lamps if broken may release phosphor and cathode powders that are contaminated with mercury. Inhalation of this dust must be avoided and face masks should be worn when breaking lamps. Although the amount of mercury in each lamp is small, the disposal of large quantities should only be to suitably licensed containment landfill sites, selected in consultation with the Local Environment Agency Waste Regulations Office. European Directives are due to be implemented and UK legislation introduced.

## Lampholders

The conventional lampholder is a simple bi-pin at each end. Some American lamps use recessed contacts.

## Life

Fluorescent tubes have a typical life of 10,000 to 15,000 hours. Apart from physical failure the light output reduces through life and so there is an economic life where it is better to change the lamp since although the light decreases the electrical consumption remains the same. With the latest versions the lighting performance is much better maintained through life and so the case for bulk replacement of fluorescent tubes does not have the same economic advantage.

The life of fluorescent tubes is affected by the frequency of switching and the type of control gear used. This is because the different starting procedures erode the cathode coating at different rates.

Typical values of average lamp life ('000 hours) with 50% survivors, in brackets with 90% survivors.

| Freq. | 50Hz | 50Hz | HF | HF |
|---|---|---|---|---|
| gear | lag | lead | cold/start | warm/start |
| continuous | 19 (16) | 16 (11) | 18 (14) | 20 (17) |
| 12 hours | 18 (15) | 15 (10) | 17 (13) | 20 (17) |
| 3 hours | 15 (12) | 12 (7) | 13 (10) | 17 (15) |
| 1 hour | 12 (9) | 9 (6) | 7 (5) | 14 (12) |
| 15 min | 6 (4) | 4 (3) | 2 (1) | 12 (10) |

## Control Gear

All fluorescent lamps require control gear for two separate reasons.

Firstly the fluorescent tube has a 'negative' resistance. When current passes through the lamp this generates free electrons which enable the lamp accept a higher electrical current. If left to its own devices the lamp current would continue to rise until the weakest part of the lighting circuit failed. An external ballast or choke is necessary to stabilise this lamp current.

Secondly the fluorescent lamp is too long to start reliably from the standard mains voltage (230V). It is necessary to preheat the cathodes, which as described earlier are coated, and when heated, provide extra electrons which enable the arc to be established.

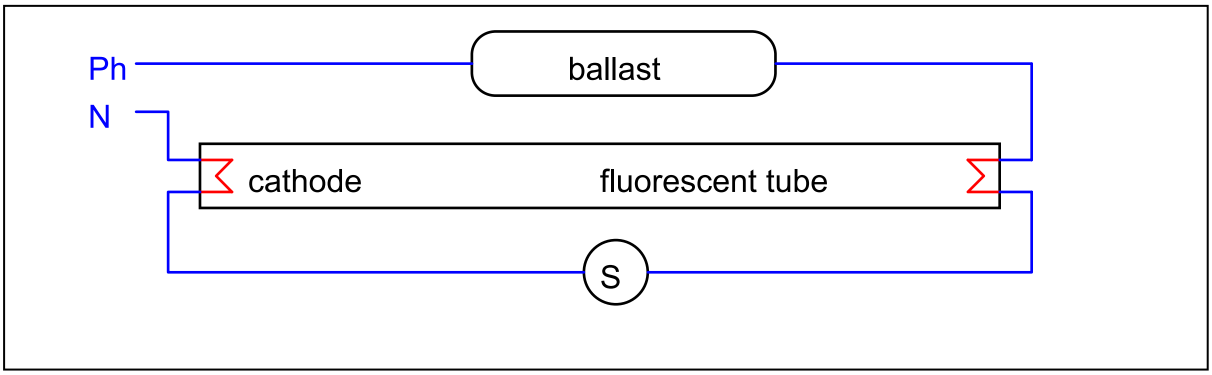



Fig 42 Basic fluorescent lamp control gear circuit.

When switch S is closed the two cathodes are in series and the current passing through heats the electron emitting material. After a short delay of about 1 second the switch S opens and if sufficient electrons have been produced the electrical current flows from one cathode to the other and the tube has 'struck'. Initially the current flows through the argon gas but the heat from the discharge will vaporise the mercury and the lamp will reach a stable condition after about 15 minutes. Once the arc has been created the starter S plays no further part in the operation of the lamp.

The tube is in series with the ballast and this controls the current that flows through the tube.

The starter switch can be a simple bimetallic switch which if the tube fails to 'strike' first time will repeat the starting sequence. There are also more sophisticated electronic starters which control the preheating so that the lamp always starts first time. These devices can also include the ability to sense a failed lamp and will automatically switch off rather than continue to attempt to start and prevent that irritating flicker.

Electronic control gear will improve lamp life because the starting process is "softer" so the cathode coating erodes more slowly. Note that not all electronic circuits include "soft starting". There are cheaper "cold start" versions which can reduce lamp life (see table above). Also most electronic circuits use the improved efficacy to give the same light output with reduced input power. Under running the lamp will increase life.

## Induction lamps

The induction process can be likened to a cordless telephone. The energy required to operate the lamp is transmitted via an antenna at radio frequencies. This electromagnetic radiation will set up eddy currents in the lamp which can be used to create light. There is no hard wire connection to the light bulb and this fundamentally changes the bulb design.

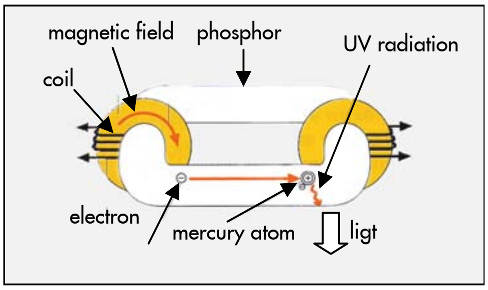



Fig 43 Induction lamp.
*Courtesy of Osram*

In theory induction can be used for incandescent and discharge lamps, but the only commercial induction lamps are based on the fluorescent discharge. The bulb contains a low mercury pressure and is phosphor coated.

The production of light is exactly the same process as the conventional fluorescent tube. The only difference is the transfer of electrical energy to within the lamp.

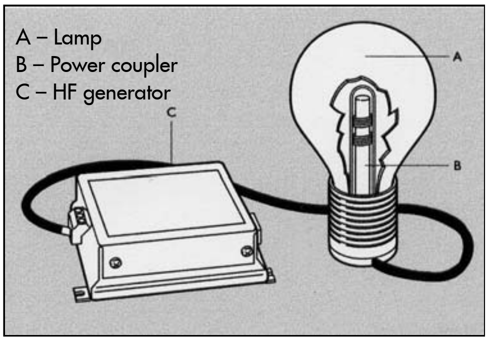



Fig 44 Illustration of Philips Master QL.
*Courtesy of Philips Lighting*

As there are no cathodes or filaments the lamp construction is simplified and no wires have to penetrate the glass wall. Also there is no cathode coating to erode and induction lamps are capable of very long life independent of switching frequency. Currently lamp life is determined by the durability of the electronic components used.

Philips QL lamps (55 and 85W) have separate control gear and claimed lamp life is 60,000 hours. GE Genura is a smaller lamp (23W) with integral control gear contained within the cap and lamp life is about 15-20,000 hours. The Osram Endura lamps (100 and 150W) are larger and uses external induction coils and ballast. Rated lamp life is 60,000 hours.

All three lamps use tri-phosphor coating and CRI of 80+.

## Compact Fluorescent lamps

Technically these operate on the same principles as the linear fluorescent lamps. Originally introduced as a high efficient replacement for the domestic lightbulb the range has been expanded to include lamp suitable for the commercial market place.

The aim was to reduce the overall size to that of the tungsten filament lamp. Early versions did not achieve this objective although the later versions are much closer. (Fig 45)

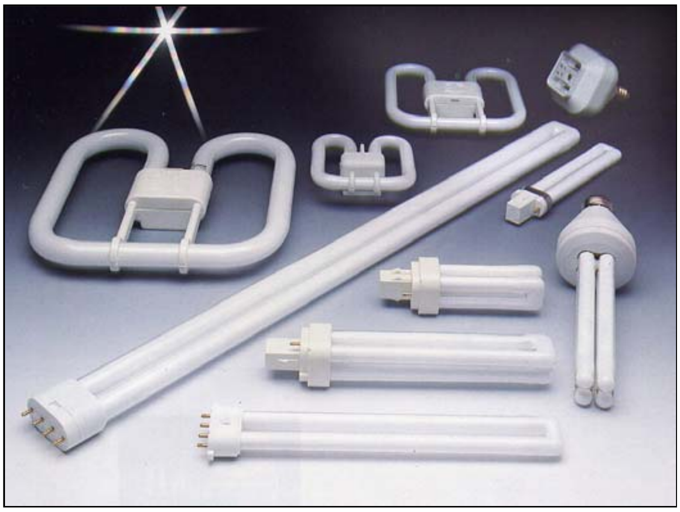


Fig 45 Compact fluorescent lamps. *Courtesy of GE Lighting*

The glass tubes use bends, hoops, parallel limbs and even coils to make a shape as compact as possible but at the same time avoiding too much obstruction which reduces the light output. Whatever configuration there is a single discharge path between two cathodes.

### Tube Diameter

Slimmer tubes are used T.4 and T.5. This reduces the surface area of the tube and even though the compact fluorescent lamps are low wattage the brightness per unit area is almost twice that of linear lamps.
The higher luminous flux density means that

halophosphate phosphors proved unsuitable as they decay rapidly with the increased load. Consequently CFLs did not become a practical proposition until the more durable tri-phosphors were discovered in 1970s.

Philips launched their SL lamp in 1981 followed by Thorn 2D in 1982.

As all CFLs use tri-phosphors so it makes sense, when combining these lamps with linear versions in the same space, to use tri-phosphor lamps throughout to ensure consistent colour appearance and rendering.

**Glare and Shadows**
Because the CFLs are smaller, they are more likely to create glare and thus luminaires require more precise optical control. Also as CFL lamps approach a 'point source' hard shadows are created. It is only the linear fluorescent lamp that provides 'shadow-less' lighting.

**Integration of Control Gear**
The original aim was for the CFL to replace the tungsten lamp, so it had to include the necessary control gear, which was normally within the luminaire for linear lamps. This increased both the bulk and weight of the CFL.

