The Basics of Efficient Lighting

A Reference Manual for Training in Efficient Lighting Principles
Comments Sought - by 31 March 2010

Comments are sought from stakeholders on this Edition of the Reference Manual. If you would like to make any comments or suggestions, please email Ren Webb at the Department of the Environment, Water, Heritage and the Arts, at ren.webb@environment.gov.au. The closing date for comments is 31 March 2010.

Acknowledgments

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1 Introduction

The purpose of this training material is three-fold. The first aim is to provide the lighting and allied industry workforce with an overview of the key principles of light and lighting which includes an understanding of basic design concepts and lighting technologies currently available, in the context of sustainability. The second aim is to help users understand the importance of energy efficiency and the implications of choosing a product in the overall scope of energy consumption. It also aims to assist users with the selection process when specifying, recommending, designing and installing various lighting systems.

In residential dwellings, lighting energy consumption has increased dramatically with the popularity of halogen downlight systems, which are grossly inefficient when compared to the increasing range of residential compact fluorescent lamps (CFLs). This is an example of where improved lighting design knowledge may lead to more efficient installations.

Qualification as a lighting designer requires a great depth of knowledge in the lighting design process. This knowledge is acquired through extensive, detailed training, covering a large variety of lighting design applications such as interior lighting, (differentiated into commercial, retail, industrial and residential), floodlighting, emergency and exit lighting, exterior lighting, road lighting, public lighting, facade lighting, and theatre lighting. Detailed design methodology is beyond the scope of this document.

This section introduces the basic concepts of light and lighting, and explores the key requirements of a lighting system and what standards need to be met. It also explains what we mean by sustainability and energy efficiency and how good lighting design can contribute to these.

1.1 The function of lighting

We need light to see the world around us. Light is a natural phenomenon vital to our very existence. The advent of a wide range of electric light sources means we are now less dependent upon light from the sun, moon and stars and flames from combustible fuels. The quality, quantity and intensity of light around us greatly affects our visual appreciation of our surroundings. It is important for us to understand the relationship between light, colour, what we see and how we see it.

Artificial lighting would not be required if our buildings were not occupied or visited by human beings. The sole purpose of lighting installations is to allow people to adequately perform physical or visual tasks, and the effectiveness of performing these tasks correlates to the quantity and the quality of the lit environment.

In the ideal world lighting installations should be designed primarily for the comfort of the occupants within. The task efficiency, energy efficiency and aesthetic value of the lighting installation a secondary consideration. However, the importance of energy efficiency is greatly increased with issues such as climate change and energy pricing, which all impact in our community.

The major aim of lighting is to provide the correct lighting solution for the installation to attain the highest quality product, or image, whilst realising the need for energy efficiency. The quality of the lighting system is paramount - the quality of output, morale of the employees and perceived working conditions are all directly related to the lighting system installed.

The most important thing to remember is that lighting is based on 50% fact and 50% psychology. The needs of the site and the occupants, or potential customers, are critical. Many complaints stem from the perceived inadequacies of the lighting system.
1.2 Why we use lighting

Artificial lighting is a key part of our everyday lives. We use it to:

- Help us find our way around, to assist visibility
- Provide a safer environment
- Increase the number of useful hours in the day
- Help perform visual tasks, increase productivity
- Display objects and/or control how they appear, improve sales
- Attract attention
- Improve employee working conditions

It is also possible to use lighting to reduce fatigue, encourage concentration or to improve awareness or decision-making. It can create an atmosphere of comfort, relaxation or trust or help people recover from illness or fatigue.

1.3 Fitness for purpose

It is important that any lighting system is fit for purpose: It should provide a quality and quantity of light that is appropriate for the environment in which it is being used; enable tasks to be performed efficiently and effectively; be perceived as comfortable and give people a high level of satisfaction. The aim is to achieve this whilst providing a good balance of cost and energy consumption through good design and optimum selection of products.

1.4 Definition of energy efficiency

Energy efficiency is defined as optimisation of energy consumption, with no sacrifice in lighting quality. It is a combination of thoughtful design and selection of appropriate lamp, luminaire and control system selection, made in conjunction with informed choices of the illumination level required, integration and awareness of the environment or space which is being lit.

It is very easy to produce an inefficient lighting installation with efficient equipment.

Generally, the most common cause of an inefficient lighting system in the home where the excessive use of low voltage tungsten halogen downlights produce extremely high lighting levels in some sections of the house (for example the breakfast bar in the kitchen). By producing a high lighting level in the kitchen (in excess of 1000 lux), the rest of the house can look dull by comparison. Typically we try to increase the lighting levels in the rest of the house to match the kitchen, rather than reducing the lighting levels in the kitchen in the first place. This scenario is also prevalent in offices, industry and particularly retail applications.

1.5 Definition of lighting design

Lighting design is often incorrectly considered to be simply the selection of the lighting equipment for a system. While selecting the most cost-effective and energy-efficient products is important, they are just the tools to achieve the design. True lighting design involves assessing and meeting the needs of the people who use the space and balancing function and the aesthetic impact supplied by the lighting system.

Lighting is an art as well as a science. This implies that there are no hard and fast rules for lighting design nor will there be one ideal or optimum solution to a lighting problem. More often than not, the lighting designer is confronted with a set of conflicting requirements for which priorities must be allocated before a satisfactory compromise can be found. There is no substitute for experience, careful planning, assessment and analysis.
1.6 Sustainability and the importance of energy efficiency

There are many definitions of sustainability yet probably the most straightforward is that in the Brundtland Report, ‘Our Common Future’. This states that ‘Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.’

It is about sensibly and effectively using the resources currently available. Energy is one such resource and energy efficiency is a key component of sustainability. Linked to this are the environmental benefits associated with using less energy, primarily a reduction in the production of greenhouse gases which are a major contributor towards climate change.

Lighting accounts for between 5 and 15% of residential energy use and up to 30% of commercial building energy use, and continues to increase. In certain business types, for example the retail sector, lighting can account for up to 80% of energy use. This is due to long operating hours and the need to “keep things bright” and stand out from the competition.

Therefore, in this context, greater sustainability can be achieved by making a conscious decision to reduce the amount of electricity used through appropriate lighting design (including the use of natural light and design techniques to reduce the amount of artificial lighting needed) and by selecting energy efficient luminaires and effective control systems. The manufacturing process and the choice of materials to make luminaires also have a relatively small impact on sustainability in comparison to operational energy consumption.

2 Fundamentals of Light and Photometry

This section describes the nature of light, how it is perceived by the eye and how it is measured.

2.1 The Nature of Light

Light is one of the forms of energy known as electromagnetic radiation, which also includes heat, radio waves and X-rays. Electromagnetic radiation travels outwards from its source in a waveform, like ripples in a pond. Electromagnetic waves travel in space at approximately 300,000 kilometres per second. This is commonly known as the speed of light, but it is the same for all electromagnetic waves.

2.1.1 Velocity, frequency and wavelength

The rate at which an electromagnetic wave ‘vibrates’ is known as the frequency (measured in Hertz (Hz)). Different frequency electromagnetic waves are responsible for different effects, such as light, heat, radio waves and X-rays.

The wavelength is the distance the wave travels in one complete cycle.

Because the velocity (speed) of electromagnetic radiation in air is always constant (at approximately 300,000 kilometres per second), the wavelength decreases as the frequency increases and vice-versa as shown in the diagram.
From this fact, the following relationships can be derived:

- Velocity = frequency x wavelength, and hence:
- Frequency = velocity/wavelength, and
- Wavelength = velocity/frequency

2.1.2 The electromagnetic radiation spectrum

The table below shows how electromagnetic waves of varying frequencies, produce different effects such as radio, light, and X-rays.

The small coloured bands show the range that represents visible light. This visible colour spectrum (more commonly shortened to visible spectrum) is a very small part of the total electromagnetic spectrum.

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>frequency</th>
<th>wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long wave</td>
<td>140 kHz</td>
<td>2027 m</td>
</tr>
<tr>
<td>Medium wave</td>
<td>862 MHz</td>
<td>34 cm</td>
</tr>
<tr>
<td>Short wave</td>
<td>900 - 1900 MHz</td>
<td>15 cm</td>
</tr>
<tr>
<td>VHF - FM</td>
<td>2500 MHz (2.5 GHz)</td>
<td>12 cm</td>
</tr>
<tr>
<td>UHF - TV</td>
<td>2.5 GHz - 3.6 GHz</td>
<td>0.3 mm</td>
</tr>
<tr>
<td>Mobile phones</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microwave Oven</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infra-red</td>
<td>3 THz - 400 THz</td>
<td>1 mm - 750 nm</td>
</tr>
<tr>
<td>Visible Spectrum</td>
<td>430-750 THz</td>
<td>780 nm - 380 nm</td>
</tr>
<tr>
<td>Ultra-violet</td>
<td>$7.5 \times 10^{14}$ - $3 \times 10^{16}$ Hz</td>
<td>380 nm - 10 nm</td>
</tr>
<tr>
<td>X-ray</td>
<td>$3 \times 10^{16}$ Hz and higher</td>
<td>10 nm and shorter</td>
</tr>
<tr>
<td>Gamma-ray</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.1.3 The visible spectrum

The visible spectrum extends from a wavelength of approximately 360 nanometres to 780 nanometres.

One way to specify the performance of a lamp is to show how its light is made up of the individual colours across the visible spectrum. This is done with a spectral power distribution graph (y axis = Power (mW/5nm/1,000lm)):

2.1.4 The eye and vision

We need light to see. When light reaches an object, some is absorbed and some is reflected by the object. Some of the reflected light reaches the eye and enables it to be seen.

As shown in the diagram, light from the object passes through the pupil and is focused by the lens onto the light sensitive retina. The lens is attached to a set of muscles which contract and relax to change the shape of the lens. It is this change in shape that allows both near and distant objects to be focused. The retina converts light into electrical impulses that are sent to the brain by the optic nerve. It is made up of two kinds of light sensitive cells, rods and cones. The cones distinguish colour information, but need a high level of light to work well. Rods distinguish only black and white, but work well at low light levels which explains why colour vision does not work well at night.
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As can be seen, the image on the retina is inverted, but this is corrected during processing in the visual cortex of the brain.

2.1.5 The sensitivity of the eye

The sensitivity of the eye is not even over the visible spectrum, but varies with the wavelength. The cones operate during the day and normal daylight conditions and enable us to see in detailed colour. This is known as PHOTOPIC or daytime adaption. As the light level drops, say to that of a well-lit street, the cones become less effective and are assisted by the more sensitive rods. Therefore, the eye is using a mixture of cones and rods to see.

However, as the rods can only "see" a black and white image, the overall impression is much less brightly coloured. This is called MESOPIC vision. At even lower levels, much lower than average street lighting or moonlight, the cones cease to function. The eye loses all its facility to see in colour and the rods take over, giving completely black and white vision, called SCOTOPIC, or night-time adaption.

These different adaptions are important because not only does the eye discriminate between different wavelengths of light with the sensation of colour, it is also more sensitive to some wavelengths than others - and this sensitivity alters between photopic and scotopic vision.

For photopic vision, the eye has peak sensitivity at 555 nanometres, which is a yellow-green colour. However, for scotopic vision, peak sensitivity moves to 505 nanometres which is blue-green light, although the vision is in terms of black and white. The mesopic vision peak will be somewhere between the two. This accounts for the perception that white light appears brighter at night than yellow light.
As we get older our ability to adjust the lens’ focus reduces, and our retinas become less sensitive. The result is that we need more light and often spectacles to be able to see well.

2.2 Introduction to Photometry

Light sources emit electromagnetic waves in the Ultra Violet (UV), visible and infra-red spectrum. Measurement of all these is called radiometry. Photometry is a special branch of radiometry in which we only measure visible light.

Four terms are used to describe light:

- Luminous Intensity (candela)
- Luminous Flux (lumen)
- Illuminance (lux)
- Luminance (candela/m²)

In addition, the term efficacy is useful when describing lamps, and is a measure of how efficiently they convert electricity to visible light. Efficacy is measured in lumens per watt.

When we refer to energy efficiency within lighting systems, we use the system efficacy which includes the losses of any control system incorporated in operating the lamp.

As an example, the system efficacy of a 1 x 28 watt T5 fluorescent lamp (tri-phosphor with 2600 lumen output at 25 deg C) operating on a standard electronic ballast of 3 watts loss would be:

28 watt + 3 watt = 31 watts divided by 2600 lumens = 83.87 lumens/watt

2.2.1 Luminous Intensity

The luminous intensity is a measure of how much flux (lumens) is emitted within a small conical angle in a particular direction from a light source (lamp) or luminaire. Its unit of measurement is the Candela. The symbol for candela is symbol is \( I \). The intensity of light sources used to be referred to as candle power.

If a source emits the same luminous flux in all directions, then the luminous intensity is the same in all directions. For most sources, however, the flux emitted in each direction is not the same. For example the luminous intensity of a spotlight varies with angle. Similarly, the flux emitted from a luminaire (light fitting) also varies with angle. If these candela values are plotted in graphical form, then a polar distribution diagram can be produced for a luminaire or reflector lamp, as shown below.
Most reflector lamps will have a light output stated in candela. This value is the peak intensity, usually quoted at 0 degrees or directly below the lamp in the vertical position as shown above.

2.2.2 Total Luminous Flux

Candelas indicate how bright a light is in a given direction. The term luminous flux is used to measure the visible light output of lamps, where light is not directional. It refers to the visible light emitted in all directions at any given moment (whereas radiant flux is the total radiation (ultraviolet, visible and infrared) being emitted from a light in all directions). The symbol for luminous flux is \( F \) or \( \Phi \) (phi).

2.2.2.1 Lumens

It is impractical to use the watt as a measure of light because of the variation in sensitivity of the eye with wavelength. Instead we use the LUMEN which is a measurement of the rate of flow of the luminous energy, or the LUMINOUS FLUX as it is more often called. One lumen of luminous flux at 555 nanometres corresponds to a radiated power of \( \frac{1}{680} \)th of a watt, but at 400 nanometres, 3.5 watts of radiated power is equal to one lumen.

This relationship between the watt and the lumen is important as it is possible to calculate the luminous flux a particular lamp will produce by considering the radiated power at each wavelength and the corresponding eye sensitivity (as defined by the CIE) at that wavelength. This can be done mathematically or by means of specially corrected photocells with a response identical to that of the CIE standard observer.