There are now three CFL formats:

1) The fluorescent tube alone. This can be identified by a lampbase with four pins. This requires an external starter and ballast, just like the linear lamp. This format is suitable for the more complicated electrical circuits such for emergency lighting or dimming. (Fig 46)

2) The fluorescent tube and starter. In this case the lamp base has only two pins and only an external ballast is required. The integral starter may be electronic or a simple bimetallic type. The luminaire has a 'dedicated' socket and is only suitable for CFLs. (Fig 47)

3) The fluorescent tube, starter and ballast. This can be directly connected to the mains supply and the lampbase will be Bayonet Cap or Edison Screw. This is often called 'retro-fit' as it enables energy saving lamps to be applied to existing sockets. However the process is reversible and tungsten lamps may re-appear as a false economy. (Fig 48)

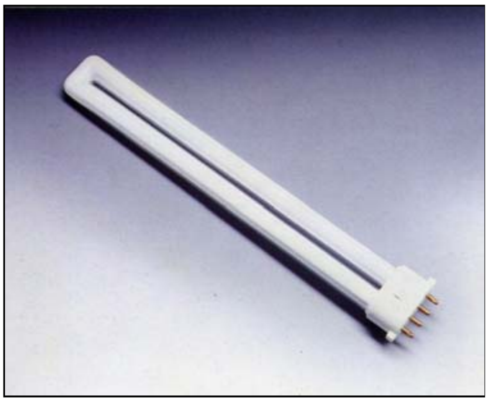


Fig 46 CFL – four pin.
*Courtesy of GE Lighting*

Fig 47 CFL – two pin.
*Courtesy of GE Lighting*

Fig 48 CFL – Retro-fit.
*Courtesy of GE Lighting*

A common application of 'retro-fit' integral gear CFL is for domestic use in luminaires originally designed for tungsten lamps. Although the CFL runs cooler and draws less electrical current there are potential problems. Retro-fit CFLs will be:

- larger, can foul shade brackets, not fit reflectors;
- heavier (GLS <40g, electronic CFL >100g, conventional CFL >400g);
- different physical shape, which may alter the light distribution.

It is important to ensure that the intended luminaire is capable of accepting these differences safely.

The diagrams below show schematically the electrical component differences. These differences are important when specifying the correct lamp and luminaire combination.

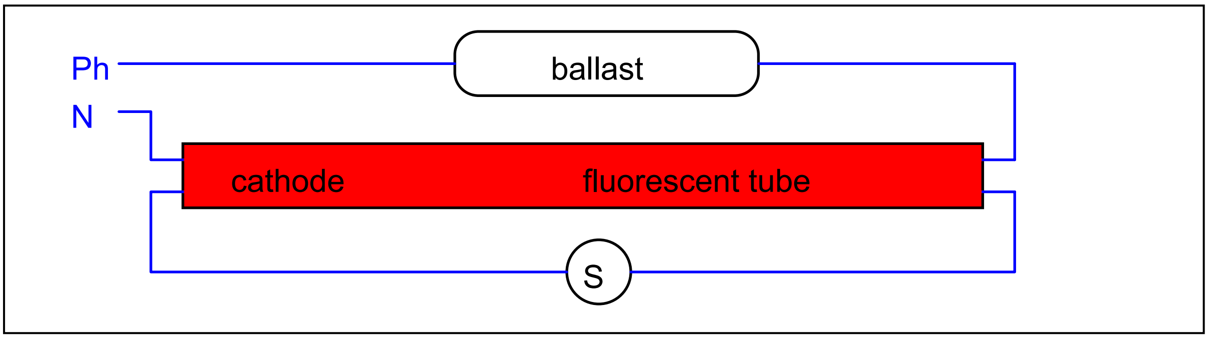



Fig 49 CFL requiring external control gear (Type 1).

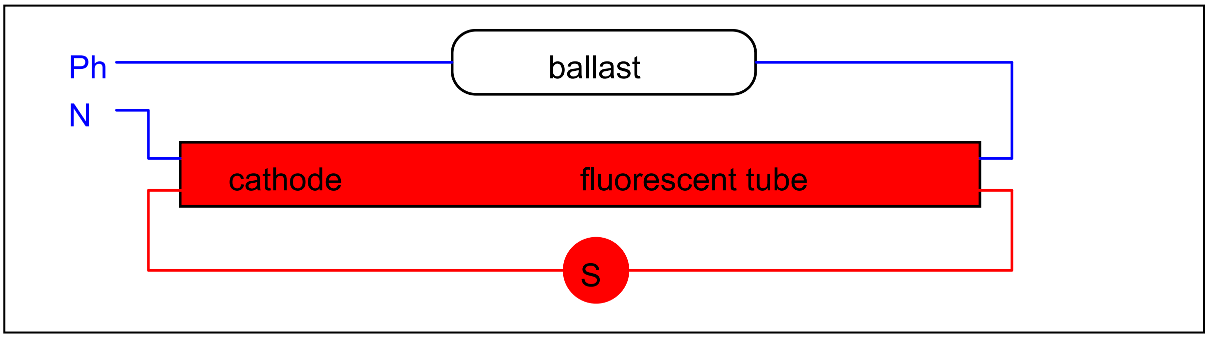



Fig 50 CFL with integral starter (Type 2).

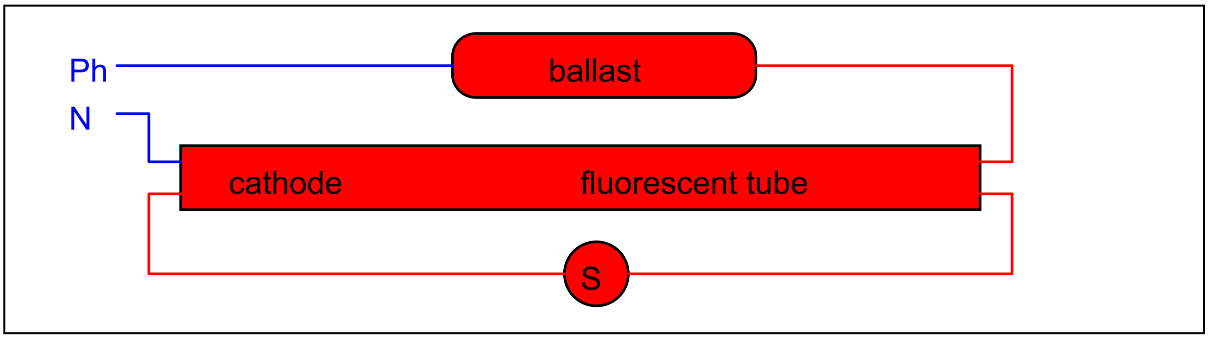



Fig 51 Retro-fit CFL requiring no external control gear (Type 3).

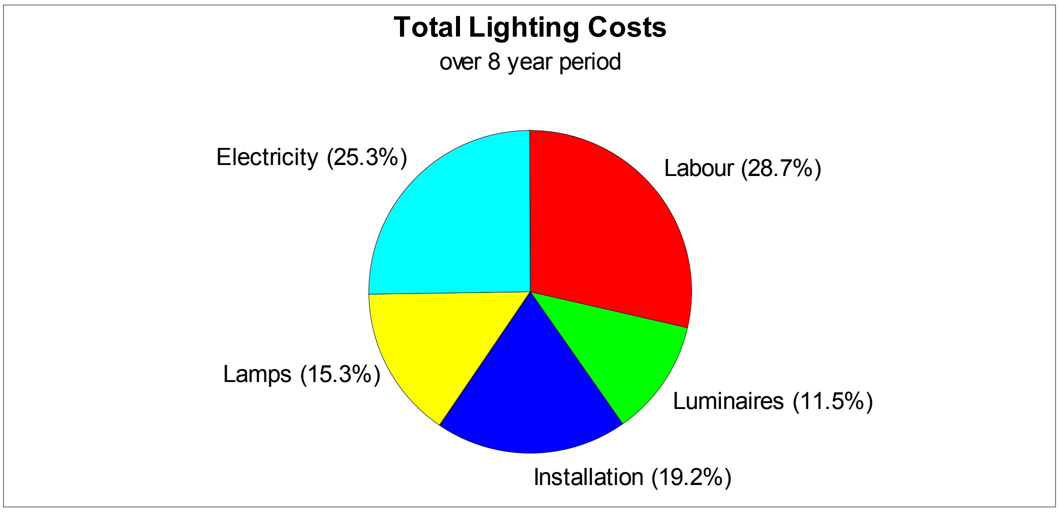
**Lamp Life**
The rated average life for CFLs is in the range of 8 - 10,000 hours, which is less than linear lamps.

**Lumen Maintenance**
Triphosphors are exclusively used but the complex shapes make it difficult to apply the two coatings required for the Second Generation linear lamps. There is a greater light depreciation to about 85% of initial lumens at the end of life.

**Lighting Costs**
This second example uses CFLs and shows the problems that can occur because of the limited light output.

Five twin 24W floodlights are necessary to match the lumens from two 500W tungsten halogen lamps. The lighting is operated for 3000 hours per year and the installation has an anticipated life of 8 years. Lamp life is 2000 hours and cost of electricity is 5p per kilowatt-hour.

| *Component Costs* | | TOTAL |
|---|---|---|
| Luminaires | 5 floodlights at £30 each | £150 |
| Installation | wiring and fixing 25 luminaires at £50 each | £250 |
| Lamps | total burning hours per floodlight is 2 x 3000 x 8 = 48000 hours<br>number of lamps used per floodlight is 48000/10000 = 5 approx.<br>5 x 5 = 25 lamps at £8 each | £200 |
| Labour | labour cost to change one failed lamp £15<br>25 lamps will cost | £375 |
| Electricity | Electrical load is 5 x 55W = 0.275 kW<br>electricity consumed 0.275 x 3000 x 8 = 6600 kWh<br>cost 0.05p x 6600 | £330 |
| | GRAND TOTAL | £1305 |




Using a relatively large number of expensive lamps produces high labour costs to maintain the installation. Thus the savings in energy consumption are offset by increased maintenance costs but the overall cost is still reduced by 28% compared with tungsten halogen scheme (see p 22).

*Questions 3*

1. Give two reasons why fluorescent lamps are so widely used in commercial buildings.

2. What is the purpose of the phosphor coating?

3. What is the efficacy (lumens/Watt) of the following tubes:
a) GE Standard Halophosphate T.8 18W White
b) GE Standard Halophosphate T.8 58W White
c) GE Polylux XL 835 T.8 58W White
d) Philips TL5 35W (HE) 840

4. List two factors which affect the life of fluorescent lamps.

5. Fluorescent tubes are designed to operate in an ambient temperature of 25°C. What happens if this temperature is:
a) higher
b) lower

6. List three advantages when fluorescent lamps are run on HF electronic control gear.

7. What type of phosphors is used for CFLs and why?

8. What is the difference between a CFL with a 2 pin lamp cap and one with a 4 pin cap? (Apart from 2 extra pins!)

# 4 Discharge Lamps

There are four main types used for general lighting and as they have different characteristics the following descriptions are subdivided in the four sections:

- Low Pressure Sodium (SOX)
- High Pressure Sodium (SON)
- High Pressure Mercury (MBF)
- Metal Halide (MBI)

Fig 52 Group of discharge lamps.
*Courtesy of GE Lighting*

## General characteristics

**How light is generated**
As for fluorescent tubes the electrical energy is transformed into radiated energy by the discharge through a gas/metal vapour. The spectral distribution of the radiated energy is based upon the chemical and the pressure/temperature of the discharge.

Discharge lamps generate most of their light direct from the discharge although phosphor coatings are used for the mercury types to improve the colour and increase efficacy.

**Control Gear**
The lamps require control gear to initiate the discharge and to stabilise the current flowing through the lamp. The most common type of circuit is the electronic ignitor circuit, which operates on the following principle.