For example, a low pressure sodium lamp emits practically all its light at wavelengths 589 and 589.6 nanometres. As this is very close to the peak photopic sensitivity of the eye, it is very efficient in terms of the number of lumens produced for each watt of power. Therefore it is possible to make a lamp which will produce 160 lumens for each watt of power. However being mono-chromatic light, the results are often undesirable.

The lumen (\( \text{lm} \)) is equal to the flux emitted by a uniform point source of 1 candela in a solid angle of 1 steradian. A steradian is the standard unit solid angle in three dimensions. As an example, the total luminous flux of a 60W GLS lamp is 710 \( \text{lm} \). These 710 lumens are emitted in every direction from the lamp.
2.2.2.2 Lumen Maintenance

When a lamp is new its light output is at a maximum. As it burns through its life, the output declines. The term used to describe how the light output declines is lumen maintenance. It is usually shown in graphical form.

Lumen maintenance information is important for those who are responsible for maintaining or designing the lighting levels in buildings etc. It makes it possible to schedule replacement of lamps before the light level becomes too low. This is referred to as planned maintenance and often includes the cleaning of luminaire reflectors and diffusers. The lumen depreciation of discharge lamps (fluorescent and HID) and LEDs is much greater than that of incandescent or tungsten lamps.

2.2.3 Illuminance

When a ray of light hits a solid surface, the process is known as ILLUMINATION. In the same way we have lumens to measure luminous flux, we need a measurement for the quantity of illumination or ILLUMINANCE. The illuminance E at a point on a surface is defined as the luminous flux F (lumens) incident upon a small element of the surface divided by the area A (m²) of the element.

\[ E = \frac{F}{A} \]

In the SI or International System of units, the basic unit of illuminance is the Lumen per square metre or LUX. For example, if an area of 0.1 square metres in size receives a luminous flux of 20 lumens, the illuminance which is usually given the symbol E, will equal 20 divided by 0.1, that is 200 lux.
Although the lux is the metric measurement, sometimes the imperial measurement of lumens per square foot is referred to which is also called the FOOTCANDLE in the USA. One of these imperial units is equal to 10,761ux by virtue of 10.76 square feet being equal to one square metre.

Some typical examples of illuminance levels are shown below.

<table>
<thead>
<tr>
<th>Situation</th>
<th>Illuminance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very bright summer's day</td>
<td>100,000 lux</td>
</tr>
<tr>
<td>Overcast summer's day</td>
<td>30,000 - 40,000 lux</td>
</tr>
<tr>
<td>Shady room in natural light</td>
<td>100 - 150 lux</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Light levels for working</th>
<th>Illumination levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>General office task</td>
<td>320 lux</td>
</tr>
<tr>
<td>Rough tasks with large detail</td>
<td>160 lux</td>
</tr>
<tr>
<td>Ordinary tasks with average detail</td>
<td>320 lux</td>
</tr>
<tr>
<td>Difficult tasks with fine detail</td>
<td>600 lux</td>
</tr>
<tr>
<td>Minute tasks, detailed inspection</td>
<td>1600 lux</td>
</tr>
</tbody>
</table>

In practice, when designing lighting schemes and predicting illumination levels it is necessary to have information not just about the lamps, but also the luminaire in which the lamp will be used. A technical specification sheet of the luminaire, showing the polar distribution diagram of the luminaire using a specific lamp, is essential to determine the light distribution and performance levels of the luminaire.

Legislation varies from country to country, but in Australia, such statutory instruments as the Building Code of Australia and Occupational Health and Safety Act require that the lighting at places of work shall be both sufficient and suitable. Sufficiency is normally taken to imply an adequate quantity of light (illuminance) both on work tasks and in areas where people circulate. Legislation is normally concerned with what is adequate, unlike the recommendations in lighting guides which focus on good practice.

**Definition - Maintained Illuminance:** The defined level below which the average illuminance on any surface is not allowed to fall. It is the minimum illuminance at which maintenance operations, (such as replacing lamps and cleaning the luminaires, windows, roof lights and room surfaces), are to be carried out.

The schedule in the Australian Standards recommends maintained illuminance for interiors according to the tasks involved. The relevant area may be the whole of the interior or just that occupied by the tasks and their immediate surround. In the latter case, the maintained illuminance of the general surround areas of a working environment should be based upon tasks that are carried out in these areas, but should not be less than one-third of the highest task illuminance, or problems of adaptation will arise.

Illuminance should be increased or decreased if task details are unusually difficult or easy to see or if the task is done for an unusually long or short time. Illuminance should be increased if there are concerns that errors could have unusually serious consequences. Where eye protection is worn, or tasks must be carried out through transparent screens, the contrast of the task may well be reduced and, in such circumstances, the illuminance on the task should be increased in an attempt to compensate. Also, if the most onerous visual tasks are to be carried out by occupants with poor sight or an average age that is higher than normal (say over 50 years), then the designer is justified in increasing the illuminance. The maintained illuminance should not be less than 500 lux for situations involving critical colour matching.

The illuminance recommendations apply to the tasks themselves, which may be complex in both shape and position. This can cause major difficulties in both prediction and measurement. It is commonly assumed that the illuminance on the task will be the same as the illuminance on a plane at the same angle and position as the task. This is good enough for most practical purposes, but is nevertheless an assumption and its validity should always be questioned.
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It frequently happens that the precise location of a task is not known, and therefore a horizontal plane at workstation height is usually taken. Where vertical tasks are involved, but their orientation is not known, then mean vertical (i.e. cylindrical) illuminance may be used. In addition to providing sufficient light for tasks to be carried out, the occupants must also feel that there is enough light.

When it comes to energy efficiency, the most common mistake made in designing an installation, is the installation of a lighting system that provides **too much** light, i.e. illuminance levels well above those recommended by the Australian Standards.

### 2.2.3.1 Inverse square law

Importance is placed on the illuminance required for different purposes; therefore it is essential to have a secondary method for calculating this quantity. In the mid-18th century, J. H. Lambert established one of the earliest lighting laws thus enabling the calculation of illuminance, called the INVERSE SQUARE LAW.

To understand this law, consider a cone-shaped beam of light coming from a small point source and hitting a surface some distance away. Suppose that the luminous flux within the cone is one lumen, and it strikes a surface 1 metre away, producing an illuminated area of 1 square metre. By dividing the luminous flux by the area, we can find the illuminance, which will be 1 lux.

If the surface is moved further away to a distance of 2 metres, then the luminous flux within the cone will stay the same, but the illuminated area will increase in size to 4 square metres. This will result in an illuminance of ¼ lux. By doing this, the area has increased in proportion to the square of the distance from the light source, and the illuminance has changed inversely with the square of the distance.

If the surface is moved still further away to a distance of 3 metres, the inverse square law operates again. The area has increased in proportion to the distance squared and is now 9 square metres and the resultant illuminance falls inversely to 1/9th lux. All of this is encompassed by the inverse square law which states that; the illuminance E equals I, the intensity of the light source, divided by the distance squared.

\[ E = \frac{I}{d^2} \]

So far these calculations of illuminance have only covered situations where the rays of light hit the surface at right angles. Here the illuminance, which is the flux falling onto the surface divided by the area, can be found by using the inverse square law.
2.2.3.2 Cosine Law

If the surface is turned so that the rays hit it at an angle, the illuminated area will increase in size and the illuminance will drop accordingly. The ratio of the original illuminated area to the new area is equal to the cosine of the angle through which the surface has been moved. Therefore the illuminance will fall by the factor of the cosine of the angle.

This is where Lambert's second law comes in; the COSINE LAW of illuminance. If a surface is illuminated to 100 lux and is twisted through an angle of 60 degrees, then the illuminance will fall to half or 50 lux because the cosine of 60 degrees is 0.5. This cosine law can be combined into one equation with the inverse square law:

Returning to the angled spotlight mentioned earlier, if it is 3 metres above the floor, aiming at a point 3 metres away, and its intensity in this direction is 1000 candelas, the distance from the point of illumination to the spotlight is calculated using Pythagoras theorem, and is 4.24 metres. The light is striking the floor at an angle of 45 degrees so using the combined inverse square and cosine law equation, we can calculate the illuminance.

\[ E = \frac{I}{d^2 \cos A} \]
\[ = \frac{1000}{4.24^2 \cos 45} \]
\[ = 39 \text{ lux} \]

These calculations have only referred to one light source. But when there are several, the illuminance is calculated in the same way for each source in turn, and then these are added together for the total illuminance.

This is the basis for computer aided lighting design software which calculates the illuminance contribution from all luminaires in a room and adds them together through a series of point by point calculations and inter-reflectance assumptions.

High pressure discharge light sources normally conform to the inverse square law when calculating illuminance, but fluorescent fixtures are larger and need to be dealt with separately.

For most practical applications, the inverse square law can be used with reasonable precision if the point of illuminance is more than five times away in distance than the maximum dimension of the light source. In the case of a 600 millimetre (2ft) fluorescent tube, the inverse square law is sufficiently accurate at distances of 3 metres (10 ft) or more.

2.2.4 Luminance

Luminance is the measure of the amount of light emitted from a surface. This surface can be as small as a pixel (or LED surface) or as large as a wall or even the sun. It is measured as luminous intensity (candela) per unit area of light emitting surface.
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This is usually candelas per square metre (cd/m²) and the symbol is L (sometimes B). Whereas brightness is qualitative (it depends on our eye adaption at the time), luminance is an absolute value. Some examples of luminance for common light sources are shown below.

<table>
<thead>
<tr>
<th>Light source</th>
<th>Luminance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar disk at noon</td>
<td>1,600,000,000 cd/m²</td>
</tr>
<tr>
<td>Solar disk at horizon</td>
<td>600,000 cd/m²</td>
</tr>
<tr>
<td>Frosted bulb 60W</td>
<td>120,000 cd/m²</td>
</tr>
<tr>
<td>T5 cool white fluorescent High Output</td>
<td>26,726 cd/m²</td>
</tr>
<tr>
<td>T5 cool white fluorescent High Efficiency</td>
<td>17,400 cd/m²</td>
</tr>
<tr>
<td>T8 cool white fluorescent (triphosphor)</td>
<td>11,000 cd/m²</td>
</tr>
<tr>
<td>Average clear sky</td>
<td>8,000 cd/m²</td>
</tr>
<tr>
<td>Moon surface</td>
<td>2,500 cd/m²</td>
</tr>
<tr>
<td>Average cloudy sky</td>
<td>2,000 cd/m²</td>
</tr>
</tbody>
</table>

In simple terms, the luminance is the product of the illuminance arriving on the surface and the reflectance of the surface. The eye sees luminance rather than illuminance. Therefore with the same illumination, by changing the surface reflectance, the luminance of the surface can change proportionally.

As an example, if we have one large object, an internally illuminated sign - 40m x 10m and a small object such as a small floodlight. The intensity in a direction at right angles = 5000 candela in both cases.

The small floodlight has an area = 0.1 m² with the same intensity of 5000 cd. Both objects are viewed from 300 m.

The illuminance produced on the eyes of the viewer will be the same for both objects (Inverse Square Law).

But this does not take into account the fact that the internally illuminated sign looks larger and less bright than the small floodlight.
However, the Luminance L will be –

\[ L = \frac{I}{A} \]

Building \( = \frac{5000}{40 \times 10} \) \( = 12.5 \text{ cd/m}^2 \)

Floodlight \( = \frac{5000}{0.1} \) \( = 50000 \text{ cd/m}^2 \)

*Luminance is a measure of the concentration or Intensity Density of a light source.

### 2.2.5 Efficacy

The word 'efficacy' is now an established lighting term used when describing how efficiently a lamp converts electrical energy into visible light. Its unit of measurement is lumens per Watt, usually written as lm/W. For example, as previously mentioned, the total luminous flux of a 60W GLS lamp is 710 lm. Therefore the efficacy is 710 / 60 = approximately 12 lm/W.

The efficacy of a fluorescent lamp includes the power losses of the ballast. So a 36 watt T8 fluorescent lamp produces 3450 lumens, and a low loss ferro-magnetic ballast has a hot watts loss of 5 watts. Therefore the efficacy is 3450 / (36 +5) = 84.14 lm/W.

A chart showing the efficacy of most lamps is shown in the Lamp choice section of this reference document.

### 2.2.6 Reflector Lamps

Reflector lamps are designed to perform without the need of an additional reflector (which would normally be built into a luminaire). In assessing the performance of reflector lamps we need to know the extent to which they distribute their light. This is measured in terms of:

- Beam angle
- Illumination levels
- Polar distribution (candela values in a particular direction)

Typical reflector lamps:

- Incandescent PAR lamp
- MR16 (Dichroic) lamp
- Mercury Vapour Reflector Lamp
2.2.6.1 Beam angle

A beam similar to that of a torch is emitted by reflector lamps. This beam is usually shown accompanied by a 'beam angle' in degrees. This is a guide as to how light from the beam is concentrated or spread out.

Some lamp types are manufactured with a variety of beam angles. Lighting designers take advantage of this to tailor lighting schemes.

The beam angle is decided first by knowing the value of 'peak intensity'. Peak intensity is quoted in candelas and measured in front of the lamp on an imaginary line called the axis, which usually runs directly through the centre of the lamp.

To one side of the axis the luminous intensity gradually diminishes. The line at which the intensity has diminished to half is called the line of half peak intensity. The line of half peak intensity is also measured for the other side. The angle between the two lines of half peak intensity is the beam angle.

2.2.6.2 Illumination levels

Published beam angle diagrams for reflector lamps also show illumination levels. These are shown as circular patches of light whose diameters and illumination levels are quoted at various distances from the lamp; a common way of showing the output of a low voltage tungsten halogen lamp (Dichroic or MR16).

There is a simple relationship between luminous intensity (cd) and illumination (lux):

\[ \text{Lux} = \frac{\text{candelas (cd)}}{\text{distance in metres squared (m}^2\text{)}} \]

Example:

A reflector lamp with a peak intensity of 1,800 candela, is used to illuminate a jewellery display from a distance of 3 metres. The illumination level on the display will be:

\[ \frac{1,800 \text{ cd}}{3 \text{ m}^2} = \frac{1,800}{9} = 300 \text{ lux} \]

2.2.6.3 Polar distribution

Polar distribution diagram, also called a polar curve, is a graph showing how luminous intensity values vary with increasing angles from the imaginary axis of the lamp.