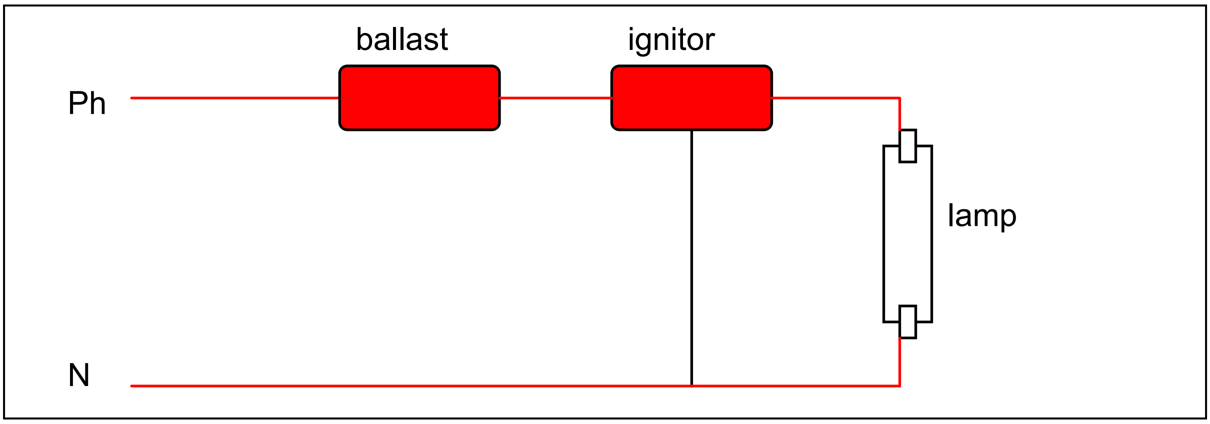



Fig 53 Discharge lamps – stage one.

Stage One - When switched on the current flows through the ballast and ignitor but the mains voltage cannot establish an arc across the lamp.

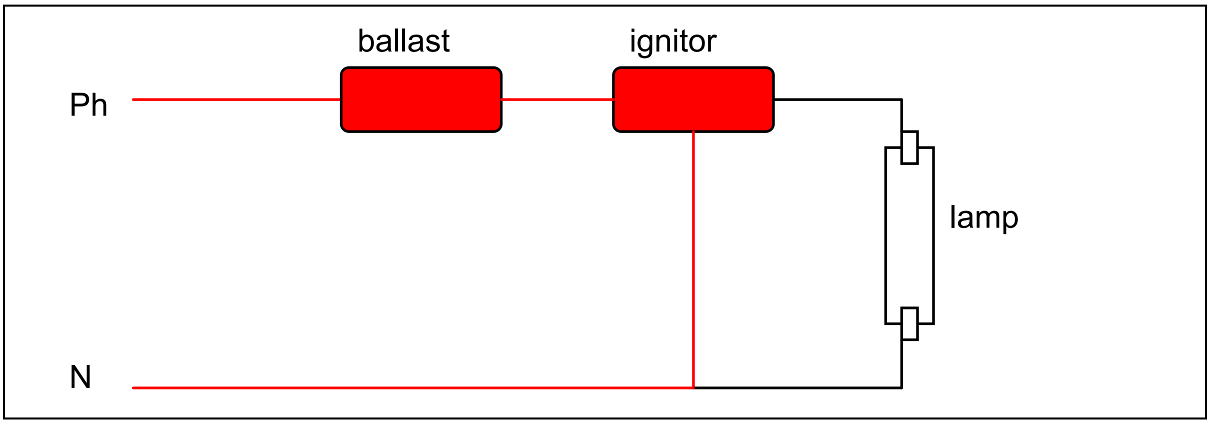



Fig 54 Discharge lamps – stage two.

Stage Two - The ignitor bypasses the lamps and stores energy.

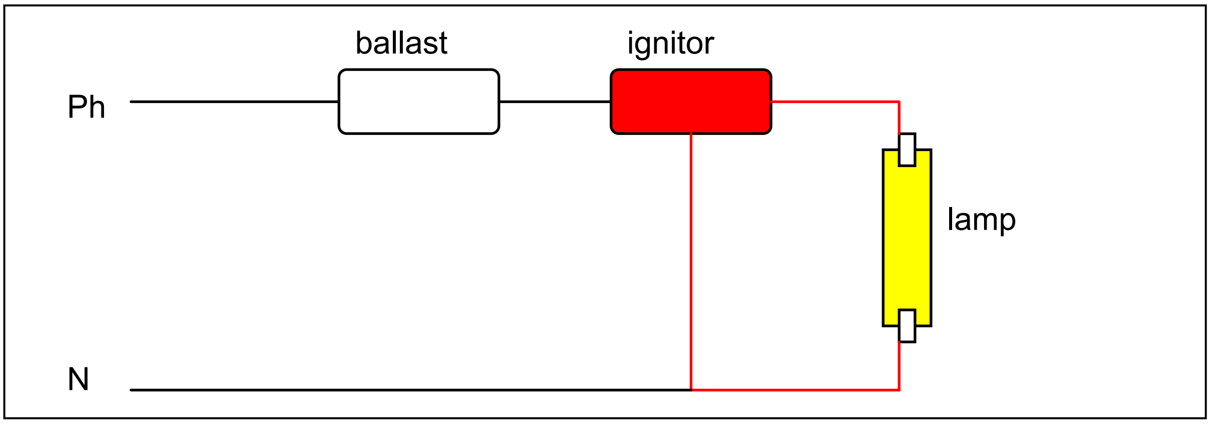



Fig 55 Discharge lamps – stage three.

Stage Three - After a few seconds the ignitor releases the energy it has stored, converted from mains voltage to between 2-4 kilovolts. This will start the arc across the lamp.

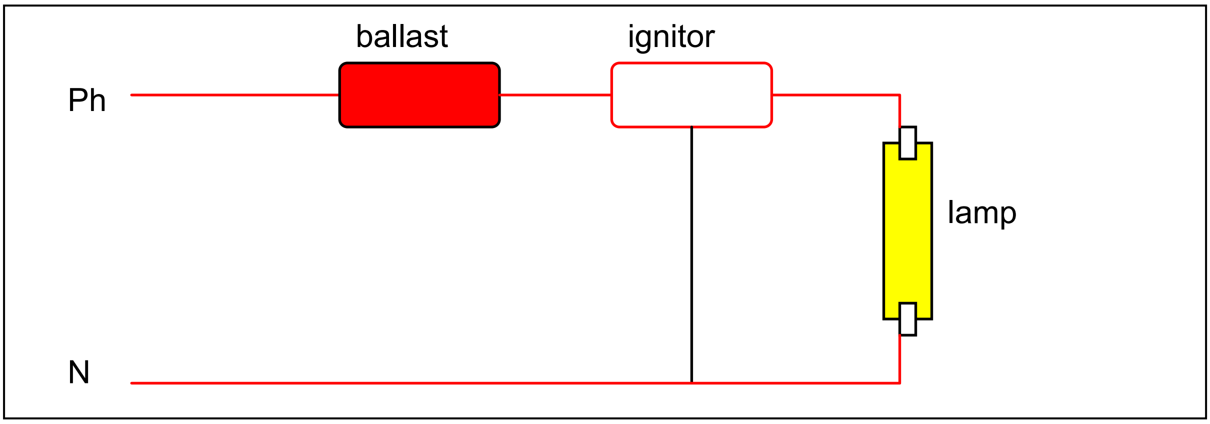



Fig 56 Discharge lamps – stage four.

Stage Four - The ignitor detects that current is flowing through the lamp and will not repeat the starting process. The ballast controls the current through the lamp.

**Dimming**
High pressure discharge lamps are not normally suitable for dimming. When the power is altered lamp life and colour is affected. Also the response may not be immediate.

**High Frequency operation**
This can be useful to avoid flicker. However high pressure discharge lamps do not increase in efficacy so there is no saving in power to offset the additional costs associated with electronics. Consequently the use of electronics has not proved as popular as for fluorescent lamps where a clear economic argument can be put.

**Bulb Shape**
With very few exceptions discharge lamps consist of an arc tube contained in an outer bulb. This enables the arc tube to be in a vacuum which provides thermal stability and prevents oxidation of the arc tube lead wires which can become extremely hot.

The outer bulb may be single ended, double ended, tubular, elliptical or reflector. The bulb may have phosphor coating, be frosted or clear.

**Orientation**
Some discharge lamps are only suitable of operation in certain positions. There is a suffix at the end of the lamp code which indicates these limitations. No suffix normally means universal burning which may be shown as /U. The more common variations are:

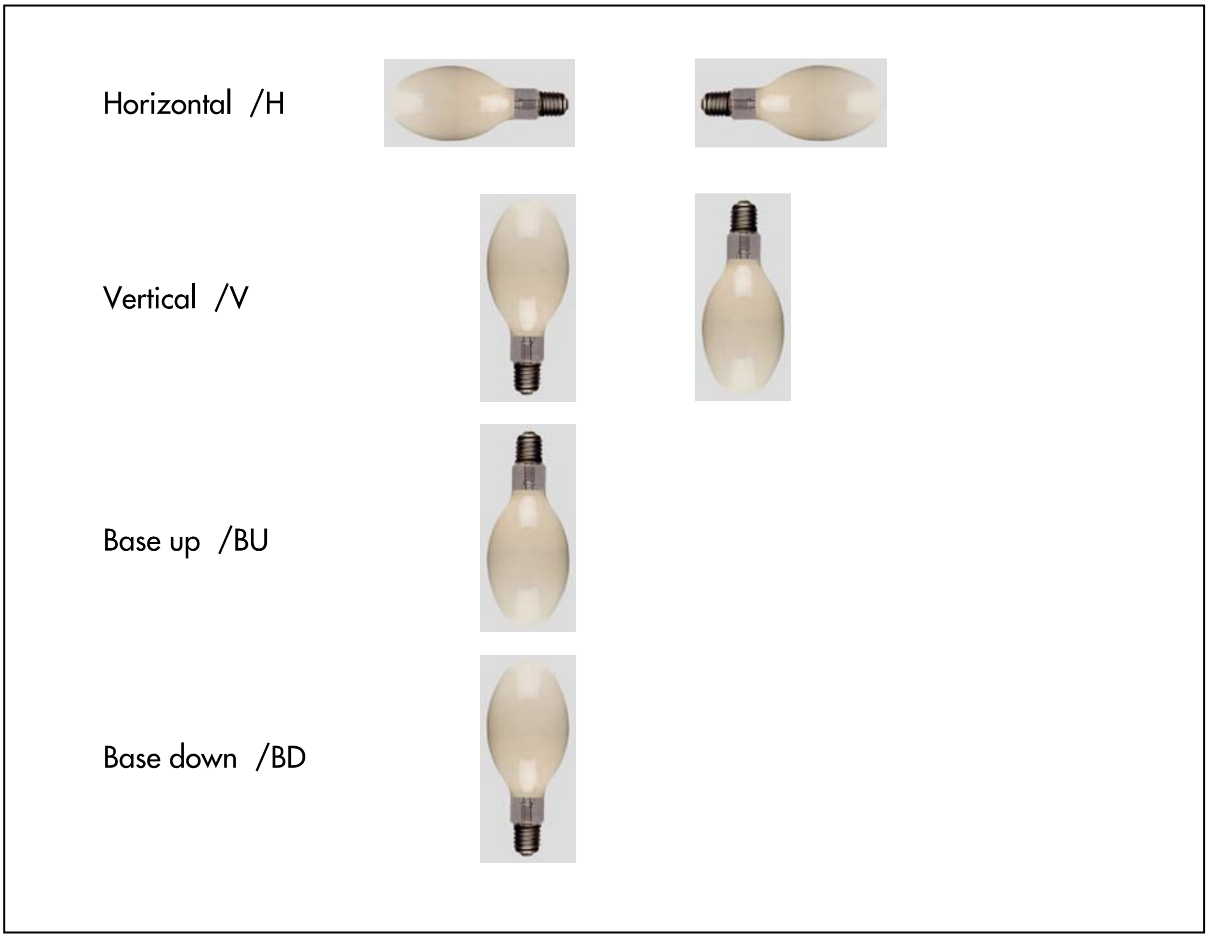



Fig 57 Discharge lamp orientation.

## Low Pressure Sodium Lamps (SOX)

**Lamp construction**
This is a low pressure lamp and has a similar geometry to PL-L fluorescent tubes. SOX lamps have a "U" tube which is made from a special ply glass with the inner surface providing protection against chemical erosion from the sodium metal. The tube contains about 400 mg of sodium, and neon gas. (Fig 58)

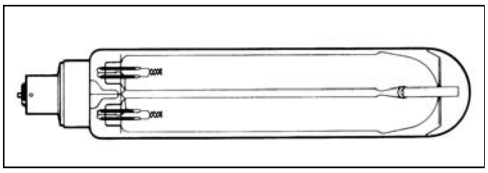


Fig 58 SOX lamp.

Starting is by applying a high voltage which initially creates a discharge in the neon gas. This is a characteristic red colour. The heat from this discharge gradually vaporises the sodium and the lamp colour changes to yellow as the light output increases.

The "U" tube is housed in an outer glass envelope which has a special infrared reflecting film and contains a high vacuum. Both help to keep the inner tube at a stable temperature even when the exterior ambient conditions may change.

**Lampholders**
SOX lamps use bayonet cap lamp holders because historically when these lamps were introduced in the early 1930s it was the only lamp holder in common use. However it is not well suited to such large and heavy lamps so the luminaires normally have additional lamp supports to keep the lamp at the optical centre and to prevent damage from vibration with column mounted street lighting equipment.

Fig 59 SOX lamp road lighting.

**Efficacy**
SOX lamps are the most efficient lamps available and the larger ratings provide 200 lumens/Watt. Where light for long periods is required at the lowest operating cost then these lamps remain popular although the yellow colour is a draw back. (Fig 59) For a long time the UK Government required trunk road lighting to use SOX lamps although high pressure sodium lamps are now acceptable.

**Colour**
The monochromatic yellow colour makes it impossible to distinguish colours and this limits the applications for this lamp type. However the roadway lighting market is sufficiently large to justify its continued existence.

**Lamp Life**

The average rated lamp life is 16,000 hours and over this period the light output falls by 20%.

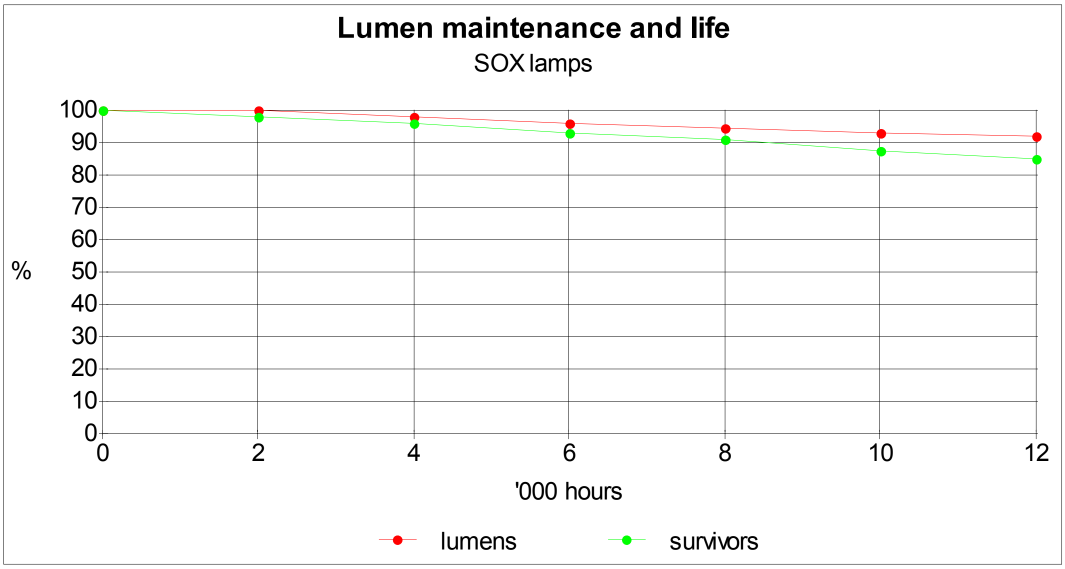



Fig 60 SOX lamp – lumen maintenance and life.

**Unique characteristics**

The lamp warm-up period is about 10 minutes and hot re-striking can be immediate or take up to 3 minutes. The largest practical size is 180W.

The sodium content requires careful handling during the disposal process as there is sufficient sodium to ignite should it come into contact with moisture. For this reason these lamps are not allowed to be used in the vicinity of flammable areas.

## High Pressure Sodium Lamps (SON)

**Lamp construction**
These are much more compact than SOX lamps. For example the 400W lamp has a discharge tube smaller than a pencil. Operating sodium at higher pressures and temperatures makes it exceedingly reactive and it was not until the 1960s that a suitable material called poly-crystalline alumina (p.c.a.), became available.

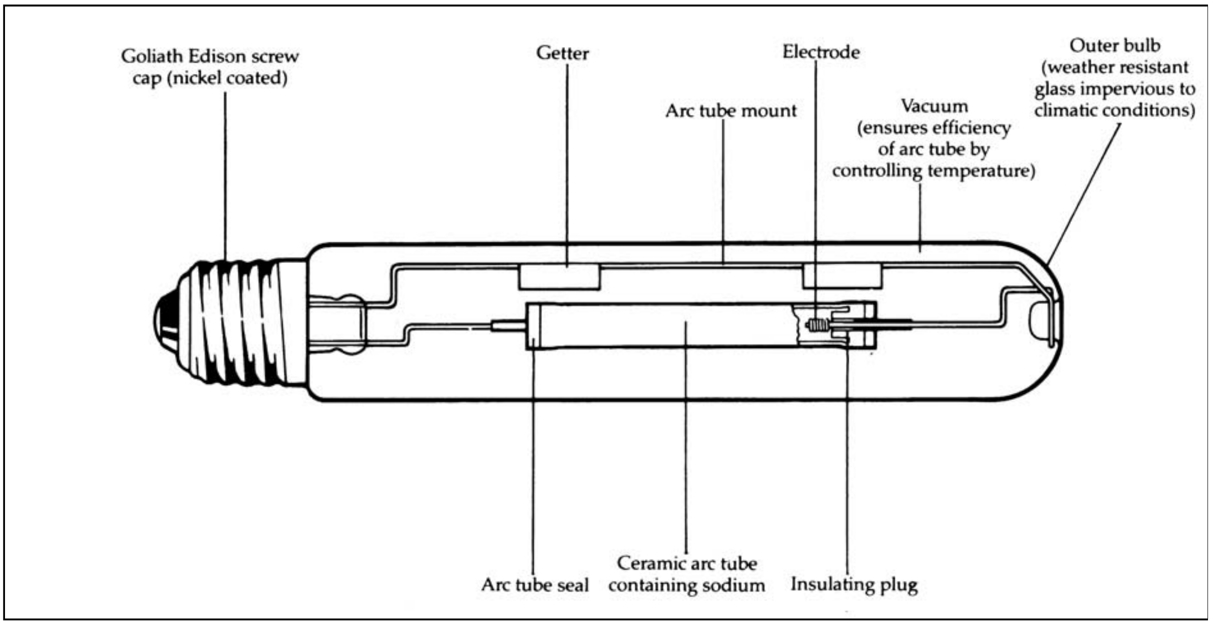



Fig 61 High pressure sodium lamp.

The discharge tube contains about 1-6 mg of sodium and also up to 20 mg of mercury. Recently there has been a move for mercury free SON lamps particularly for the street lighting market where large scale disposal of lamps containing mercury is now controlled by anti-pollution legislation.

The gas filling is xenon and both this gas and the mercury affect the efficiency of the lamp. Increasing the amount of xenon gas enables the elimination of mercury but the lamps become harder to start.

The arc tube is contained in an outer bulb which may be tubular or elliptical in shape, and the latter often has a diffusing coating to reduce glare. The SON lamps produce no significant UV radiation so the coating used is not a phosphor material. The outer bulb provides a vacuum around the arc tube to prevent heat losses and to create a stable operating thermal environment. The arc tube becomes so hot that oxidation of the seals would occur if they were not protected by the vacuum.

**Lampholders**
Most SON lamps use conventional ES and GES lamp caps. The lamps use ignitors which give starting pulses of 2 to 4kV and the lampholders must be capable of carrying these high voltages.

**Efficacy**
At high pressures/temperature the emitted radiation is a broad band either side of the peak yellow sodium line. The higher the pressure, the broader the band, but the lower the efficacy.

There are several types of SON lamps. The standard lamps have the highest efficacy at about 140 lumens/Watt but with indifferent colour rendering (CRI=25) as most of the radiation is close to the yellow. There are "deluxe" SON lamps with higher pressure giving 90 lumens/Watt but better colour rendering (CRI=60), and finally there are "White" SON lamps of 48 lumens/Watt and good colour rendering (CRI=80+).

For interior lighting most SON lamps do not meet the minimum colour rendering requirements laid down by Society of light and Lighting. The few exceptions are of relatively low efficacy and may not fulfil the minimum efficacy set by the Building Regulations. The use of SON lamps in the future is likely to the mainly for exterior lighting purposes. (Fig 62)

Fig 62 Channel Tunnel transport terminal.

**Colour**
In addition to the options of colour rendering mentioned above, the colour temperature increases with the pressure. Standard SON-2000K, Deluxe SON-2200K, White SON-2500K. All SON lamps provide "warm" colour appearance, and this can limit their application.

**Lamp Life**
The standard SON lamp combines long life of 24,000 hours with excellent lumen maintenance, 80% of initial lumens at the end of life. 'HO' or 'Plus' versions have increase light output and even better lumen maintenance of 90% at end of life.