It is sometimes customary to show the curve for only one half of the distribution because in nearly all cases the other half would be an exact mirror image (i.e. the polar curve is symmetrical about the lamp axis). An example of a polar distribution curve and the intensity table from where it is derived, is show below.
2.2.7 Measuring light levels

There are three commonly used methods of measuring light levels:

- Detectors
- Illuminance meters (light meters)
- Luminance meters

2.2.7.1 Detectors

The most common type of detector used today is the solid state detector. There are several types incorporating semi-conductor materials which work from ultraviolet through the visible spectrum to infrared. Most of these work in what is called the photovoltaic mode where the short-circuit current is measured. They have the advantage that they are very linear over $10^{10}$ range, have a very fast response when used with no smoothing/averaging capacitor (creating a long time constant) and are not greatly affected by temperature (but are most accurate when operated near the calibration temperature, which is typically 23°C). In order to measure “visible” light a specially matched filter must be used so that the light measured is the same as that seen by the human eye. That is the detector with filter has a photopic response.

2.2.7.2 Illuminance meters

Illuminance meters are the most common type of meter. They collect light over a full half hemisphere. They may receive light from several ‘sources’ at one time so the detector must have a good cosine response. The reading can also be affected by stray light. Well matched photopic filters and good cosine response diffusers are generally the difference between an inexpensive photometer and a good photometer. The inexpensive photometers generally don’t have any photopic filter and have cosine diffuser which have poor performance when the light source is at high angles of incidence (typically above 70° from the normal to the photometer). Inexpensive photometers are acceptable for comparative type measurements where the light sources have very similar spectra or transmissive or reflective materials don’t alter the spectrum of the light being compared.

Photometers need to be calibrated by a photometric laboratory approximately every 12 months in order to maintain their correct reading. Re-calibration is required mainly due to drift in electronic components within the meter.
2.2.7.3 Luminance meters

Luminance meters have the same elements as illuminance meters but also need an optical system to view the object of interest and image it onto the detector in a similar way to a telescope with collimating lenses at the front. Luminance meters can have a range of apertures to define the measurement field, the angle of which can be $<1^\circ$ to $10^\circ$. More sophisticated (and expensive) luminance meters include colour filters for measuring the colour (and colour temperature) of the object as well as its luminance.

2.3 Reflection, transmission & refraction

2.3.1 Reflection

In lighting design it is also necessary to consider the reflective properties of the surface being illuminated. When light strikes an opaque surface - and by opaque we mean a surface that will not transmit light - some of the light is absorbed and some is reflected. The ratio of the luminous flux reflected, to the luminous flux received, is known as the REFLECTANCE. If a small element of a surface receives 1000 lumens and reflects 700 lumens, then the reflectance is 0.7. Or it can be expressed as a percentage as 70%. The remaining 0.3 or 30% would be absorbed.

Different surfaces also reflect light in different ways. For example, surfaces such as paper, emulsion paint, carpets and so on, exhibit what we call matt or DIFFUSE REFLECTION. That is, the light reflected from the surface is scattered equally in all directions.

2.3.2 Specular Reflection

At the other extreme is mirror or SPECULAR REFLECTION exhibited by shiny metal surfaces such as chrome, silver or pure aluminium.

It is most important to realise that although specular reflections produce a clear image in the surface of the material, the actual amount of light reflected may be deceptively low. A matt white painted surface for instance has a reflectance of 75% to 80% compared with only 60% specular reflectance from a polished stainless steel surface. Many surfaces such as gloss paint, wood, plastic and so on, exhibit a combination of these two types of reflection. Gloss paint, for example, scatters most of the light that it reflects, but also produces a specular reflection in the surface of the paint.

In lighting design it is important to measure and assess the reflectances of the main surfaces of a room because they will reflect any light that falls onto them and increase the illuminance within the space. Colour charts exist that have reflectances marked on them and matching these with the surfaces of the room will give a guide to the reflective properties of the surfaces.

The reflective properties of surfaces are used by the control of light from light sources, and luminaires. (The international name, LUMINAIRE is often used instead of light fitting or fixture). Specular reflection occurs in smooth polished surfaces, such as mirror glass or polished aluminium. For any ray of light that strikes the specular surface of a reflector, the angle of incidence is equal to the angle of reflection.
This principle still applies to each part of a specular reflector regardless of its shape. Practical specular reflectors are often curved or a series of flat facets. The degree of optical control will depend upon the size of the source relative to the reflector; how much light from the lamp the reflector collects and the degree to which the reflective material will scatter light (i.e. non mirror reflection). For example, compact low voltage tungsten halogen display lamps with integral mirrors (MR16 Lamps) use facetted reflectors. The overall shape of the reflector is approximately parabolic to give a near parallel beam. Because the lamps have a compact filament, precise beam control can be achieved with a small reflector.

**A basic rule of thumb for reflector design is that the reflector must be 5 times the size of the light source to provide accurate beam control.**

### 2.3.3 Diffuse Reflection

DIFFUSE REFLECTION occurs in matt surfaces and scatters light uniformly in all directions. Matt surfaces therefore appear equally bright from any direction of view and, in fact, this is the definition of a UNIFORM DIFFUSER. A diffusing reflecting surface will scatter light without producing a clear image of the source. The interiors of most luminaires use matt white diffusing paint because this is the most efficient way of reducing the light being absorbed in the fitting and increasing the output.
2.3.4 Mixed Reflection

Some surfaces show a mixture of a diffuse and specular reflection. For example, the bodywork of a car would look shabby if it did not provide both types of reflection. A specular image of the sky will be produced in the paint surface, yet most of the light will be reflected in a different manner by the pigment to produce the car’s colour.

2.3.5 Transmission

Certain materials have the ability to transmit and diffuse light. This principle is known as diffuse transmission and occurs with opal glass and opal plastic diffuser luminaires. When a ray of light falls on translucent (light transmitting) opal material, some light is reflected specularly and some light passes through the material. This light is scattered or diffused, thus spreading the brightness of the bare lamp over a larger area. The area of illuminated brightness is therefore enlarged and for a given number of lumens coming from the luminaire, the lumens per unit area or candelas per unit area, are reduced which in turn reduces the brightness, i.e. glare from the luminaire is reduced. The amount of light that is emitted from a material, after passing through it, as a fraction or percentage of the light falling on the material is called the TRANSMITTANCE.

When light passes from one transparent medium to another of different density, it bends, this is known as REFRACTION, e.g. air to glass, the light bends towards the perpendicular to the surface. When light passes from a dense to a rarer medium, e.g. glass to air, the reverse occurs. If light is passed through a triangular glass prism, it is deflected from its original path. Prisms, in glass or plastic can be designed to control light. Plastics are used extensively in prismatic controllers for both interior luminaires and street lighting lanterns.

The prismatic attachments for interior luminaires consist of a series of prisms designed to redirect the light away from the glare zone down onto the work area. This has the effect of both reducing direct DISCOMFORT GLARE and producing a more efficient light distribution, because more lamp lumens are directed downwards on to the work area. Prismatic attachments although clear, will absorb some light, but the losses are much less than for an OPAL DIFFUSER which may absorb up to 25% of the lamp lumens.
2.4 Colour

The three primary colours are red, green and blue. They are called primary colours because the colour sensitive components of the retina (the cones) are sensitive to red, green and blue. Any other colour can be derived from a combination of the three primary colours.

When the brain processes the signals from the retina of the eye, it collates and processes the individual light colours received by the eye into the colour actually seen. For example, if red and green light is focused on the retina, yellow light is seen. If blue and red light is focused, then violet (magenta) is seen etc.

![Diagram of primary colours and their combinations]

**Note:** Red, green and blue are the primary colours for light. The primary colours for paint and inks are red, blue and yellow.

2.4.1 Colour and objects

We see objects because of the light reflected from them. Objects reflect only their own colour, and absorb all other colours falling upon them. For example, a red post box appears red because it absorbs all colours other than red, which it reflects.

When light passes through an object all colours are absorbed, except for the colour of the object itself. An example is a blue lamp. When light from a lamp filament passes through its blue glass bulb, all colours apart from blue are absorbed. The blue glass does not convert all the light to blue, as is often thought.

2.4.2 Colour in relation to lamps

Natural sunlight (daylight) contains all the colours in the visible spectrum. However, this is not true for all lamps.

Lamps have two properties which describe their colour performance:

1. **Colour appearance** describes the colour the lamp appears to be when lit, or the general ambience of the light it provides.

2. **Colour rendering** indicates to what extent its light is capable of making objects appear their true colour.

2.4.3 Ultraviolet radiation

Just beyond the violet end of the visible range of the electromagnetic radiation spectrum is ultraviolet radiation. This radiation occurs naturally from the sun. It affects pigments and is responsible for colour bleaching and sun-tanning of the skin.
The Basics of Efficient Lighting

Ultraviolet (UV) is also artificially created in small amounts by all light sources, usually as an unwanted and mostly harmless by-product. However, some products are designed to produce UV, examples being sun-bed tubes and lamps for curing plastics and erasing certain types of computer micro-chip.

2.4.4 Infrared radiation

Just beyond the red end of the visible electromagnetic radiation spectrum is infrared (IR), which is heat. Like UV, infrared occurs naturally from the sun and is created to a greater or lesser extent by all artificial light sources. All lamps except LEDs give out more energy as infrared than they do as visible light.

Some lamps are designed to redirect the infrared content of their output, so that less heat is directed onto users or displays. This is the purpose of the dichroic coatings on some lamps. These lamps are said to give a cool beam or cool light, because the dichroic coating reduces the heat in the beam by up to 66% (this removal of heat should not be confused with colour temperature or colour appearance).

2.4.5 Colour Appearance / Colour Temperature

Colour appearance describes the ambience that a lamp provides, i.e. how 'warm' or 'cool' the light from a lamp makes the room feel. The lighting industry has adopted terms like 'Warm White' and 'Cool White' to describe this effect.

However, in practice, colour appearances of lamps can be difficult to judge. Sometimes, particularly with fluorescent tubes, colour appearance can be assessed by looking at the lamp which will appear 'cold' or 'warm' in line with the light being emitted. Other light sources are too bright to look at directly.

In these cases it is best to assess the colour appearance by illuminating a white background. From a design perspective, it should also be noted that the ambience of a room can also be due to decor, rather than lighting. Because the terms 'warm' and 'cool' are associated with temperature, a more technical description of a lamp's colour appearance is it's colour temperature.

CIE Chromaticity Chart

The colour temperature of a light source is the temperature of a "black body" radiator having the same colour appearance. If we heat a tungsten filament it 'glows' red hot. The hotter it becomes, the whiter it becomes to the extent that the hottest objects have a bluish white appearance. The usual temperature scales of Celsius (°C) and Fahrenheit (°F) are not used for colour temperature measurement. Instead, the more scientific 'absolute temperature scale', which is measured in Kelvin is used. Kelvin is not quoted in degrees or °K, but simply K or Kelvin. The unit 'size' of the Kelvin and Celsius are the same. Water freezes at 0°C and boils at 100°C. The equivalent Kelvin temperatures are 273.16K and 373.16K.
The Basics of Efficient Lighting

The warmer a lamp (or light emitted from it) appears, the lower its colour temperature. The cooler (bluer) it appears, the higher the colour temperature. This is the opposite of heat measured on a thermometer. For example, a typical GLS lamp produces much of its light in the red wavelengths, giving it a ‘warm’ yellowish appearance, but its colour temperature is low, only around 2,700K whereas a daylight fluorescent tube having a high colour temperature (6,500K) has a cool bluish appearance because it produces more of its light in the blue wavelengths. General classifications of colour appearance and temperature:

<table>
<thead>
<tr>
<th>Colour temperature</th>
<th>Colour appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3,300K</td>
<td>Warm</td>
</tr>
<tr>
<td>3,300 – 5,300K</td>
<td>Intermediate</td>
</tr>
<tr>
<td>&gt;5,300K</td>
<td>Cool</td>
</tr>
</tbody>
</table>

2.4.6 Colour Rendering

The extent to which a light source is capable of making objects appear their true colour is known as colour rendering and it is determined by the spectral power distribution or spectrum of the light source. Only those colours that fall onto a surface can be reflected from it. For example, when buying an item of clothing, people instinctively take it close to a window as they know that it will make it appear its true colour, without distortion. In other words, daylight has excellent colour rendering ability.

Lamps vary in their ability to render colours correctly. For example, incandescent lamps emit all colours of the spectrum. Therefore they will render almost all colours accurately. On the other hand, low pressure (SOX) sodium lamps give out nearly all their light in the yellow/orange part of the spectrum, so will only render yellow/orange colours properly. Other colours appear dull and lifeless under SOX lighting. Low pressure sodium lights are often chosen for tasks that do not require good colour rendition, such as security, roadway and tunnel lighting, because of their high efficacy.

2.4.6.1 The CRI or Ra scale

The colour rendering ability of lamps is measured on the Colour Rendering Index (CRI) or Ra scale (pronounced ar-ray). The scale ranges from 0 to 100, where lower values indicate poor colour rendering and higher ones good colour rendering. One hundred being as good as a black body radiator of the same colour temperature.