Initial lumens - tubular lamps

| Rating | Standard SON | SON Plus |
|---|---|---|
| 70W | 6,000 | 6,500 |
| 100W | 9,600 | 10,000 |
| 150W | 15,000 | 17,500 |
| 250W | 27,500 | 33,000 |
| 400W | 50,000 | 56,500 |

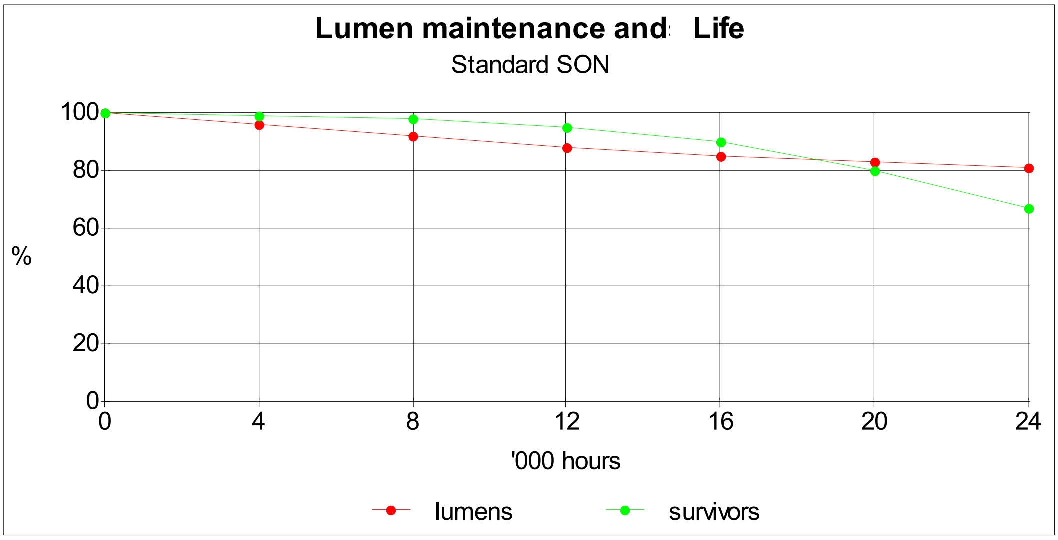



Fig 63 SON lamp – lumen maintenance and life.

The "deluxe" lamps have a shorter life of 14,000 hours but similar lumen maintenance.

The "White SON" lamps have an effective life of approx. 5000 hours and this is determined by colour shift (± 75K) rather than loss of lumens. However for less critical colour situations the lamps will function up to 10,000 hours when the lumen maintenance will be 70% of initial lumens.


Fig 64 SON lamps in industrial application.

**Unique characteristics**
SON lamps have a relatively slow warm-up period of 10 minutes but will re-strike within 60 seconds when hot.

**Lamp 'Cycling'**
The minimum operating voltage for SON lamps increases as the lamp ages. With an old lamp the ignitor will start the lamp, but as it warms up the lamp voltage rises until the supply voltage cannot sustain it and the lamp extinguishes. After it has cooled down slightly, the lamp will restart and the sequence is repeated. Some ignitors will detect this condition and refuse to restart lamps to avoid this irritating end-of-life condition.

## High Pressure Mercury (MBF)

**Lamp construction**
The arc tube containing the mercury (10-100mg) and argon gas is of quartz to withstand the high operating temperature. There is no cathode pre-heating and starting is by a third electrode adjacent to one of the main electrodes. Initially the discharge is across the shorter gap and when sufficient free electrons have been created the main discharge is established.

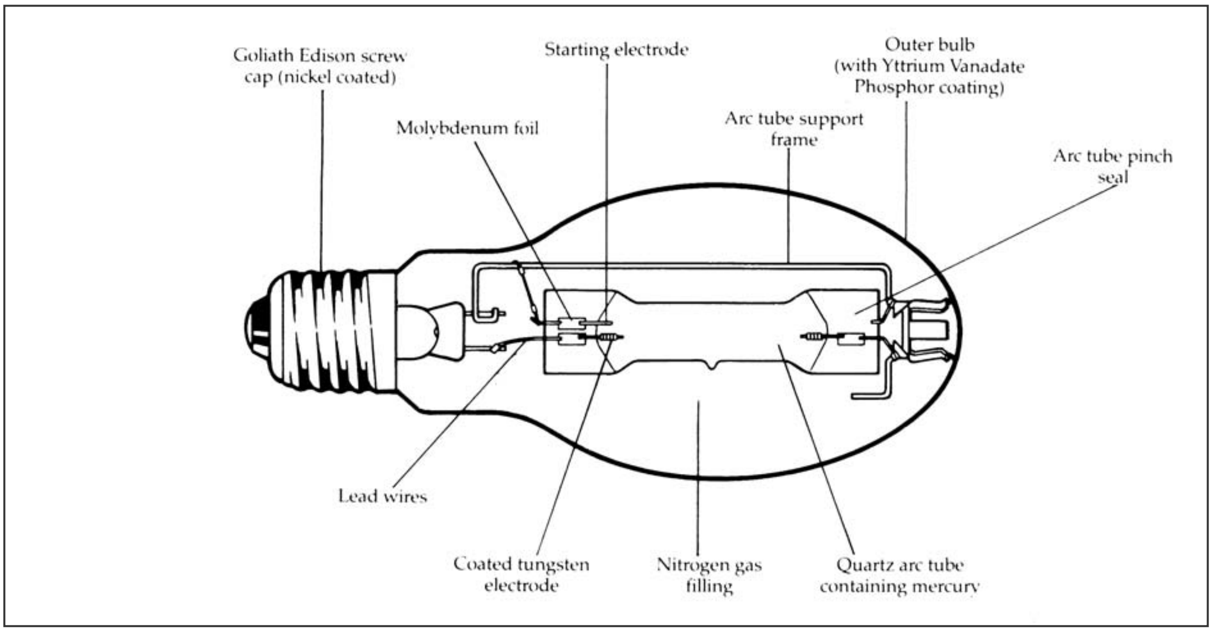



Fig 65 High pressure mercury lamp.

The mercury arc tube with the third cathode on the left is connected in series with a resistor to the right hand cathode. Initially the arc cannot be established across two main cathodes, but a local discharge is created between the third cathode and the adjacent main cathode. This generates free electrons and when enough are available the arc is struck as an easier route than via the third cathode and resistor.

There is an outer bulb and this is normally phosphor coated. The phosphor provides additional red light utilizing the UV from the mercury discharge to correct the blue /green bias of the light radiated directed from the mercury at high pressure. The outer glass envelope prevents UV radiation escaping from the lamp as well as containing a vacuum to maintain the correct arc operating temperature.

**Lampholders**
Most MBF lamps use ES or GES caps but there are some 3-pin BC caps. These were introduced when street lighting was by incandescent lamps in the mid 1930s and was to prevent the wrong lamp being inserted.

**Efficacy**
MBF lamps only produce 50-60 lumens/Watt and their use is now waning.

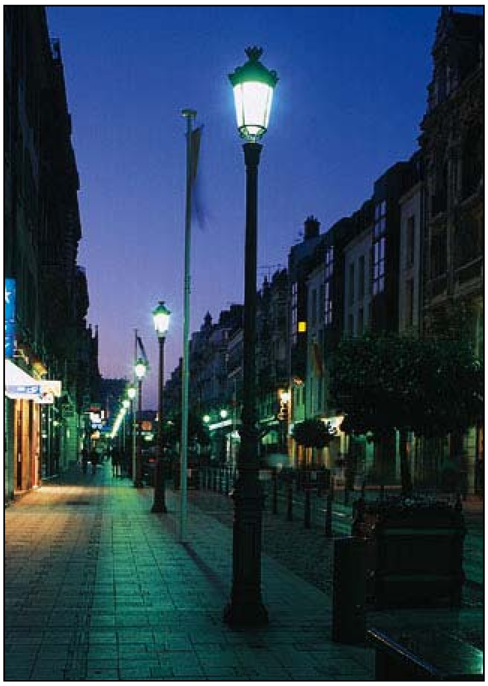


Fig 66 MBF lamps used in amenity lighting.

**Colour**
Although various options can be found, the colour appearance is 3400-3800K and the colour rendering only average (CRI=55). This is inadequate for interior lighting. (Fig 66)

**Lamp life**
Lamp life is long and varies with rating, from 16,000 to 24,000 hours. However at the end of life, the light output is only about 55% of initial. This poor lumen maintenance normally means that group lamp replacement with a shorter lamp life is necessary to maintain the required illuminance.

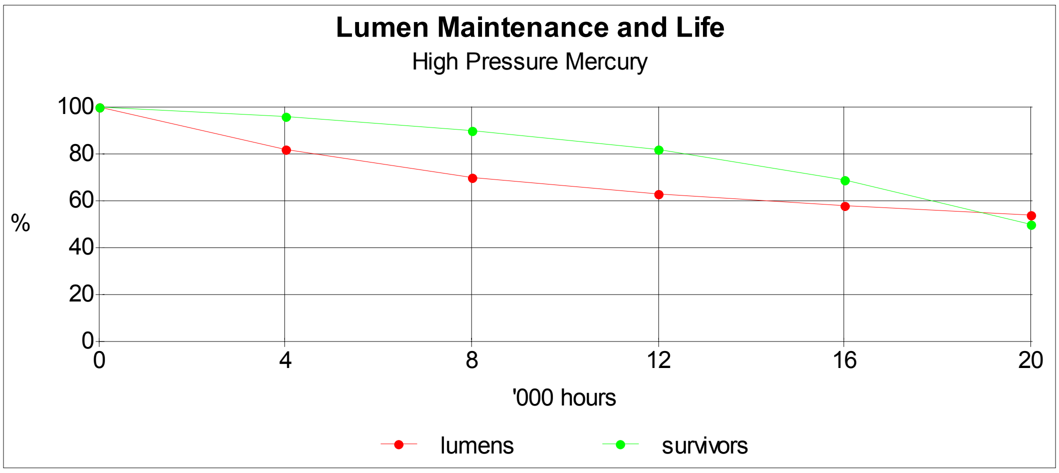



Fig 67 High pressure mercury lamp – lumen maintenance and life.

**Unique characteristics**
The third electrode makes the control gear simpler and cheaper and the physical lamp duration is good. MBF lamps can thus provide low operating and capital cost. Some countries have used this source widely for street lighting where the yellow SOX lamp was not considered appropriate.

## Metal Halide Lamps (MBI)

**Lamp construction**
MBI lamp uses a quartz arc tube similar to the MBF lamp but in addition to the mercury and argon gas there are a selection of metal halides. These can be chosen from a number of elements such as dysprosium, gallium, indium, lithium, scandium sodium, thallium, thorium and thulium. The purpose of the additional elements is to enhance the spectral content of the radiated light. With such a wide choice it is possible to produce a wide range of metal halide lamps with different colour characteristics in both appearance and rendering. There are special lamps suitable for TV and film studios as well as large floodlighting lamps for outside broadcasts such as major sporting events.

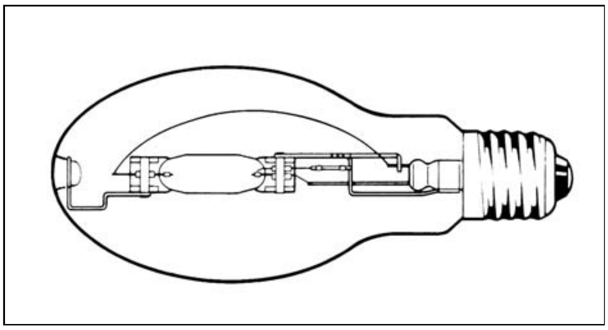


Fig 68 Metal halide lamp.

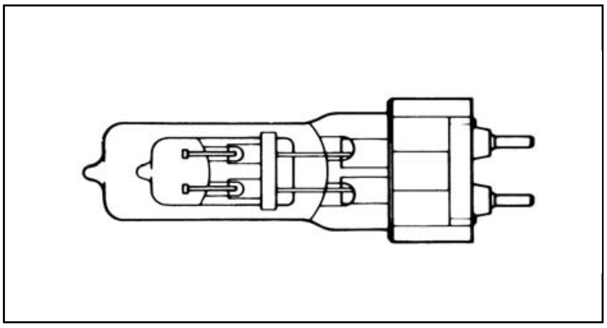


Fig 69 HIT lamp (Arcstream). [not to scale]

Some MBI lamps use the third electrode for starting, but others have only two electrodes, particularly the smaller lamps, and these rely on external ignition devices which create high voltage starting pulses.

Halides are used because it is easier to control accurately the mixture and dose. Also the halides act in a similar manner to the tungsten halogen cycle. As the temperature rises there is dissociation of the halide compound releasing the metal into the arc. The halides provide protection of the quartz arc wall from attack by the alkali metals.

NOTE: The electrical characteristics of the lamp depend upon the mixture of metal halides. Each lamp maker developed their own formulation and thus many lamps are not interchangeable. Always check that the lamp and control gear is a compatible combination.

The newer, smaller lamps used for commercial display lighting are produced to internationally agreed standards. The lighting industry has realised the importance of compatibility, and is now producing standards for the larger lamps as well.

**Lampholders**
As for SON and MBF lamps ES and GES caps are the norm but for the smaller lamps there is a specially designed bi-pin cap (G.12), more suited to compact luminaire design.

**Efficacy**
With a wide rating range from 35W to 10kW the efficacy varies but typically 80 lumens/Watt is achieved.

**Colour**
Metal halide lamps all improve upon the colour rendering of MBF lamps and the CRI can range from 70 to 90 depending upon the complexity of the halide mixture. Check carefully if the colour rendering is adequate for interior lighting.

For the same reason the colour appearance can range from 3000K to 6000K.

**Lamp Life**
The smaller "display" lamps have rated lives of 6,000 hours whereas the larger industrial lamps can be 20,000 hours. Some of the special floodlighting lamps are designed for maximum light output and have a life as short as 3500 hours. However this is related to usage and a major football ground may only play 100 games per season under lights, so the annual burning hours will be less than 1500 hours.

Where the best colour rendering is required a larger combination of halides is used and the proportions will shift through lamp life. The simpler mixtures are more durable.

Lumen maintenance is not as good as sodium lamps and MBI lamps will only produce typically 65% of initial lumens at the end of life.

Fig 70 MBI lamps used in retail lighting.

**Unique characteristics**
The choice of colour, size and rating is greater than any other lamp type.

Unlike sodium lamps the MBI lamps have a rapid warm-up from cold and can reach full output in 2/3 minutes. In contrast the hot re-strike may take 10-20 minutes. In a few cases special 'hot restrike' lamps and control gear are available. These use very high ignition voltages (20kV+) which call for extra protection within the lamp and the luminaire. They are only normally justified in exceptional circumstances such as American sports stadia where the electrical supply is subject to greater fluctuation than in the UK and the risk of a blackout has both safety and commercial implications (loss of prime time advertising revenue).

Fig 71 HIT lamps used in foyer.

**Latest developments**
There has been some cross fertilisation and the latest metal halide lamps are using arc tubes manufactured from p.c.a., the material used for SON lamps. This enables arc tube production to be of high precision and no loss of sodium will occur. These latest lamps are more consistent in colour both between individual lamps and through life. Typical examples are Philips CDM and GE Lighting CMH ranges. (Fig 72)

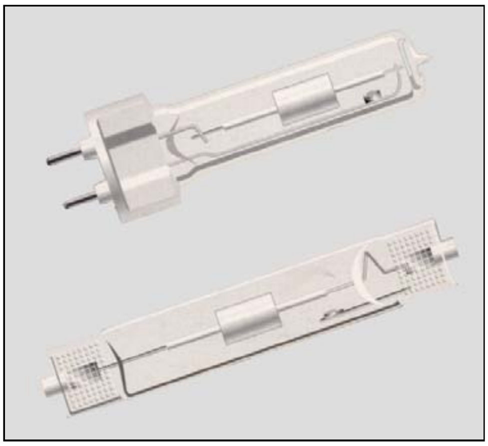


Fig 72 Philips CDM lamps. *Courtesy of PhilipsLighting*

**Control Gear Compatibility**
Initially the different operating characteristics required different control gear for each type of lamp. However to extend the retro-fit market there are lamps created for use with control gear designed originally for a different type of discharge lamp. Examples are:

SON lamps for use with MBF control gear
MBI lamps for use with SON control gear

It is important to check that the lamps are optically interchangeable.

**UV Reduction**
Some metal halide lamps incorporate an additional UV inhibiting sleeve surrounding the arc tube. This reduces the yellowing of plastic components and for open reflectors can prevent fading damage to objects illuminated.

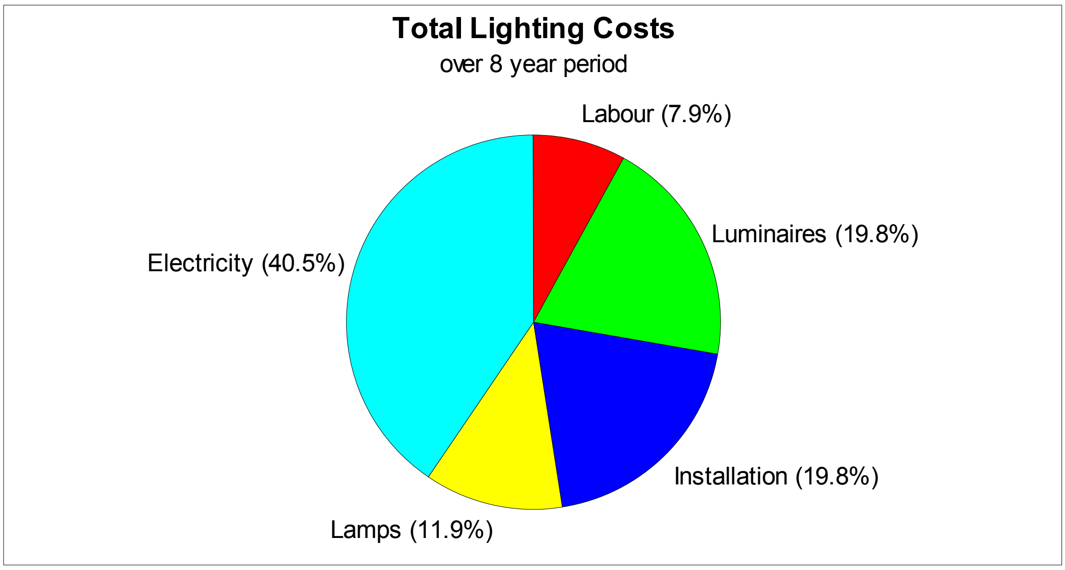
**Arc Tube Protection**
Metal halide lamps run at a positive arc tube pressure and for interior use should normally be contained in enclosed luminaires. Additional arc tube protection is provided for some lamps so that open reflectors can be safely used. The outer sleeve will contain any particles of hot arc tube should it fracture.

## Lighting Costs

The high pressure sodium lamp example is clearly the cheapest in the long run, provided the 'golden-yellow colour suits the shop front. It would not be the best option if the predominant colour for the shop was blue.

Three 70W high pressure sodium floodlights are used. As before the lighting is operated for 3000 hours per year and the installation has an anticipated life of 8 years. Lamp life is 24000 hours and cost of electricity is 5p per kilowatt-hour.

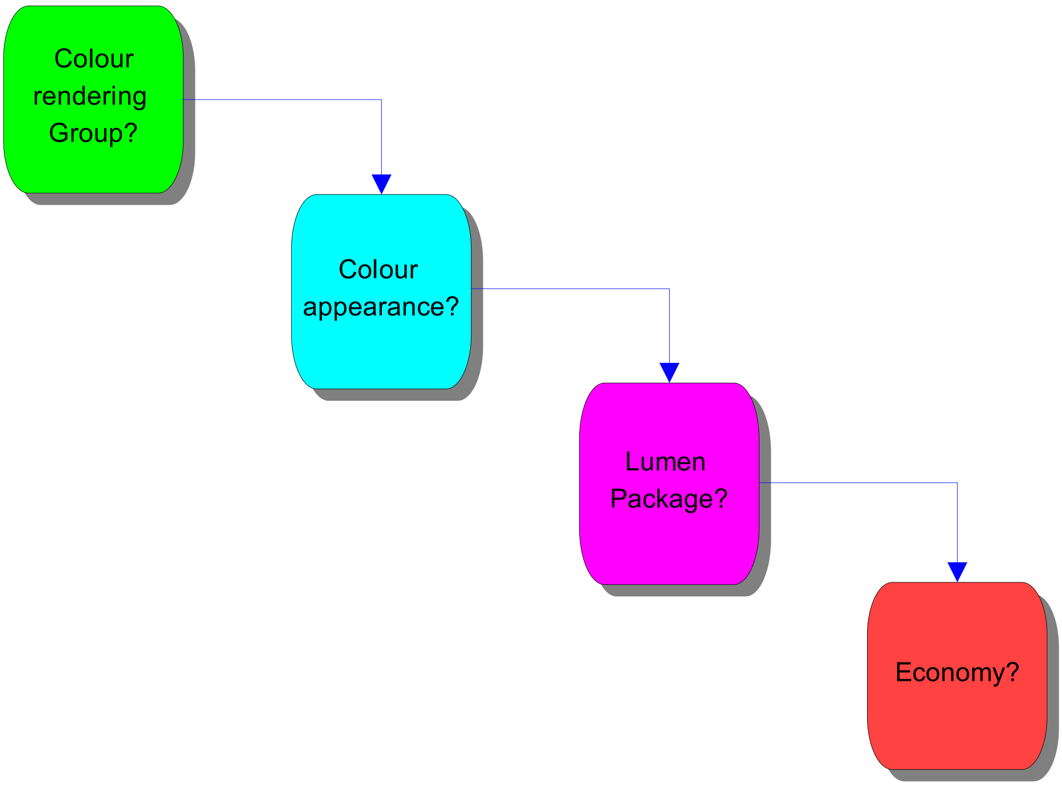
| *Component Costs* | | TOTAL |
|---|---|---|
| Luminaires | 3 floodlights at £50 each | £150 |
| Installation | wiring and fixing 3 luminaires at £50 each | £150 |
| Lamps | each socket will have total burning hours of 3000 x 8 = 24000 hours<br>therefore only 3 lamps will be required<br>3 lamps at £ 30 each | £90 |
| Labour | as the initial lamps will last the life of the installation only cleaning will be necessary at<br>£5 per fitting every 2 years<br>3 x 4 x £5 | £60 |
| Electricity | Electrical load is 3 x 85W = 255W<br>electricity consumed 0.255 x 3000 x 8 = 6120 kWh<br>cost 0.05p x 6120 | £306 |
| | GRAND TOTAL | £756 |




Selecting this SON option would be 58% cheaper overall than the tungsten halogen scheme outlined on page 22. However to achieve this saving would entail a threefold capital investment initially.