To make comparing the colour rendering qualities of light sources easier, the Australian Standards (based on CIE international standards) group the Colour Rendering Index (CRI or Ra) for lamps as shown below:

<table>
<thead>
<tr>
<th>Group</th>
<th>CRI or Ra value</th>
<th>Colour rendering</th>
<th>Typical application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>90 - 100</td>
<td>Excellent</td>
<td>Galleries, medical examinations, colour mixing</td>
</tr>
<tr>
<td>1B</td>
<td>80 - 89</td>
<td>Very good</td>
<td>Home, hotels, offices, schools</td>
</tr>
<tr>
<td>2A</td>
<td>70 - 79</td>
<td>Good</td>
<td>Industry, offices, schools</td>
</tr>
<tr>
<td>2B</td>
<td>60 - 69</td>
<td>Fairly good</td>
<td>Industry, offices, schools</td>
</tr>
<tr>
<td>3</td>
<td>40 - 59</td>
<td>Acceptable</td>
<td>Industry, sports halls</td>
</tr>
<tr>
<td>4</td>
<td>20 - 39</td>
<td>Poor</td>
<td>Traffic lighting</td>
</tr>
</tbody>
</table>
Typical CRI or Ra figures for the various lamps are:

- Incandescent: 100
- Tungsten Halogen: 100
- Fluorescent (halophosphor): 60+
- Fluorescent (triphosphor): 80+
- Compact Fluorescent (CFL): 80+
- Specialised Fluorescent (enhanced CRI): 90+
- Standard Quartz Metal Halide: 65
- Ceramic Metal Halide: 80+
- Standard Mercury Vapour: 45
- High Pressure Sodium: 25
- White High Pressure Sodium: 60
- Low Pressure Sodium: 15
- Light Emitting Diode (LED): 75+

2.4.6.2 Spectral power distribution

The colour rendition of a lamp (and hence its CRI or Ra rating) is directly influenced by its 'spectral output'. It is conventional to show this as a graph.

The graphs' two axes are power and wavelength. The wavelengths are shown in nm (nanometres) as usual. The power axis is known as 'radiated power', which is measured in Watts (W) or milliWatts (mW). In this graph the power is measured for a light output of 1000 lumens for every 5nm step, i.e. mW/5nm/1000lm.

The resulting line on the graph is called the Spectral Power Distribution Curve, and shows how power is distributed across the visible spectrum.

2.4.6.3 Continuous spectrum and line emission

As can be seen in the graph, the emission from incandescent lamps is radiated across all the wavelengths and blends smoothly from one wavelength to the next. This type of output is called 'continuous spectrum'.

In contrast, discharge lamps such as fluorescent tubes are designed to give out energy only at certain wavelengths, making the graph peaks erratic. This is known as 'line emission'. The colour rendering ability of discharge lamps is determined by the particular wavelengths of the energy emission.
2.4.6.4 Colour rendering – Incandescent lamps

The lamps rely on the process of incandescence to produce light from a tungsten filament. (Incandescence is the emission of visible light from a substance or object as a result of heating it to a high temperature.) At a colour temperature of 2,700K, the filament emits light as a smooth continuous spectrum, producing a CRI or Ra value of 99, almost as good as that of a true black body.

2.4.6.5 Colour rendering – Fluorescent Lamps

The white appearance of an unlit fluorescent tube is due to the phosphor powder coating on the inside of the tubing. It is this coating which is responsible for most of the light, and the colour performance of the lamp once lit.

Basic fluorescent lamps are sometimes referred to as 'halophosphate' fluorescent tubes. They use a single phosphor belonging to the chemical family of 'halophosphates'. These lamps do not have good colour rendering abilities and are now unavailable in Australia due to their inefficiency.

Fluorescent lamps with better colour rendering use three additional phosphors, which has led to these tubes being called 'tri-phosphor' fluorescent tubes. Each of the three additional phosphors produces one of the primary colours of the spectrum, red, green and blue. The primary colours mix to produce a white light, which combined with the halophosphate phosphor, produce an improved balance of colour in the spectral output. The result is that the quality of the light produced is superior to tubes only coated with the single halophosphate.

2.4.6.6 Colour rendering – Discharge Lamps

High Pressure Mercury

Mercury lamps generate light from the excitation of mercury atoms by an electrical discharge. The light given off is a cold bluish/green colour which is deficient in red light. This gives them a relatively poor colour rendering value. However some mercury lamps have a golden brown filter coating which allows them to emit a similar light colour to that from an ordinary light bulb.

Metal halide (HCl and HQI)

These lamps are essentially high pressure mercury lamps with other chemicals added to the mercury to improve the balance of the spectral output. The HCl lamps incorporate ceramic technology whilst the HQI feature quartz technology. The chemical additions result in largely good colour performance.

Low pressure sodium (SOX)

These lamps use sodium to produce their characteristic orange light, which at a wavelength of 589nm is near that of peak eye response. These lamps achieve the highest efficiency of any light source (up to about 200lm/W), but they have the worst colour rendering of any lamp - because they are monochromatic.

High pressure sodium

These lamps use mercury and sodium together with Xenon (a gas) to produce light. The contribution of the bluish-green of the mercury produces a better spectral colour balance than that of SOX lamps. They produce a golden coloured light at around Ra25.
3 Lamp Choices

This section discusses the various types of lamps that are available, how they work and their pros and cons, particularly with respect to their efficacy and, therefore, their contribution towards sustainability. The diagram below summarises the main categories of lamps.

The diagram also highlights the types of lamps that are referred to by the lighting industry as high intensity discharge (HID) lamps. These lamps share the characteristic that light is generated from the excitation of atoms of certain metals in an electrical discharge between two electrodes, through inert gases.

<table>
<thead>
<tr>
<th>HEADS UP: Lamp Choice and Energy Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Choosing the lamp type has an enormous impact on energy efficiency, although it is only one link in the design chain. It is possible to design a very inefficient lighting system, using very efficient lamps.</td>
</tr>
<tr>
<td>As can been seen in figure below, gas discharge lamps are more efficient than incandescent lamps. Incandescent lamps are discouraged for general purpose illumination, except for special effects such as highlighting.</td>
</tr>
<tr>
<td>Low voltage halogen reflector lamps (dichroic lamps) have become very popular in recent years and are marginally more efficient than tungsten incandescent lamps. However, from a design perspective, their highly directional light output makes them a poor choice for general purpose illumination, meaning that large quantities are required to light open spaces.</td>
</tr>
<tr>
<td>LEDs are an emerging technology and are often claimed to be very efficient. However recent experience shows that LEDs have a range of efficiencies, thus great care should be taken in selecting LEDs for any lighting purpose.</td>
</tr>
</tbody>
</table>
The Basics of Efficient Lighting

The name lamp is the generic term for a device that creates light either by thermal emission or by discharge radiation. Light can be produced from electricity in many ways, of which the following are the most important in lighting engineering.

i. **Incandescence** or thermo-luminescence is the production of light from heat. Light from a filament lamp is produced in this way; electricity is used to raise the temperature of the filament until it is incandescent.

ii. **Electrical Discharge** is the production of light from the passage of electricity through a gas or vapour. In lamps using this principle the atoms of the gas are agitated or excited by the passage of the electric current and this atomic excitation produces visible radiation, ultra-violet and infra-red energy.

iii. **Phosphorescence & Fluorescence** are the processes of converting the invisible ultra-violet energy emitted normally from an electrical discharge, into visible light. Material called phosphors cause ultra-violet energy to make the transition into visible light.

The efficiency of a lamp (also known as **efficacy**) is measured in lumens per watt. The chart below shows the typical efficacy of the standard lamps including standard control gear losses. This allow the relative efficiency comparison of lamps to be made. As an example, a 100 watt incandescent lamp produces approximately the same amount of lumens as a 20 watt fluorescent lamp. Similarly, a 250 watt metal halide lamp produces approximately the same amount of lumens as a 400 watt mercury vapour lamp.

![Comparison of Light Sources](chart.png)

In general, fluorescent lighting provides the most efficient lighting system mounted up to the height of 4 - 5 metres. Above this height the use of high bay luminaires incorporating high intensity discharge lamps are ideal for providing general background lighting. Combined with localised fluorescent task lighting for finer detail tasks, the overall lighting system can be made far more efficient. In general, the task lights used need only be single tube fluorescent luminaires. Care should be taken not to “over-light” areas for specific tasks.
3.1 Incandescent lamps

Incandescent lamps are the most commonly used type of lighting. They are inexpensive to buy, but their running costs are high. Standard incandescent lamps are most suitable for areas where lighting is used infrequently and for short periods, such as laundries and toilets. However, because of their low efficiency, incandescent lamps are being phased out of the Australian market.

The Australian Government is targeting any lamps that have an efficiency level of less than 15 lumens per watt (depending on lamp light output – 15 lm/W is the minimum efficacy for a lamp of 900lm). The traditional pear-shaped incandescent lamps (GLS) are the least efficient, wasting about 95% of the energy that they use, mainly as heat. These have already been phased out.

Although they are being phased out, it is useful to describe the construction and operation of incandescent lamps because of their current prevalence in the market and because it provides a good foundation for understanding the other technologies in the market place.

Incandescence is technically ‘thermo-luminescence’, which means to create light by means of heat. When an electric current flows in a tungsten filament or other conducting material, heat will be generated. Should the temperature of the filament be raised sufficiently, not only will heat be emitted but visible light as well. This method of producing light is intrinsically inefficient as more heat is produced than visible light, which comprises only about 5% of its output.

<table>
<thead>
<tr>
<th>Performance summary</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>25 – 300 watt</td>
</tr>
<tr>
<td>Colour temperature</td>
<td>2,700 Kelvin</td>
</tr>
<tr>
<td>Life</td>
<td>1000 hours</td>
</tr>
<tr>
<td>CRI</td>
<td>100</td>
</tr>
<tr>
<td>Efficacy</td>
<td>12 lm/watt</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate on</td>
<td>Very expensive to operate</td>
</tr>
<tr>
<td>Immediate full light output</td>
<td>Low colour temperature</td>
</tr>
<tr>
<td>No extra equipment</td>
<td>Shorter lamp life</td>
</tr>
<tr>
<td>Cheap initial cost</td>
<td>300W maximum power</td>
</tr>
</tbody>
</table>
3.1.1 Incandescent Lamp Components

The main components of an incandescent lamp are shown below. Although the principle of operation of all GLS and special incandescent lamps is the same, some of the components may differ in size and shape.

3.1.1.1 Glass bulb

The glass bulb of the lamp, when sealed and airtight, is known as the 'envelope’. It is important that all traces of air are removed from the envelope. This is because the presence of oxygen would cause the filament to burn away when the lamp is first turned on (oxidation). The air is removed by the pumping tube (either creating a vacuum, or by filling the envelope with inert gas).

A typical envelope for these lamps is the familiar bulb shape made of soda-lime glass. The shape has lent its name to the general public term 'light bulb’. The industry preferred name is 'lamp'.

The shape of these lamps is convenient for handling during manufacture, and makes the lamp very resistant to breakage, especially considering the glass used is only about 1 millimetre thick.

Excluding coloured and lacquered lamps, there are three basic finishes of glass bulb in GLS lamp production - clear, opal and pearl:

- **Clear** bulbs are fully transparent, allowing the filament to be seen. This type can appear to have a harsh glare, but are still very popular, particularly for traditional and decorative uses (e.g. chandeliers).

- The glass of **opal** bulbs appears white (or more accurately the colour of the gemstone opal). This is achieved by depositing silica or titania onto the inside surface of the envelope. This becomes translucent when lit, and diffuses the light so it appears to emanate from the surface of the lamp, resulting in a softer light. The coating provides excellent light diffusion, but results in some light loss.

- The glass of **pearl** bulbs looks as if it has a fine film of condensation on it. This is achieved by etching the inside surface with hydrofluoric acid.
3.1.1.2 Tungsten filament

A typical tungsten filament operates at about 2,400°C. Tungsten is the material of choice for the filament, because it is the best of the few materials available that can be drawn into fine wires, maintain very high temperatures without melting and produce considerable light. More information on how filaments are coiled (single coil or coiled coil) is provided in the tungsten filaments section.

During the high speed production of lamps it is not possible to remove all traces of air (and therefore oxygen, which is 20-21% of normal air). Left unchecked this oxygen would result in early filament failure from oxidation. To counter this, the filament is coated with red phosphorus known as 'getter'. Its role is to 'get' any residual oxygen inside the envelope. The getter does not harm the tungsten filament, but is extremely reactive with oxygen, and instantly combines with it the first time the lamp is lit. The resultant compound does not react with tungsten, but is hydroscopic, meaning it absorbs any residual water vapour from production.

The introduction of getter has enabled lamps of high quality to be mass produced.

3.1.1.3 Molybdenum support wire

Even when wound as a coil, the tungsten filament is a brittle material and prone to breaking, a condition which worsens throughout the lamp's life.

The support wires restrict the filament's movement and prevent it sagging when hot. This gives the filament the best possible chances of survival under reasonable conditions of use, but cannot protect it from excessive vibration or mechanical shock.

Most lamps have two support wires, but rough service lamps may have up to seven.

Support wires are made from very thin, but extremely strong molybdenum wire. It is important that the wire supports are thin so as not to cool the filament at the point of contact. Molybdenum has a very high melting point, capable of withstanding the high filament temperature.

3.1.1.4 Lead wire (nickel part)

Connecting the lamp's contacts to the filament are two lead (pronounced leed) wires. They are an important component and are from three different wires, the copper clad lower part, the middle Dumet part and the upper nickel part.

This rigid nickel wire provides a solid structure to which the filament can be attached. The nickel is malleable - meaning it can be easily flattened and bent in order to clamp the filament in place.

3.1.1.5 Lead wire (Dumet part)

This part of the lead wire is made of a special nickel-iron wire coated in copper borate, known as 'Dumet wire' (pronounced 'du-may').

The Dumet wire runs through the glass tube, the top end of which is heated until molten and then pinched flat around the wire making an airtight glass to metal seal. Dumet wire has a similar expansion rate to soda lime glass. If the wire expanded at a greater rate than the glass, the glass would crack. This would allow air into the lamp.
It also serves as a fuse system for the case of lamp failure (the filament breaks). The Dumet wire melts and the electricity is safely cut off, preventing arcing between the filament ends and a dangerous increase in current.

3.1.1.6 Screw base

The cap shell is the outer structure of the lamp cap (also referred to as the lamp base). The cap shell provides a safe, easy to use secure physical connection to a lamp holder.

In Edison screw lamp types, the lamp cap may also provide one of the electrical contacts. More details about the different types of lamp caps can be found in the 'lamp caps' page.

Most lamp cap shells are made of aluminium, although brass or nickel plated brass can be used.

3.1.1.7 Insulating glass

The inside surface of the lower half of the lamp cap is coated with a black glass called 'vitrite' which provides the necessary insulation between the live and neutral contacts on the cap.

3.1.1.8 Eyelet (lamp contacts)

The lamp contacts are small brass eyelets (round for Edison screw - ES, oval for Bayonet cap - BC) with a hole in the centre. They are set into the vitrite.