## How do you select the best discharge lamp?

There is no single answer to this question , but a logical approach is to ask four questions and find the answers by reference to simple graphical charts.



**Question 1. What Colour Rendering Group is necessary for the visual tasks to carried out satisfactorily?**
This will eliminate all lamps with inferior colour rendering. Lamps with superior colour rendering may be considered, but normally high colour rendering properties are only achieved at the expense of life and/or efficacy. There is usually no customer benefit in providing higher colour rendering than required. Normally lamps with CRI of less than 80 should not be considered for interior lighting. Check the recommendations given by the Society of Light and Lighting.

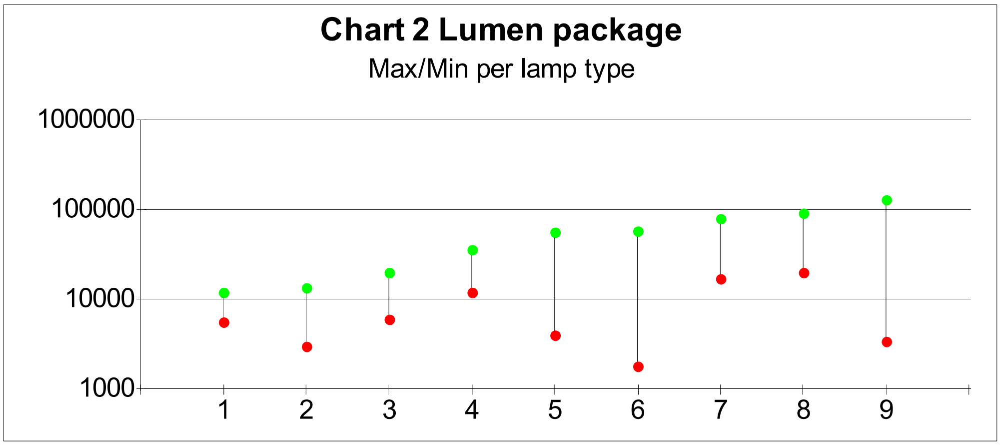
**Question 2. What colour appearance is desired?**
This is a subjective criterion although the following are useful guides.
- Warm colour appearance is more acceptable at low illuminance levels.
- Cool colour appearance is more consistent with daylight.
- Is the objective to provide contrast with existing or adjacent lighting?

**Chart 1 Colour Appearance vs Colour Rendering**

| Colour Group<br>Ra Index | Warm Appearance<br>< 3000K | Neutral Appearance<br>3000-4200K | Cool Appearance<br>>4200K |
|---|---|---|---|
| 1A Ra 90-100 | | CDM | Kolorarc Daylight<br>MH Super |
| 1B Ra 80-89 | White SON | CDM<br>CMH<br>(CSI) | MHN, (MHD) |
| 2 Ra 60-79 | SON Comfort<br>Lucalox Classique | Arcstream, MQI,<br>Kolorarc | (HPI)<br>(MBIL) |
| 3 Ra 40-59 | | HPL Comfort<br>Kolorlux | |
| 4 Ra 20-39 | SON<br>SON Plus<br>Lucalox HO<br>Lucalox Standard | | |

The lamp types shown in parenthesis are special types normally used for large scale floodlighting. The most suitable type of floodlighting luminaire may be the most important criterion and thus dictate the required lamp. These specialised lamps are not included in the following charts for this reason. For general lighting the answers can be found by applying the answers to the first two questions to the co-ordinates of Chart 1.

**Question 3. How many lamp lumens required?**
The exact answer is part of the detail lighting design but a rough approximation will help the initial assessment. Hence Chart 2 uses a logarithmic scale for light output. For example for 10,000 lumens then Arcstream(1) ,MQI(2) or ConstantColor(3) would be suitable, but for package approaching 100,000 lumens then Kolorarc(8) or Lucalox(9) would have to be considered.




| lamp | X axis ref | Lucalox HO | 5 |
|---|---|---|---|
| Arcstream | 1 | Kolorlux | 6 |
| ConstantColor | 2 | Kolorarc Daylight | 7 |
| MQI | 3 | Kolorarc | 8 |
| Lucalox Classique | 4 | Lucalox Std | 9 |

**Question 4. How long are the lamps in use?**
This question need only be asked if the previous three have not produced a single answer.

For less than 6 hours per day, light output and capital costs are likely to be the significant factors. However, the longer the burning hours per annum the more important features such as efficacy and lumen maintenance become.

**Chart 3 Durability index for GE Lamps**

| Index | Lamp Type | Rating(W) | lumens | life | Maint |
|---|---|---|---|---|---|
| 3623 | Lucalox HO | 400 | 56500 | 28500 | 0.90 |
| 3386 | Lucalox HO | 250 | 33000 | 28500 | 0.90 |
| 2993 | Lucalox HO | 150 | 17500 | 28500 | 0.90 |
| 2565 | Lucalox HO | 100 | 10000 | 28500 | 0.90 |
| 2387 | Lucalox Std | 400 | 50000 | 28500 | 0.67 |
| 2382 | Lucalox HO | 70 | 6500 | 28500 | 0.90 |
| 2100 | Lucalox Std | 250 | 27500 | 28500 | 0.67 |
| 2090 | Lucalox Std | 1000 | 130000 | 24000 | 0.67 |
| 2052 | Lucalox HO | 50 | 4000 | 28500 | 0.90 |
| 1910 | Lucalox Std | 150 | 15000 | 28500 | 0.67 |
| 1833 | Lucalox Std | 100 | 9600 | 28500 | 0.67 |
| 1637 | Lucalox Std | 70 | 6000 | 28500 | 0.67 |
| 1298 | Lucalox Std | 50 | 3400 | 28500 | 0.67 |
| 1127 | Lucalox Classique | 400 | 37000 | 14000 | 0.87 |
| 1121 | Lucalox Classique | 250 | 23000 | 14000 | 0.87 |
| 1056 | Lucalox Classique | 150 | 13000 | 14000 | 0.87 |
| 805 | Kolorarc | 400 | 39000 | 14000 | 0.59 |
| 760 | Kolorarc | 1000 | 92000 | 14000 | 0.59 |
| 743 | Kolorarc | 250 | 22500 | 14000 | 0.59 |
| 638 | Kolorlux | 1000 | 58000 | 20000 | 0.55 |
| 629 | Kolorlux | 700 | 40000 | 20000 | 0.55 |
| 619 | Kolorlux | 400 | 22500 | 20000 | 0.55 |
| 572 | Kolorlux | 250 | 13000 | 20000 | 0.55 |
| 554 | Kolorlux | 125 | 6300 | 20000 | 0.55 |
| 480 | Kolorarc Daylight | 1000 | 80000 | 10000 | 0.60 |
| 456 | Kolorarc Daylight | 250 | 19000 | 10000 | 0.60 |
| 420 | Kolorarc Daylight | 400 | 28000 | 10000 | 0.60 |
| 418 | Kolorlux | 80 | 3800 | 16000 | 0.55 |
| 336 | Arcstream | 70 | 5600 | 6000 | 0.70 |
| 336 | Arcstream | 150 | 12000 | 6000 | 0.70 |
| 319 | MQI | 70 | 6000 | 6000 | 0.62 |
| 313 | ConstantColor | 150 | 13500 | 6000 | 0.58 |
| 308 | ConstantColor | 70 | 6200 | 6000 | 0.58 |
| 298 | ConstantColor | 35 | 3000 | 6000 | 0.58 |
| 298 | MQI | 150 | 12000 | 6000 | 0.62 |
| 298 | MQI | 250 | 20000 | 6000 | 0.62 |
| 238 | Kolorlux | 50 | 1800 | 12000 | 0.55 |

Chart 3 gives a ranking of lamp type and rating using an arbitrary "Durability Index". Minor variations of bulb shape or colour have been ignored to prevent the table becoming too large. The higher the "Index" value, the more suited is the lamp for prolonged usage. Note that efficacy has been included because the cost of electricity consumed is normally the highest element in operating costs, so indirectly a high "Index" measures economy.

This table should only be used if there is still a choice after answering the first three questions. The index is not an officially recognised measure but is based upon:

- Lamp efficacy (lumens/Watt)
- Lumen maintenance (ratio lumens at end of rated life against initial)
- Rated lamp life (hours).

**Question 5. Do the lamps meet the requirement of the Building Regulations for interior lighting?**
Part L of the Building Regulations for England and Wales and Part J of the Building Standards for Scotland set out a range of calculations depending upon the type of building to determine the minimum acceptable energy efficiency for the complete lighting system. Note that these regulations apply not only to new buildings but also when a new lighting system is to be installed.

**Finally……**
Always check compatibility of the lamp and luminaires combination for correct:

- Lamp Cap
- Orientation
- Gear/Ignitor
- Protection required for UV radiation
- Enclosure required for exploding lamps.

The charts above were lamps selected from the GE range. Such charts can be tailored to your personal requirements and updated as new Thorn products extend the types of lamps that can be considered.

*Questions 4*

1. Name the two main metals used in discharge lamps.

2. If the lamp code includes the suffix '/U' what does this mean?

3. What is the main advantage of SOX lamps?

4. What is the main disadvantage of SOX lamps?

5. How does the life of SON Deluxe lamps compare with standard SON?
   a) shorter
   b) longer

6. Is the lumen maintenance of MBF lamps
   a) better than standard SON
   b) same as standard SON
   c) worse than standard SON?

7. Why does the MBF lamp have a third electrode?

8. How long does it take MBI lamps to run up to full light output?

9. Why have some metal halide lamps changed to p.c.a. arc tubes?

10. What is the minimum colour rendering index for interior general lighting?

# 5 Answers to Questions

*Questions 1*

1. GE Lighting, OSRAM and Philips Lighting.
2. Glass/quartz, tungsten, sodium, and mercury.
3. 40W.
4. Goliath Edison Screw.
5. 2 pins.
6. Green.
7. Spotlights.
8. Above 5300K.
9. Eight pastel shades.
10. ILCOS is an International lamp coding system.