In BC lamps the lead wires are passed through the holes in the centre of each contact, cropped level and soldered or welded into place.

In ES lamp types, one lead wire is passed through the hole in the single contact, cropped and soldered. The other lead wire protrudes out of the side of the lamp, between the cap and envelope, and is soldered to the cap shell. There is no standard requiring the whole eyelet be covered in solder. Therefore, on some lamps part of the brass eyelet may be visible.

3.1.2 Tungsten Filaments

As has already been discussed, tungsten is specifically chosen as the material to manufacture filaments, because it can be drawn into very fine wires and maintain a high temperature without melting whilst giving off considerable light.

A lamp filament is made from a piece of fine tungsten wire approximately a meter long and about the thickness of a human hair. The length and thickness of the wire dictates its electrical resistance, which in turn determines the wattage of the lamp. The supply voltage is also a factor, meaning filament parameters vary for power supplies in different countries.
3.1.2.1 Single coil filaments

To accommodate approximately a meter of wire into a lamp of a useful size, the wire is wound into a tight coil. The result is a single coil about 1mm in diameter and 40mm long. Lamps which incorporate this type of filament are single coil lamps.

In operation, less heat dissipates from a coiled wire than from a straight wire. This is because the coils, being close together, help heat each other, minimising heat loss. This means less energy is required to maintain the temperature of a coiled filament than a straight wire. Hence the coil is more efficient in converting electrical energy to light, i.e. it achieves greater efficacy.

Further improvements in efficacy can be achieved by a secondary coiling of the single coil. The result is a ‘coiled coil’, which gives its name to lamps in which it is incorporated.

Because of the very high operating temperature, the surface of the filament constantly evaporates. This tungsten vapour settles on the inside of the glass bulb, eventually building up a dark film which reduces light output. Eventually a point in the filament becomes so thin it fails.

The blackening of the inside of vacuum lamps has always been a major disadvantage. It is less of a problem at lower wattages because filaments operate at lower temperatures and hence evaporate more slowly.

The main advantage of vacuum lamps is that the vacuum, because a vacuum does not conduct heat, it prevents heat conduction, so the glass envelope stays relatively cool. The same principle is used in vacuum ‘Thermos’ flasks, which keep their contents hot for several hours.

The lower surface temperature (than gas filled lamps) allows vacuum lamps to be used uncovered outdoors. This is because the glass does not become so hot it can shatter due to thermal shock if it gets wet. Obviously, electrically safe waterproof lamp holders need to be used. The lower glass temperature is also useful indoors where a cooler running lamp is required, for example, in a slumber light in a nursery.

3.1.3 Gas Filled Lamps

It has been discovered that evaporation of the filament and migration of tungsten to the inner surface of the glass bulb is reduced if the envelope is filled with gases which are inert (i.e. non reactive). This means that the filament can operate at a higher temperature (and hence provide more light output) for the same lifespan.

Gas filled lamps are therefore more efficient than vacuum lamps.

The inert gas mixture currently used is a combination of argon and nitrogen (air cannot be left in the envelope because it contains very reactive oxygen). It is introduced via the pumping tube. Krypton is sometimes used, but is expensive and reserved for higher priced products such as long life lamps, or those offering a higher efficacy.
3.1.3.1 Lamp gas fill pressure

Cold Lamp: Lamps are filled to about 20% less than normal atmospheric pressure. When cold, if a lamp breaks there will be an immediate in-rush of surrounding air, taking the glass fragments with it, i.e. the lamp will implode.

Hot Lamp: In operation, when hot, the gas mixture tries to expand, but is prevented from doing so by the glass envelope. Consequently, the gas pressure increases to about 20% above atmospheric pressure. If the lamp were to break under these conditions, there would be a violent out-rush of air, forcing glass outwards, i.e. the lamp would explode.

3.1.4 Coloured and Lacquered Lamps

3.1.4.1 Coloured lamps

Colour effects are achieved in two ways.
- The first is to apply a suitable colour filter to the outside of the glass envelope of the lamp. The filter is a coloured glaze which is sprayed on and then baked to form a strong resilient coating. The coating is weather resistant, which is ideal, as most coloured lamps are used outdoors.
- The other method used to achieve a coloured effect is to internally coat the glass envelope with either silica or titania, to which a trace of the appropriate pigment is added.

3.1.4.2 Lacquered lamps

Coloured reflector lamps are examples of lacquered lamps. Coloured lacquers are applied to the outside of the glass envelope. As these lacquers are prone to deterioration from weather, they are recommended for internal use only.

3.1.5 Lamp Caps

As mentioned earlier, the lamp cap (or lamp base) provides the live and neutral connections for the appropriate voltage electricity supply. It also provides safe and easy to use mechanical and electrical connections to the lamp holder.

Most incandescent lamp caps are made of aluminium, but brass or nickel plated brass are also used. Incandescent lamps have essentially only three types of lamp caps; screw, bayonet and single contact.

3.1.5.1 Screw caps

Designed by Thomas Edison, this was the earliest form of lamp cap. It consists of a course screw thread, which is screwed into a complementary thread in the lamp holder. It is known as the ‘Edison Screw’ (ES).

Unlike the bayonet cap, the ES cap has only one insulated contact. The other contact is the cap shell itself, which forms part of the electrical circuit. ES caps for GLS and special incandescent lamps are produced in several different sizes/diameters. They are also popular for low voltage lamps, such as torch bulbs.
The Basics of Efficient Lighting

### Edison screw lamp sizes

<table>
<thead>
<tr>
<th>IEC</th>
<th>Description</th>
<th>Approximate diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>E14</td>
<td>Small Edison screw</td>
<td>14mm</td>
</tr>
<tr>
<td>E27</td>
<td>Edison screw</td>
<td>27mm</td>
</tr>
<tr>
<td>E40</td>
<td>Goliath Edison screw</td>
<td>40mm</td>
</tr>
</tbody>
</table>

### 3.1.5.2 Bayonet caps

The bayonet cap (BC) fixing method gets its name from the 'push and twist' action required to fix a bayonet to early rifles.

Two or three protruding pins (about 2mm long) on the cylindrical cap engage and lock into 'J' shaped slots on the lamp holder. Two spring loaded 'fingers' (the electrical contacts) in the holder push on the contacts, helping to hold the pins in the lamp holder's slots.

Most GLS BC lamps have two pins. The three pin cap was originally designed for lamps with abnormal voltage requirements, and ensured they couldn't be put into two pin lamp holders.

<table>
<thead>
<tr>
<th>IEC</th>
<th>Description</th>
<th>Approximate diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>B15d</td>
<td>Small bayonet cap</td>
<td>15mm</td>
</tr>
<tr>
<td>B22d</td>
<td>Bayonet cap</td>
<td>22mm</td>
</tr>
<tr>
<td>B22d-3</td>
<td>Bayonet cap 3 pin</td>
<td>22mm</td>
</tr>
</tbody>
</table>

### 3.1.5.3 Single contact

Single contact (SC) lamp caps are cylindrical and have a single contact at their base, similar to ES caps. However, unlike ES caps, the shell of an SC cap does not form part of the electrical circuit.

The reason for this is that SC caps are used on strip light lamps which have a cap at either end, one connected to each of the supply terminals. Generally, lamps which have contacts at one end only are known as 'single ended'. Linear lamps (such as strip lights) with a contact at each end are known as 'double ended'.

**Note:** When BC and ES lamps are inserted into their lamp holder, the electrical contacts brush or 'wipe' against each other, giving a good electrical contact. However, with SC lamps there is no contact wiping, because they are pushed in place, or held by the tension of the lamp holder. For this reason, the lamps should be 'seated' by rotating back and forth two or three times. This ensures good electrical contact and helps prevent arcing.
3.1.6 Reflector Lamps

Coating part of the bulb with a reflective material such as aluminium causes a lamp to have a directional output. Design of reflector lamps is a science and involves tailoring the glass envelope into a shape which disperses light in the required fashion.

3.1.6.1 Blown glass reflector lamps

The glass bulbs for most reflector lamps are made by blowing soda-lime glass into a mould which produces the characteristic reflector shape. Consequently they are known as 'blown glass reflector lamps'. These reflector lamps are referred to by a short alpha-numeric code. Prefixed with 'R', the numbers indicate the lamp diameter in millimetres at its widest point e.g. R95, R80, R63 etc.

3.1.6.2 PAR reflector lamps

PAR reflector lamps are not blown but moulded in two pieces - the reflector and the front glass. The two parts are sealed together by heating their edges to a molten state during production. The lamps are known as 'sealed beam reflector lamps' or more commonly 'PAR lamps' (pressed glass aluminised reflector).

The borosilicate glass (similar to Pyrex) used to make PAR lamps is thicker and heavier than that of GLS lamps. This results in lamps able to withstand higher temperature and thermal shock, making them suitable for outdoor use.

The reference for sealed beam reflector lamps is different to blown glass reflectors. The prefix is PAR, but the number (e.g. 38 in PAR38) refers to the lamp diameter in multiples of 1/8 inch, i.e. a PAR38 lamp is 38 x 1/8 inches in diameter.

3.1.7 Lamp Performance

Incandescence is an inefficient way of producing light. Most energy is given out as heat (infrared) and relatively little emitted in the visible part of the spectrum. The typical energy output of a GLS lamp - as a percentage of the total wattage supplied to it - is as follows:

<table>
<thead>
<tr>
<th>Energy type</th>
<th>Percentage output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultraviolet</td>
<td>0.03%</td>
</tr>
<tr>
<td>Visible light</td>
<td>9.0%</td>
</tr>
<tr>
<td>Infrared</td>
<td>84.0%</td>
</tr>
<tr>
<td>Conducted and convected heat</td>
<td>7.0%</td>
</tr>
</tbody>
</table>

Conducted heat is that lost through the lamp holder, Convected heat is that lost to the air surrounding the lamp.

3.1.7.1 Applied voltage

The applied voltage affects all aspects of a lamp's performance. For small changes to the applied voltage (up to a few percent) the following is a useful guide:

A 1% change in applied voltage results in a:
- 0.5% change in current
- 1.5% change in wattage
- 4.0% change in lumen output
• 14% change in life expectancy (life decreases as voltage increases)

The following graph shows the full impact that changes in supply voltage have on lamp life, and other aspects of its performance. Voltage is shown as a percentage along the bottom (x axis) - 100% is the specified rating of the lamp. Lamp life is shown on the green line and green number scale as a percentage. Other aspects of performance are shown as a dark red line and dark red number scale.

3.1.8 Lamp life

The average life of GLS lamps is specified in national and international standards as 1000 hours. This is universally recognised as a compromise between lamp life and light output.

3.1.9 Lamp Standards

The national and international standards for GLS and associated types are as follows:

• IEC 64 (EN 60064), ‘Specification for tungsten filament lamps for general service (batch testing)’ - this standard covers the whole product batch appraisal for checking the lamp manufacturers' claim of compliance. It applies to diffused and clear lamps having a nominal life of 1000 hours, of 100-250V, from 25-1500W and fitted with either BC or ES caps.

• IEC 432 (EN 60432), ‘Part 1: Safety and interchangeability of tungsten filament lamps for domestic and similar lighting purposes.’ - applies to lamps with rating from 50V to 250V and up to 200W.

• IEC 432 (EN 60432), ‘Part 2: “Method of assessment for safety and interchangeability’ - this specifies the method of sampling and inspection to check compliance to part 1.

• IEC 61 (EN 60061), ‘Lamp caps and holders’ - this standard covers lamp caps and holders together with details of gauges needed to check conformity.

• AS/NZS 4934.2 Incandescent lamps for general lighting services - Minimum Energy Performance Standards (MEPS) requirements
3.2 Tungsten Halogen Lamps

Halogen lamps are also a type of incandescent lamp. They are more expensive to buy but last up to 10,000 hours. They can be either 240V lamps, which are usually tubular and are often used in up lighters and outdoor floodlights or low voltage lamps (typically 12 volt). They are generally bi-pin capsule lamps or MR16 (50mm) dichroic lamps, used in down lighting.

**HEADS UP: Tungsten Halogen Lamps and Energy Efficiency**

Tungsten halogen lamps are marginally more efficient than traditional tungsten incandescent lamps. However they cannot compete with fluorescent lamps for efficiency.

Tungsten halogen and tungsten incandescent lamps are discouraged for general purpose illumination, except for special effects such as highlighting.

Low voltage halogen reflector lamps are a poor choice for general purpose illumination – large quantities of lamps are required to light open spaces. In modern homes this is a common error, resulting in poor lighting quality and very poor overall efficiency.

For retrofit purposes, high performance 30W and 35W IRC lamps are available which, together with electronic transformers, can reduce energy consumption by up to 40%.

Some halogen lamps require special light fittings. Low voltage halogen lamps are slightly more efficient than normal lamps of the same wattage but they use a transformer that can consume from 10% to 30% of lamp energy, reducing the efficiency gain.

Halogen lamps were developed as a result of the drive to improve the efficacy and reduce the size of incandescent lamps. This resulted in a worsening of the blackening of the inner surface of the lamp envelope as a result of evaporation of tungsten from the hot filament.

In the 1950's it was found that the addition of a small amount of a halogen (a group of chemical elements with certain properties, one of which has a marked tendency to chemically combine with metals) could prevent the blackening. The five halogen elements are iodine, bromine, chlorine, fluorine and astatine. Lamps with this addition became known as tungsten halogen lamps.

These lamps are sometimes referred to as quartz halogen lamps, as the envelope is almost always made not from glass, but from quartz, which can better withstand the high temperatures at which these lamps operate (although some lower wattage lamps that do not generate too much heat, use 'hard glass'. This is a cheaper material which has thermal properties between soda glass and quartz).

**Performance summary**

<table>
<thead>
<tr>
<th>Range</th>
<th>Low voltage: 20 – 50 watt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mains voltage: 40 – 600 watt</td>
</tr>
<tr>
<td>Colour temperature</td>
<td>2,800 – 3,200 Kelvin</td>
</tr>
<tr>
<td>Life</td>
<td>2,000 – 5,000 hours</td>
</tr>
<tr>
<td>CRI</td>
<td>100</td>
</tr>
<tr>
<td>Efficacy</td>
<td>10-30 lm/watt</td>
</tr>
</tbody>
</table>

**Pros**

<table>
<thead>
<tr>
<th>Immediate on</th>
<th>Expensive to operate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate full light output</td>
<td>May require a transformer</td>
</tr>
<tr>
<td>Whiter light than incandescent</td>
<td>Limited range</td>
</tr>
<tr>
<td>Long life</td>
<td>High cost lamps</td>
</tr>
</tbody>
</table>

Page 40
Compact size, designer luminaires | Reflector lamps not appropriate for general lighting design
More economical than incandescent

3.2.1 The Halogen Cycle

Stage 1: The hot filament causes all the gases, including the halogen to circulate. This is called convection.

Stage 2: Tungsten atoms evaporate from the filament. Normally these are responsible for blackening the envelope.

Stage 3: The tungsten atoms readily combine with the halogen to form a compound known as tungsten halide (also a vapour)

Stage 4: Being chemically bound to the halogen, the tungsten does not deposition the inside of the envelope. Instead, the tungsten halide vapour circulates around the envelope as a result of convection.

Stage 5: When the tungsten halide passes close to the filament, the intense heat splits it back to its components, tungsten and halogen. The tungsten deposits itself back on the cooler parts of the filament and the halogen is free to circulate again. The cycle then repeats.

3.2.1.1 Notes on the use of halogens

1. Air is evacuated during manufacture through an exhaust tube at the crown (top) of the envelope. The envelope is then filled with an inert gas (argon, krypton or xenon) to which is added a precise small amount of the halogen, typically approximately, 10 micrograms (10 millionths of a gram).

2. Iodine and bromine are the two main halogen elements used in lamp manufacture. Very occasionally chlorine is used. Fluorine and astatine are very toxic and are never used for this application.

3. During lamp operation the high temperature ensures the halogen is in vapour form.

4. During manufacture, 'getter' cannot be used to get residual oxygen as is the case with GLS lamps, because the phosphorus would stop the halogen cycle working. Instead, during production the lamp is filled with hydrogen, and the filament is lit. The high temperature causes the hydrogen to combine with any oxygen and form water vapour. The hydrogen and water vapour are then evacuated from the envelope ready for inert gas filling.

5. Early halogen lamps used iodine, and whilst successful, the iodine absorbed part of the spectral output (in the green wavelengths), giving the emitted light a purple tinge. At the time there was a large potential market for tungsten halogen lamps in the film and TV industries. With the advent of colour TV, colour rendering became more important and bromine was found to have a much better colour performance. Now, virtually all halogen lamps use bromine.
### 3.2.2 Lamp Construction

The components of a typical halogen lamp are shown below.

#### 3.2.2.1 Envelope

The quartz envelope is many times stronger than the soda-lime glass used in GLS lamps, and has a much higher melting point. This means it can be closer to the very hot filament without softening, and that the gas pressure inside the envelope can be much higher, reducing tungsten evaporation rates.

One disadvantage quartz has against glass is that it can be contaminated by oils and greases. The natural oils present in human skin contain traces of lithium, sodium and potassium. These, if deposited onto quartz, can locally modify its atomic arrangement when subjected to the extreme heat of operation.

On rare occasions the contamination can be so severe the quartz is weakened enough for the envelope to break. Even when this doesn't happen, the grease left by the fingerprints will permanently mark the quartz.

If a quartz envelope is touched accidentally, it should be wiped clean with a soft cloth moistened with methylated spirits before the lamp is lit for the first time.

#### 3.2.2.2 Filling gas

The environment inside a tungsten halogen lamp envelope is typically composed of an inert gas (argon, krypton or xenon) and a small amount of a halogen (usually bromine). The amount of halogen is very small (typically about 10 millionths of a gram). It is in vapour form during lamp operation, due to the high filament temperature.

#### 3.2.2.3 Exhaust ‘pip’

The exhaust ‘pip’ is the sealed top of the envelope where the exhaust tube was located during manufacture. The exhaust tube is used for evacuating air and filling with gas.
The Basics of Efficient Lighting

3.2.2.4 Filament

The tungsten filament of a halogen lamp is generally made of a superior grade of tungsten to that used in a GLS lamp. The higher grade is required to prevent the filament distorting at the higher operating temperature of a halogen lamp (typically 2700°C).

Halogen lamps use both single and coiled coil filaments, and can be orientated transversely or axially. See the tungsten filaments page for more details.

3.2.2.5 Filament tails

Unlike a GLS lamp, which has lead wires running up to the filament, a tungsten halogen lamp’s filament has long ‘tails’ which attach to the molybdenum foil.

3.2.2.6 Molybdenum foil

In a GLS lamp, the glass to metal seal is made around the Dumet wire, which has a similar expansion rate to soda lime glass. Quartz has an expansion rate so low that no suitable metal can match it. This means that if a wire was used, it would expand more than the quartz and it would crack, destroying the seal.

Therefore, instead of wire, extremely thin metallic foil is used. The foil is so thin that when it becomes hot, the expansion is not enough to break the seal. The foils are usually made of molybdenum and are a few millimetres wide (2-5mm) and up to 10mm long, the two long sides of which are tapered to a razor edge (see point 3.2.2.8 pinch). The width and thickness of the foil depends on the current it is required to carry.

Molybdenum is chosen because it is relatively inexpensive and can withstand the high temperatures used in quartz lamp production.

3.2.2.7 Lamp pins

Lamp pins are usually made completely of molybdenum. However, some lamp types use a pin made of two metals, molybdenum and nickel. These are called joined wire or composite pins. The molybdenum part is always spot welded to the molybdenum foil, leaving the nickel part to protrude from the pinch for connection.

3.2.2.8 Pinch

The base of the quartz envelope encapsulates the metal components (the lamp pins, molybdenum foil and lower part of the filament tails). A gas tight seal is formed around the molybdenum foils by applying a squeezing/pinching action to the hot semi-molten quartz. For this reason the seal is referred to as a pinch seal or pinch.

The long edges of the molybdenum foil are tapered to a razor edge. This is necessary so that the semi-molten quartz will seal perfectly around the foil during the pinching process and make an airtight seal.

The molybdenum foil does have a greater expansion rate than the surrounding quartz, but because the actual expansion rate is so minute, the quartz can withstand it without cracking.

The pinch seal

The most sensitive area of a halogen lamp is the pinch seal. The lamp does not form a complete seal around the lamp pin, but allows air to come into contact with the part of the foil to which the pin is welded. If the temperature at this weld exceeds about 350°C, the foil will begin to oxidise.
The Basics of Efficient Lighting

The gradual accumulation of oxide will eventually stain the quartz, causing it to crack. The crack will run up the pinch seal, allowing air into the envelope. This is one of the most common reasons for lamp failure, usually caused by users not heeding recommendations regarding pinch operating temperatures.

Also, the oxidation of the foil can cause it to become disconnected from the lamp pin, resulting in an 'open circuit' lamp failure.

3.2.2.9 Welds

Before the pinching process creates the lamp's airtight seal, the filament tails and lamp pins are spot welded to the molybdenum foil. Spot welding involves passing a high electrical current through two adjoining components, which become molten and fuse together at the point of contact. This welding together of components ensures a good electrical connection.

3.2.3 Base details

Halogen lamps come with a variety of bases and fittings. It is important to check that these are compatible with the luminaires to be used.

Popular bases for pin based halogen lamps:
The Basics of Efficient Lighting

Popular domestic bayonet and Edison screw fittings:

3.2.4 Tungsten Filaments

The tungsten filament in a halogen bulb has the following features:

1. It is made of a superior grade of tungsten wire than a GLS lamp. This is required to prevent distortion at the extremely high filament temperature.
2. The length and thickness of the wire dictate the wattage (as with GLS lamps).
3. Both single coil and coiled coil filaments are used. Depending on the shape of the mandrel used to wind the filament, the filament may be cylindrical or box shaped.
4. Low voltage halogen lamps (6V, 12V, 24V) must have lower electrical resistance than equivalent mains voltage lamps. This is achieved with thicker, shorter filament wire, which means the filament can be a simple single coil that is so rigid it does not require additional filament supports.

3.2.4.1 Filament orientation

Low voltage halogen lamps use one of two basic orientations: axial or transverse. For many years transverse filaments were the norm, but they are gradually being replaced with axial types because they offer a greater uniformity of light distribution which improves reflector efficiency.

3.2.4.2 Filament supports

Low voltage halogen lamps have filaments that are rigid enough not to require additional support. Mains voltage lamps have filaments similar to those of GLS lamps, in that they are floppy and have to be supported to prevent them sagging when hot. There are two types of filament support used in mains voltage halogen lamps:
Hook supports are used in mains voltage halogen studio/theatre lamps. In these lamps the filament is held in a ‘grid’ pattern by appropriately positioned hooks. Coil supports are used in linear lamps. Loops of tungsten wire are fixed to the filament at 10 to 15mm intervals. They keep the filament centrally positioned and prevent sagging during operation.

Support hooks and coils are made from thin tungsten wire. This minimises heat loss at the point where the support meets the filament. Molybdenum wire (as used in GLS lamps) cannot be used because the halogen would react preferentially with the molybdenum, causing a molybdenum halogen cycle. The supports would rapidly become so thin they would collapse. Bulb-pinched support offers an alternative method for supporting the filament. It uses the quartz bulb itself to grip the filament and securely hold it in the correct position.

During manufacture, the quartz bulb is heated at certain points and ‘pinched’ in to grip and hold up the filament in the bulb. This not only minimises the number of components needed to make the lamp (i.e. no support hooks are required) but it is an extremely effective method of holding the filament securely in position and lamps made with this technique are very resistant to shock and vibration.

### 3.2.5 Operating temperature

A typical tungsten halogen lamp filament operates between 2,400°C and 3,200°C, depending on the lamp type and application. It is not unusual for the quartz envelope to have a temperature as high as 900°C (e.g. in a 1,000W lamp). Smaller, lower wattage lamps generate less heat and therefore the envelope is cooler.

Halogen lamps should not be run so the envelope temperature is less than 250°C. Below this temperature the halogen cycle does not work and envelope blackening can occur. Cool running can typically occur through excessive dimming or forced cooling from, for example, a fan blowing on the lamp.
3.2.6 Low Voltage Lamps

Although the lighting industry refers to 6V, 12V and 24V lamps as low voltage, the correct technical term for any voltage below 50V is extra low voltage or ELV. The electrical industry regards low voltage as anything below 1,000V. These lamps require a suitable battery or appropriately rated transformer. They must NEVER be operated off the mains supply, even through a phase control dimmer, because they are liable to explode.

Low voltage tungsten halogen lamps can be divided into two main categories; capsule lamps and reflector lamps.

3.2.6.1 Low voltage capsule lamps

This is the term used to describe low voltage bi-pin halogen lamps. Some low voltage capsule lamps incorporate a special infra red coating (IRC) on the outside of the envelope. This reflects infrared heat back towards the filament which helps keep the filament at operating temperature with less electrical energy. Luminous efficacy is improved as a result.

3.2.6.2 Low voltage reflector lamps

**HEADS UP: Low Voltage Reflector Lamps and Energy Efficiency**

Low voltage halogen reflector lamps are a poor choice for general purpose illumination because large quantities of lamps are required to light open spaces. From a lighting design perspective, they are simply not suitable for large spaces.

For retrofit purposes, high performance 30W and 35W IRC lamps are available which, together with electronic transformers, can reduce energy consumption by up to 40%.

Low voltage downlights require multiple holes in the ceiling and the insulation above it, thus reducing ceiling insulation performance.

These are available in three main types:

- **Built in reflector (axial and side reflector versions)** – these follow the trend toward miniaturised lamps facilitating revolutionary new lamp designs. The world’s smallest halogen reflector lamps use a special coating to reduce internal heat and can be applied in open luminaires according to IEC 60598-1.

- **Polished aluminium reflectors (or aluminium coated high temperature plastic reflectors)** – these reflectors incorporate capsule lamps fixed in position during manufacture to provide the required beam angle. The aluminium reflects both visible and infrared radiation (heat) from the filament. This means the light beam contains much of the heat given off by the filament. For this reason, these lamps are not suitable for close illumination of heat sensitive displays (meat, chocolate, delicate fabrics etc.).

- **Dichroic** – where a dual purpose reflective coating has been deposited onto the inside surface of the reflector lamp. The coating consists of alternate layers of two materials with special optical qualities - silica and zinc sulphide. These materials are deposited on the inside of the glass reflector dish in layers, each layer being only about 1/10000 mm thick.

This coating allows infrared radiation to pass through it, but reflects visible light. This means that the infrared component of the filament’s output passes through the coating and glass of the reflector and out through the back of the lamp. The visible light is reflected out through the front glass (if present) in the same way as other
reflector lamps (although a small amount of infrared radiation comes directly out of the front of the lamp, without coming into contact with the reflector).

The advantage of dichroic lamps is that their ‘cool beam’ is ideal for illuminating food, flowers and other heat sensitive displays. However, because two thirds of their heat is directed through the back of the reflector, provision must always be made to prevent the build up of heat inside and behind the luminaire.

**SAFETY NOTE:**

In Australia, due to a number of house fires caused by the incorrect installation of dichroic downlights, amendments have been made to AS/NZS 3000-2007 Wiring Rules relating to the clearance requirements from flammable materials in all installations.

![Beam Diagrams - Open 50mm](image)

Typical beam distribution and lux plots for MR16 Dichroic lamps.

**Misuse of 12 Volt Halogen Reflector Lamps**

12 volt halogen reflector lamps (dichroic lamps) have gained enormous market share in recent years, primarily due to their perceived brightness (high intensity), aesthetics and declining cost. They operate at high current, which allows for a short tungsten filament. This in turn provides for very accurate light focusing by the integral reflector. For this reason, this type of lighting has been historically used for spot-lighting objects such as artwork and retail displays. In this application they can be quite effective.
In recent years however, dichroic halogen lamps have become very popular for lighting large spaces such as homes, offices and shops. However their narrow beam requires that large numbers of lamps are needed to illuminate such open spaces whilst endeavouring to maintain some uniformity. It is not uncommon to see many dozens of lamps lighting a relatively small area.