*Questions 2*

1. Tungsten.
2. Candle, globe and reflector.
3. Lumens and Watts.
4. 20 lumens/Watt.
5. Tungsten halogen lamp
6. Colour temperature goes down.
7. 230V.
8. Electricity switched off and lamp cool.
9. Ra = 100.
10. Electricity cost.

*Questions 3*

1. Easy to provide uniform and shadow free lighting.
2. To convert UV into visible light.
3. a) 68, b) 83, c) 90, d) 104
4. Frequency of switching and control gear used.
5. a) and b) light output is less.
6. Higher efficacy, flicker free, reliable starting, longer lamp life, and quiet operation.
7. Tri-phosphor and used because it can withstand the higher load (Watt per unit length).
8. 2 pin lamp has internal starter, 4 pin lamp has external starter and ballast.

*Questions 4*

1. Sodium and mercury.
2. Lamp can be operated in any orientation (universal).
3. High efficacy.
4. Very poor colour.
5. Shorter
6. c) worse than standard SON.
7. Third electrode used in starting arc across a short gap.
8. From cold 2/3 minutes, when hot may be 10 – 20 minutes.
9. For higher precision of arc tube and no loss of sodium from arc tube.
10. Normally 80 or above.

# 6 Summary

The main lamp manufacturers supplying the UK market are:

- GE Lighting www.gelighting.com
- OSRAM www.osram.co.uk
- Philips Lighting www.philipslampsandgear.co.uk

Any lamp has to fulfil four main functions:

- match the available electrical supply
- Have a lamp base which matches the luminaire lampholder
- be of the correct physical dimensions for optical control
- provide the required quantity and quality of light

**Watts -** the power rating of a lamp is essential for the electrical designer to provide the correct wiring, switching and fusing.

**Volts -** lamps that are connected directly to the mains supply have to be of compatible voltage.

**Bayonet Cap -** limited to domestic lamps in the UK.

**Edison Screw Cap** - the rest of Europe favours this cap design.

**Bi-pin bases -** used for fluorescent and tungsten halogen lamps (G plus pin spacing in mm e.g. .G.13).

**Bulb shape and finish -** apart from the shape the surface finish can be varied from:

- clear
- diffuse (frosted)
- coated (opal or fluorescent)
- coloured
- reflective (choice of beam angles)

**Light Centre Length –** is from the bottom of the lamp base to the centre of the filament or arc tube.

**Light Output -** lumen is the measure of light emitted by a lamp and can be in any direction.

**Luminous Intensity -** this is the amount of light in a given direction and is measured in Candelas.

**Beam Angles -** beam angles are a simple way of describing light distribution.

**Efficacy -** this is a measure of the efficiency of the lamp expressed in lumens per Watt.

**Colour temperature -** a perfectly black object absorbs all visible radiation. The absorbed energy raises its temperature. At a steady temperature an equal amount of energy is radiated as absorbed. The radiated energy has a characteristic power spectrum and colour with any given temperature.

**Colour co-ordinates - t**he CIE colour triangle is a colour map based upon three primary colours near to red, blue and green. Two co-ordinates, x and y enable any point on the chart to be defined.

**Correlated Colour Temperature (CCT) –** colour temperature in K assigned to lamps which do not act as 'black bodies', which means all discharge and fluorescent lamps. Correlated means the nearest in x,y co-ordinates to a real black body on the CIE colour triangle.

**Colour Rendering –** the quality of realism given to colour under a light source.

**Colour Rendering Index** – number up to 100 assign to a lamp to give indication of colour rendering properties.

**Ultraviolet -** lamps which use quartz rather than glass can emit UV radiation. Such lamps should be used in suitable glass fronted luminaires.

**Infrared -** this is recognised as heat and occurs with all lamps.

**Flicker** – rapid variation in light output with changes in the instantaneous voltage to the lamp.

**Starting run-up and hot restrike –** time taken for the lamp to reach full brightness when the lamp is cold and when the lamp is hot.

**Lumen depreciation –** this is the reduction of lumen output through the life of a lamp with age, usually express as a per unit value or percentage of the initial lumen output at 100 hours.

**Colour shift -** high pressure discharge lamps are prone to colour shift through life, particularly metal halide versions.

**Lamp life and failure -** lamp life is often defined as the period that the lamp continues to function correctly. End of life can be the physical failure as is the normal condition for filament lamps. The end of "effective life" can be when the light output falls to such an extent that it is no longer economic or safe.

**Product Disposal -** the UK Government has announced a national lamp recycling initiative to help meet the requirements of the forthcoming Waste Electrical and electronic Equipment (WEEE) Directive.

**Lamp Codes -** In 1994 IEC 1231 was published which provides a method of identifying different lamp types by an internationally agreed coding system. This is called ILCOS (International Lamp Code System).

## Tungsten Filament lamps

**Efficacy -** typically 12 lumens/Watt, 95% of the radiated energy is as heat and not light.

**Colour -** excellent colour rendering. The colour appearance is "warm" (2500 - 2700K) - which is not normally comfortable for illuminances of more than 500 lux.

**Life - s**tandard domestic lamps have a average rated life of 1000 hours, there are long life options which will last for 2000, 3000, or even 16,000 hours.

**Voltage sensitivity -** filament lamps are particularly sensitive to voltage variation.

## Tungsten Halogen Lamps

**Efficacy -** about 20 lumens/Watt. With no blackening the light output remains nearly constant through life. Infra red reflecting films are being introduced that reflect heat back onto the filament with significant increases in efficacy up to 35 lumens/Watt.

**UV Radiation -** tungsten halogen lamps produce more Ultraviolet radiation.

**Dichroic Filters -** used as an alternative to the conventional metal reflective coating on reflectors.

**Colour -** excellent colour rendering. The colour appearance is whiter and the colour temperature is normally 3000-3200K compared with 2500-2700K for conventional filament lamps.

**Life -** It is normally possible to combine increased light output with extended life and tungsten halogen lamps are rated at 2000 hours. ELV lamps are 2000 - 5000 hours and some up to 10,000 hours.

**Voltage Sensitivity -** filament lamps are particularly sensitive to voltage variation. Also under-running can cause the temperatures to fall causing the halogen cycle not to operate.

**Building Regulations Part L -** the current regulations do not include tungsten or tungsten halogen lamps in the Table of approved types.

**Safe handling –** do not handle the quartz envelope to prevent permanently damaged.

**Control –** filament lamps give light at full power instantly at switch on. They can be easily dimmed.

**Lighting Costs** - the major costs to the user are the electricity consumed and the labour for changing the lamps. These factors are usually ignored because the prices are shown in a way that hides the true costs.

## Fluorescent Lamps

**Efficacy -** lamps with halophosphate phosphor reach 80 lumens/Watt and the tri-phosphor versions over 90 lumens/Watt. With high frequency electronic control gear the lamp efficacy is increased by about 10% so fluorescent tubes are now reaching 100+ lumens/Watt.

**Colour -** determined by the phosphor used,there are many different "white" fluorescent tubes available. Halophosphate phosphor gives low efficacy and poor colour rendering. Triphopsphor gives increased efffiacy and improved colour rendering. Second generation triphosphor even high efficacy and improved lumen maintenance.

**Mercury dose -** the amount required is small, typically 12mg. The latest lamps are using a mercury amalgam which enables closer dosing control using only 5mg.

**Temperature sensitivity -** hot and cold conditions will cause the light output to decrease and below about -10°C it will be difficult to start fluorescent lamps. Luminaire design should ensure that the lamps operate as close to the bulb temperature of 40°C.

**Electronic control gear** - these are all the existing electronic benefits:
- higher efficacy,
- no discernible flicker,
- reliable starting,
- prolonged lamp life
- quiet operation.

**Lamp disposal -** lamps if broken may release phosphor and cathode powders that are contaminated with mercury. Inhalation of this dust must be avoided and face masks should be worn when breaking lamps.

**Life -** fluorescent tubes have a typical life of 10,000 to 15,000 hours.

**Control Gear -** all fluorescent lamps require control gear.

**Induction lamps -** the energy required to operate the lamp is transmitted via an antenna at radio frequencies. This electromagnetic radiation will set up eddy currents in the lamp which can be used to create light.

**Compact Fluorescent lamps (CFL) -** technically these operate on the same principles as the linear fluorescent lamps.

**Integration of Control Gear -** there are now three CFL formats:

1) The fluorescent lamp alone requiring an external starter and ballast. Lamp base with four pins. Suitable for emergency lighting or dimming circuits.

2) The fluorescent lamp including a starter. Lamp base with two pins. An external ballast is required.

3) The fluorescent lamp includes a starter and ballast. This can be directly connected to the mains supply and the lampbase will be Bayonet Cap or Edison Screw.

**Lamp Life -** rated average life for CFLs is in the range of 8 - 10,000 hours.

**Lumen Maintenance -** triphosphors are exclusively used, the light depreciation is about 85% of initial lumens at the end of life.

**Lighting Costs** - using a relatively large number of expensive lamps produces high labour costs to maintain the installation. Thus the savings in energy consumption are offset by increased maintenance costs but the overall cost is still reduced by 28% compared with tungsten halogen scheme.

## Discharge Lamps

There are four main types:

- Low Pressure Sodium (SOX)
- High Pressure Sodium (SON)
- High Pressure Mercury (MBF)
- Metal Halide (MBI)

## Low Pressure Sodium Lamps (SOX)

**Efficacy -** the most efficient lamps available and the larger ratings provide 200 lumens/Watt.

**Colour -** the yellow colour makes it impossible to distinguish colours and has limited applications.

**Lamp Life -** average rated lamp life is 16,000 hours and over this period the light output falls by 20%.

## High Pressure Sodium Lamps (SON)

**Efficacy -** standard lamps have the highest efficacy at about 140 l/W with poor colour rendering CRI=25.

**Colour - s**tandard SON-2000K, Deluxe SON-2200K, White SON-2500K.

**Lamp Life -** standard SON lamp combines long life of 24,000 h with excellent lumen maintenance. 'HO' or 'Plus' versions have increase light output and even better lumen maintenance of 90% at end of life.

## High Pressure Mercury (MBF)

**Efficacy -** lamps only produce 50-60 l/W and their use is now waning.

**Colour -** colour appearance is 3400-3800K and the colour rendering only average (CRI=55).

**Lamp life -** Lamp life is long and varies with rating, from 16,000 to 24,000 hours. However at the end of life, the light output is only about 55% of initial.

## Metal Halide Lamps (MBI)

**Efficacy -** varies but typically 80 l/W with a wide rating range from 35W to 10kW.

**Colour -** CRI can range from 70 to 90. Colour appearance can range from 3000K to 6000K.

**Lamp Life –** low wattage lives of 6,000 hours whereas the larger industrial lamps can be 20,000 hours. Typically 65% of initial lumens at the end of life.

**Lighting Costs -** the high pressure sodium lamp example is the cheapest in the long run. Selecting this option would be 58% cheaper overall than the tungsten halogen scheme but needs a threefold capital investment initially.