For example, a modern living room may contain 20 x 50W halogen lamps with 20 individual transformers, each with losses of up to 14W. This results in around 1300W of power (280W of which are transformer losses) to light a room that could alternatively be lit with perhaps 400W of GLS lamps or 100W of appropriate fluorescent lighting.

3.2.6.3 Low pressure technology

Manufacturers are now adopting the new technology of low operating pressure, low voltage halogen lamps (capsule and reflector lamps). The operating pressure is only about a tenth that of the conventional high pressure versions. Low pressure technology allows these lamps to be used in fittings without safety shields as there is insufficient pressure in the lamps to cause them to explode, a risk that is inherent with high pressure lamps (which must always be operated with safety shields on the fittings). Check the manufacturers’ information to confirm whether lamps can be safely used in open fronted fillings without a safety shield.

3.2.6.4 Transformers

Low voltage lamps must NEVER be operated directly from the mains. Instead, an appropriately rated transformer or battery must be used. There are two types of transformers - conventional and electronic. Both transform the mains supply voltage down to the required level (6V, 12V or 24V).

To operate low voltage lamps it is necessary to use a step-down transformer. This is a device that 'transforms' the mains voltage (usually 230 V) down to the appropriate level for the particular lamp. Most low voltage lamps are either 6 V, 12 V or 24 V, the most popular type being the 12 V tungsten halogen lamps.

The principle of transformer operation is similar to that of a ballast, in its use of magnetic induction. There are two coils of copper wire wound around a common iron core. The 'primary' coil is connected to the 230 V mains supply and the 'secondary' coil is connected to the lamp. The magnetic field in the iron core generated by the 'primary' coil induces a current to flow in the 'secondary' coil. The process is known as mutual induction. The voltage in the 'secondary' coil depends upon the ratio of the number of turns in each coil.

**Transformer voltage example** - for a 12 V output, the 'secondary' coil must have 19 times fewer turns than the 'primary' coil. For instance, if the supply voltage is 230 V and the 'primary' coil has 2,300 turns, the 'secondary' coil must have 19 times less turns (i.e. 121 turns) to generate a 12 V output.

Low voltage lamps require quite high currents for their correct operation. This means that the lamp supply cables and the 'secondary' coil of the transformer have to be made from much thicker wire to be able to carry such currents without the danger from overheating. Conventional transformers have to be correctly loaded according to their rating.
The Basics of Efficient Lighting

**Transformer loading example** - a 230 V to 12 V transformer rated at 300 W will safely operate 6 x 50 W 12 V lamps. If more than 6 lamps are installed, the transformer will be overloaded and could burn-out due to overheating. If too few lamps are connected so the (unregulated) transformer is under loaded, the secondary voltage will exceed 12 V and lamp life will be reduced due to being over-volted. If the operating voltage increases only 5 %, the lamp life will be halved. Note that many electronic transformers include voltage regulation.

**Conventional transformers**

Conventional transformers can be cubic or cylindrical in shape. The main component is an iron core inside a copper coil. A typical cylindrical transformer rated for a 50W lamp is similar in size to a jam-jar and weighs several pounds. Whilst reliable, their drawbacks are size and weight.

An advantage of conventional transformers is that a phase control dimmer can be used to regulate the mains voltage supplied to the transformer and dim the lamp. Never connect such a dimmer to the output of the transformer.

**Electronic transformers**

Electronic transformers use electronic components that make them light, compact and significantly more efficient than conventional transformers. They may require the use of special phase control dimmers because using the wrong type of dimmer will cause the lamps to flicker.

Minimum energy performance standards (MEPS) for transformers will come into force in October 2010, resulting in further proliferation of electronic transformers. The relevant standard is AS/NZS 4879.2 - Performance of transformers and electronic step-down converters for ELV lamps; Part 2: Minimum Energy Performance Standards (MEPS) requirements.

**Transformer loading**

- **Conventional Transformers**: Conventional control gear and transformers are usually rated not in terms of wattage but by the product of voltage (Volts) and current (Amps), called VA. For example, a 230V/12V 50VA transformer produces a 12V supply from a 230V input and can provide sufficient current to drive a 50W lamp.

  In this example, the current drawn from primary side is: \[ \frac{50VA}{230V} = 0.217 \text{ Amp} \]

  and the output (secondary) side is taking: \[ \frac{50VA}{12V} = 4.17 \text{ Amp} \]

  The VA rating of the transformer is a guide to the total wattage loading it can take.
The Basics of Efficient Lighting

Note 1: If a transformer is overloaded (the current drawn on the output side is greater than the designed maximum) then the voltage across the lamp(s) will be lower than expected and the transformer can overheat. The total wattage should never exceed the VA rating of the transformer.

Note 2: If a transformer is under-loaded there will be no risk to the transformer, but the lamps will be over-volted which will result in short life. Because of this, any failed lamp that is one of many connected to a single transformer, should be replaced as soon as possible to prevent shortening the life of the other lamps.

Electronic transformers are marked with a numeric value which indicates their ‘VA’ rating. There is also a minimum loading (in terms of watts) which is marked on the transformer. It isn’t possible to overload electronic transformers because they incorporate electronic cut-out devices which reset once the correct loading is established. Over-voltage is not a problem either, as the output voltage remains virtually constant over the entire operating range.

Cable Requirements

Cables connecting transformers to the lamps must be of the correct size (i.e. cross sectional area) and length to avoid a significant voltage drop at the lamps, or overheating of the cables themselves.

Because the currents drawn by low voltage lamps are much higher than main lamps, the cables must not be too thin, otherwise they will overheat and cause a fire risk. Cables that are very long will have significant resistance which will result in voltage drop at the lamps, with consequential loss of light output.

3.2.6.5 Lamp holders

Because low voltage lamps take much higher currents than the same wattage mains voltage lamps, the current handling capabilities of the lamp holder have to be considered as well as the cable. For example a 12V 75W lamp would draw 6.25 Amps whereas a 230V 75W mains lamp would draw only 0.33 Amps. Specially constructed low voltage lamp holders must be used.

3.2.7 Mains Voltage Halogen Lamps

There are two types of mains voltage tungsten halogen lamp:

- Single ended
- Double ended
3.2.7.1 Single ended halogen lamps

Single ended halogen lamps have a compact filament inside a quartz envelope, which can be clear or ‘frosted’ (achieved by sandblasting the outer surface of the envelope). They have caps to fit domestic lamp holders, e.g. E27, B15d and B22d.

These come in a variety of shapes including traditional pear (GLS) shape.--

3.2.7.2 Double ended halogen lamps

Double ended halogen lamps are tubular lamps with a contact at each end. These contacts are attached to a short pin emerging from the pinch seal, and recessed into a ceramic insulator.

3.2.8 Spectral Power Distribution

Tungsten halogen lamps, being incandescent, generate a continuous spectrum, with most of their energy radiated in the infra red (heat) part of the spectrum.
The output of a typical quartz tungsten halogen lamp across the spectrum is as follows:

<table>
<thead>
<tr>
<th>Energy type</th>
<th>Wavelength</th>
<th>Percentage output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultraviolet</td>
<td>below 380 nm</td>
<td>0.03%</td>
</tr>
<tr>
<td>Visible light</td>
<td>380 – 780nm</td>
<td>11.3%</td>
</tr>
<tr>
<td>Infrared</td>
<td>above 780 nm</td>
<td>88.4%</td>
</tr>
</tbody>
</table>

Without ultraviolet filter quartz in the quartz envelope, the ultraviolet output would be 0.7%.

### 3.2.9 Lamp Life

Tungsten halogen lamps typically last twice as long as standard GLS lamps, i.e. 2000 hours. However some models are now rated with a nominal life of up to 10,000 hours (see the lighting catalogue for more details). They all offer a higher light output for the same wattage.

The nominal life can be determined by running many lamps simultaneously on a test rig in a laboratory, at their rated voltage until they fail. This is known as life testing. The average life of the group is then quoted as nominal life.

### 3.2.10 Lamp Standards

Nearly all of the tungsten halogen lamps referred to in this module are covered in the international standard IEC 357 (EN 60357), ‘Tungsten halogen lamps (non-vehicle)’.

Lamp caps and bases are detailed in international standard IEC 61 (EN 60061), 'Lamp caps and holders'.

### 3.2.11 Base details

The bases of halogen lamps come in a variety of configurations. It is therefore important to check compatibility when selecting the lamps and luminaires to be used. Popular bases for pin based halogen lamps:
3.2.12 User Protection

3.2.12.1 Safety notice:

Care should be taken not to contaminate the outside surface of the quartz glass for example with greasy finger marks. If this does happen the lamp should be cleaned with a soft cloth moistened with spirits. To reduce the risk of this happening, tungsten halogen lamps are packaged so that they can be installed into luminaries without handling the quartz. Lamps that are contaminated and not cleaned before operation can develop minutely fine cracks that will eventually allow the ingress of oxygen or cause the envelope to shatter.

3.2.12.2 Fusing

Lamps that have no fuse protection or have a fusing system that does not respond quickly enough will suffer from prolonged arcing when the filament fails. Not only will this greatly increase the risk of the lamp exploding, but will permanently damage any un-fused phase control dimmer on the same circuit.

Mains voltage halogen lamps

Mains voltage linear lamps must be operated with a suitable fuse in the circuit because the size of the lamp does not allow an effective fuse system to be built into the lamp. However, these lamps rarely fail in a dangerous manner because the arc produced when the filament fails, at the end of life, cannot sustain itself. This is because the two lead wires are too far apart to allow an arc to be formed between them.

Single ended mains voltage lamps behave in the same way as GLS lamps when the filament fails. For this reason they are protected by two integral fuses (in the lamp base) which break the circuit as soon as the filament fails and an arc is formed between the filament supports.

Note: This fusing system is so effective that the lamps always fail safely. For this reason they are exempted from the safety shield/screen requirements of IEC regulations for luminaires incorporating halogen lamps.

Some lamps are far too small for separate fuse wires to be incorporated into them. These lamps however, are usually designed so that the tungsten filament itself acts as the safety fuse (a system patented by
The Basics of Efficient Lighting

OSRAM). If an arc forms in the lamps at end of life, it cannot sustain itself and very rapidly extinguishes within about 6 thousandths of a second. The lamp just goes off but more importantly, it does not explode.

**Low voltage halogen lamps**

Low voltage halogen lamps do not behave like mains voltage GLS lamps. When the filament fails, the voltage is too low to cause an arc to extend across the filament tails. For this reason no fuse is required, and none is built into the lamp.

3.2.12.3 Ultraviolet

The quartz envelope used for halogen lamps allows the transmission of ultraviolet electromagnetic waves in addition to the visible spectrum. As over-exposure to ultraviolet radiation, especially at shorter wavelengths, can have a damaging effect on skin tissue and can also cause bleaching/fading of colours in fabrics and other materials, this is undesirable. Therefore lamp manufacturers now offer a range of tungsten halogen lamps that use a ‘doped’ material that effectively cuts off the ultraviolet radiation. These ultraviolet absorbing chemicals are usually added during the molten phase of manufacture. Ultraviolet radiation is also discussed in the chapter on health.

3.3 Fluorescent Lamps

**HEADS UP: Fluorescent Lamps and Energy Efficiency**

Fluorescent lamps are typically very efficient in comparison to incandescent lamps. However within fluorescent lamps there is also a range of efficiency and ballast choice also has a significant effect on efficacy – electronic ballasts allow the lamp to run more efficiently.

When selecting fluorescent lamps for any use, the choice of colour temperature is critical to the quality of the lighting design.

Fluorescent lamps are the most energy efficient form of lighting for households. They work by causing a phosphor coating in the inside of a glass tube to glow. Different types of phosphor give different coloured light. Although more expensive to buy, they are much cheaper to run and can last up to 15,000 hours. With careful design, they can replace incandescent and halogen lights in most situations.

Materials that give off visible light when exposed to other forms of radiation, such as ultraviolet or infrared, are described as being ‘phosphorescent’ or ‘fluorescent’. Phosphorescent materials continue to glow after the exposing radiation is removed (such as the luminous paint used on wrist watches to make them visible in the dark). In contrast, fluorescent materials instantly cease to glow once the exposing radiation is removed (such as the powders used on the inside of TV screens).

The first fluorescent lamps were developed in 1940. These were straight tubes because the technology to make them in other forms was not available until the 1970s. Most fluorescent lamps in use today are still the straight tube type because they are relatively cheap and provide excellent light quality and economy of operation.

Because of their high luminous efficacy and long lamp life (compared with incandescent lamps), virtually all commercial and industrial lighting installations use fluorescent tubes. The technology continuously advances, with smaller diameter tubes, offering more light for longer and using less power.
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The more recently introduced induction fluorescent lamps are special fluorescent lamps that work by inducing a current in the lamp from electrical coils around the outside of the tube. There are no electrical components inside the lamp, so no internal components to fail. In theory, an induction fluorescent lamp should never fail.

<table>
<thead>
<tr>
<th>Performance summary (linear fluorescent tubes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
</tr>
<tr>
<td>Colour temperature</td>
</tr>
<tr>
<td>Life</td>
</tr>
<tr>
<td>CRI</td>
</tr>
<tr>
<td>Efficacy</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economical to operate</td>
<td>Expensive to purchase</td>
</tr>
<tr>
<td>Large colour range</td>
<td>Sometimes requires ballast and starter</td>
</tr>
<tr>
<td>Cool operation</td>
<td>Slow to full brightness</td>
</tr>
<tr>
<td>Long life</td>
<td>Often unattractive</td>
</tr>
<tr>
<td>Soft light</td>
<td>Contains mercury</td>
</tr>
</tbody>
</table>

3.3.1 Fluorescent Lamps Components

Inside the glass tube of the lamp is an inert gas, either argon or a mixture of argon and krypton, at a pressure of only about 0.2% of atmospheric pressure. Also in the tube is a very small quantity of mercury between 3mg and 15mg depending on the size and type of the lamp. Mercury is a metal that is liquid at normal room temperature, but inside an operating lamp (which is hot), the mercury is in a vapour form, but its vapour pressure is extremely low in fact only about 0.0007% of atmospheric pressure. Fluorescent tubes (and CFLs) are technically referred to as 'low pressure gas discharge lamps'.

At the ends of the tube are electrodes - usually referred to as cathodes - which are electrically heated tungsten coils coated with barium oxide which when hot, have the property of releasing electrons.

3.3.2 Operation

When the lamp is started, the cathodes are first heated for a short time (1 to 2 seconds) in order to heat the cathodes so they release electrons. A high voltage is then applied across the two cathodes and a discharge is created as the gas and mercury vapour conducts the electrical current. The flow of electrons (i.e. the current), energises the vaporised mercury atoms to make them give off ultraviolet (UV) radiation. The inside of the glass tube is coated with a fluorescent powder, which is referred to as the 'phosphor'. The UV radiation makes the phosphor give off visible light but only whilst exposed to the UV (i.e. the process of fluorescence).
The discharge in the argon or argon/krypton gas causes the gas to give off a bluish glow, which can only be observed in a tube without the phosphor coating. This light constitutes only about 3% of the total light output from the lamp, the remaining 97% is generated by the phosphor.

3.3.2.1 Cold spot temperature

The efficiency of the fluorescence process is dependent upon the mercury vapour pressure, which in turn is governed by the temperature of the residual liquid mercury. Mercury vapour condenses back to the liquid form in the cooler parts of the tube. The lowest temperature region of the fluorescent lamp is called the 'cold-spot' and it's temperature is crucial in controlling how well the fluorescence process works.

The optimum mercury vapour pressure for the highest light output occurs when the cold-spot temperature is in the region of 40°C - 44°C. Fluorescent lamps are usually designed so that they achieve this cold-spot temperature when operating in an ambient temperature of about 25°C (i.e. typical room temperature).

3.3.3 Fluorescent Control gear

Fluorescent lamps are not designed to be operated directly from the mains supply. All fluorescent lamps require a device to generate a high voltage (more than 230V) to initiate the discharge and an additional device to control the discharge current. Unlike incandescent lamps, fluorescent lamps cannot control the current on their own and would draw such high currents from the mains that they would destroy themselves.

Control gear is essentially a device connected in series with a lamp to limit the current it draws down. Whether the control gear is electronic or non-electronic (conventional), it is necessary for the operation of discharge lamps, both fluorescent and high intensity discharge.

All discharge lamps have a negative current-voltage characteristic, which means that voltage decreases with increasing current and, unlike incandescent lamps, their electrical resistance decreases with increasing temperature. A discharge lamp without control gear would draw an ever increasing current as it runs up, and in the process destroy itself.

Transformers for operating low voltage incandescent lamps are also classed as control gear as they control the voltage and current to the lamp. Traditionally, transformers are big, heavy devices but they are being progressively replaced by more efficient, smaller lightweight electronic versions which are significantly more efficient.

3.3.3.1 Conventional Control Gear

It is first necessary to explain how conventional control gear (CCG) works as electronic versions work on similar principles but do so more efficiently.
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The key components in the circuit are:

- **Ballast (or choke)** - the device that controls the current through the lamp
- **Starter** - the switch that starts the lamp
- **Capacitor** - the component that corrects the power factor

3.3.3.2 Ballast

**HEADS UP: Ballasts and Energy Efficiency**

Electronic ballasts allow the lamp to run more efficiently and have significantly lower losses than wire-wound ballasts.

Ballast can also be referred to as a choke. It is a device for restricting (or 'choking') the current through the lamp. It is always connected in series with the lamp. In electrical terms, the ballast is a ‘self-inductance’ and consists of a coil of copper wire wound around a heavy iron core. As the alternating mains current passes through the coil, it generates an alternating magnetic field in the iron core. This alternating magnetic field induces a current in the coil opposing the mains current. The net effect is a limited current through the ballast and the lamp. The current limiting effect is very dependent upon the frequency of the supply current - the higher the frequency, the greater is the 'choking' effect.

Ballasts for use in the Australia are designed to operate at 230-240V and at the supply frequency of 50 Hz (cycles / second), which is the Australian mains supply frequency. The inherent resistance of the copper wire coil absorbs some of the power (given out as heat). Typically, the power absorbed by the ballast (known as 'ballast losses'), is about 25% of the rated power of the lamp being operated.

For example, the total circuit power of a 40W T12 fluorescent tube operated on CCG is about 50W. The lamp consumes 40W and the ballast absorbs 10W, which is 25% of the lamp power.

There are more efficient ballast known as 'low-loss' ballasts available. They are slightly more efficient in that they absorb less of the total circuit power compared with normal ballasts. This is achieved by a more complex design of the iron core and by using much thicker copper wire, which by having a lower electrical resistance, absorbs less power but makes ‘low-loss’ ballasts more expensive.
3.3.3.3 Starter

This is the switching device used to start fluorescent lamps. Essentially, it is a switch that first completes a circuit to heat up the lamp cathodes and then instantly breaks the circuit, which induces a very high voltage across the ballast and lamp. This high voltage starts the discharge in the lamp which then runs up to its normal operation. If the lamp fails to light first time, the starter automatically repeats the process until the lamp strikes. This is what causes a fluorescent tube to flash during start-up. Once the lamp is running, the starter no longer attempts to start the lamp.

The modern fluorescent starter is known as a 'glow' starter because it glows in operation and is designed to be an easily replaceable item.

3.3.3.4 Capacitor

The current restricting effect of the ballast prevents the alternating mains current from being synchronous with the alternating mains voltage. The current is said to 'lag' behind the voltage and the magnitude of this 'lagging' is referred to as the 'power factor' of the circuit.

A capacitor has the opposite effect in that it makes the alternating current 'lead' the alternating supply voltage. By choice of suitable capacitor, connected across the L and N supply terminals, the 'lagging' effect of the ballast can be completely offset by the 'leading' effect of the capacitor. Such capacitors are referred to as 'power factor correction' capacitors (or PFC capacitors). Capacitors designed for power correction as part of fluorescent lamp control gear come in varying shapes and sizes. Many now have a plastic body.

The ideal power factor is 1. Without a PFC capacitor, the power factor is usually less than 0.5 in a fluorescent circuit. With a PFC capacitor, the power factor is restored to almost 1.

The fluorescent lamp circuit will operate normally without the PFC capacitor, but the power meter would register less than half of the apparent power being transmitted - a situation not encouraged by the electricity generation companies.

3.3.4 Starter-less circuits

'Switch start' circuits, as described above are the most commonly used CCG systems for fluorescent lamps.

There are other types of fluorescent circuits that employ only ballasts and transformers to operate the lamps. They need no power factor correction or starters - hence the name 'starter-less' circuits. These types of circuits are only seen in older light fittings and are not used in new installations.
3.3.4.1 Resonant start (RS) circuits

These circuits use two ballasts in series, one of which is connected to a capacitor to produce a high resonant voltage to start the lamp. The second ballast operates normally in controlling the lamp current.

Semi-resonant start (SRS) circuits

These circuits have a single ballast in series and a capacitor connected in parallel with the lamp. The voltage produced by this combination is sufficient to start the lamp and the ballast then operates normally to control the lamp current.

3.3.4.2 Instant start (IS) circuits

These circuits use part of the ballast windings to act as a preheat transformer to rapidly heat the lamp cathodes. The main part of the ballast is combined with a capacitor to produce a resonant high voltage to strike the lamp, which starts up very quickly, warranting the name ‘instant start’. The ballast then operates normally to control the lamp current.

3.3.5 Fluorescent Phosphors

Phosphors are special photo-luminescent chemical compounds that produce visible light when exposed to other forms of radiation, such as UV radiation. Chemically, phosphors used in fluorescent lamps are derived from mixtures of halogenated phosphates of calcium, barium and strontium.

Phosphors used in ‘basic’ tubes are referred to as ‘halophosphate’. The light these ‘halophosphate’ phosphors generate have high levels of blue and green but very little red. This bluish-green dominance results in poor colour rendering, and this disadvantage is typical of all ‘basic’ tubes.

3.3.5.1 Triphosphor fluorescent lamps

Triphosphor fluorescent lamps, tubes and CFLs, not only have the ‘basic’ halophosphate phosphor but also have three additional phosphors which give out peaks of light in the blue, green and red parts of the spectrum. Although these lamps actually have four phosphors, they are always referred to as ‘triphosphor’ lamps. Their advantage over ‘basic’ halophosphate lamps is that they reproduce colours of objects they illuminate very accurately i.e. they have very good colour rendering, with a colour rendering index of around 85.

3.3.5.2 De luxe phosphor lamps

Even better colour rendering is achieved with de luxe phosphor lamps, which have a colour rendering index from 93 to 98 and give light also as good as natural daylight. This is made possible by the addition of two extra phosphors to fill the spectral gap in the blue-green and orange-red parts of the spectral output where the triphosphors are slightly deficient. In fact, de luxe phosphor lamps have at least six different phosphors, and for this reason are also termed ‘multi-phosphor’ lamps.

These lamps are used almost exclusively for making critical colour comparison, such as colour matching of fabrics, paint mixing and colour printing. The application of so many phosphors on the inside of the glass tube has the disadvantage of absorbing and obscuring some of the light generated in the fluorescence process. As a result, de luxe phosphor lamps give out only about 70% of the light of their triphosphor equivalents, making them about 30% less luminous efficient.
3.3.5.3 Special phosphors

Red, green and blue coloured tubes contain only the phosphor that gives that particular colour - so there is minimal light loss and the colour is saturated. Because there is no suitable phosphor that produces a saturated yellow colour, yellow tubes have to be made from normal white triphosphor tubes that have a yellow coloured plastic coating on the outside of the tube. Coloured fluorescent lamps are used mostly for special colour effect displays in shops, pubs, bars and in the theatre.

For example, fluorescent tubes that have a higher emission in the red parts of the spectral output produce light that has a warmer touch and is ideal for meat and delicatessen displays (it makes meat look fresh!). Fluorescent tubes that have a higher red and blue component are used exclusively in horticultural applications for promoting the photosynthesis of plants in order to encourage their growth.

3.3.6 Colour Characteristics

Apart from light output (measured in lumens) of fluorescent lamps, the other two most important characteristics are ‘colour appearance’ (measured as colour temperature in Kelvin) and ‘colour rendering’ (measured in terms of colour rendering index).

3.3.6.1 Colour appearance

‘Colour appearance’ is how 'warm' or 'cold' a lamp's light appears. It is quantified by its colour temperature in Kelvin (the absolute temperature scale). The higher the temperature, the 'colder' the light appears. For example, Warm White which has more red and less blue is 3,000K, and daylight which has less red and more blue is 6,500K.

Quoting just a number to characterise a colour appearance is only of use to those who are familiar with the concept of colour temperature and the Kelvin scale. For triphosphor lamps, colour descriptions are used as well as the colour temperature because they are more easily remembered than numbers (see table). This helps guide users to the correct lamp for their particular application.

<table>
<thead>
<tr>
<th>Colour description</th>
<th>Approximate colour temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very warm white</td>
<td>2,700K</td>
</tr>
<tr>
<td>Warm white</td>
<td>3,000K</td>
</tr>
<tr>
<td>White</td>
<td>3,500K</td>
</tr>
<tr>
<td>Cool white</td>
<td>4,000K</td>
</tr>
<tr>
<td>Daylight</td>
<td>5,400K</td>
</tr>
<tr>
<td>Cool daylight</td>
<td>6,500K</td>
</tr>
<tr>
<td>Sky white</td>
<td>8,000K</td>
</tr>
</tbody>
</table>

3.3.6.2 Colour rendering index (CRI)

Also referred to as Ra, this is a numerical value up to 100 maximum (there is no minimum value). It indicates how good the light source is in rendering colours correctly (i.e. as they would appear in natural daylight).

The higher the number, the better the colour rendering. Natural daylight would give a CRI of 100.
The Basics of Efficient Lighting

<table>
<thead>
<tr>
<th>Phosphor type</th>
<th>Colour rendering ability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halophosphate (basic)</td>
<td>CRI 40 – 56 (fair)</td>
</tr>
<tr>
<td>Triphosphor</td>
<td>CRI 80-89 (very good)</td>
</tr>
<tr>
<td>De luxe phosphor</td>
<td>CRI 90 – 100 (excellent)</td>
</tr>
</tbody>
</table>

Note: CRI values are not given to special coloured tubes and CFLs because the value could be negative and would be of no meaningful use.

3.3.7 Types of fluorescent tubes

3.3.7.1 ‘T’ Designation

Different types of fluorescent tubes are identified by their diameter and length (as well as their wattage). Although the European lamp manufacturers specify lamp dimensions in millimetres, the original (American) system of specifying diameter in the number of eighths of an inch and the length in feet, still persists in the lamp/electrical industry today.

<table>
<thead>
<tr>
<th>T designation</th>
<th>Diameter (inches)</th>
<th>Diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2</td>
<td>2 x 1/8” = 1/4”</td>
<td>7mm</td>
</tr>
<tr>
<td>T5</td>
<td>5 x 1/8” = 5/8”</td>
<td>16mm</td>
</tr>
<tr>
<td>T8</td>
<td>8 x 1/8” = 1”</td>
<td>26mm</td>
</tr>
<tr>
<td>T12</td>
<td>12 x 1/8” = 1½”</td>
<td>38mm</td>
</tr>
</tbody>
</table>

It is still common to refer to fluorescent tubes by their ‘T’ designation to specify the diameter - see table above and images below.
Because T8 and T12 tubes date back several decades, they still tend to be specified by their T designation and by their nominal length in imperial measurement (tube lengths are specified from end to end):

### 3.3.7.2 Bases

Because of their straight format, fluorescent tubes require electrical connections at both ends. Usually, each end of the tube has two pins so that each cathode can be electrically heated to facilitate starting the lamp. The exception is type ‘X’ tubes which are designed for use in explosive atmospheres and do not have cathode heating, and therefore have only one contact pin at each end.

Two pin fluorescent tube bases are all given the prefix 'G', followed by a number which is the separation of the pins, in mm. Single pin fluorescent tube bases are given the prefix 'Fa', followed by a number which is the diameter of the pin, in mm.
3.3.7.3 Cold cathode fluorescent lamps

Cold cathode lamps are special fluorescent tubes that do not have heated cathodes. They have very long lifetimes, but are expensive and require special control gear to operate them. Their primary use is in decorative lighting and they have found many applications in the illumination of advertising displays.

3.3.7.4 Type X fluorescent tubes

Type X fluorescent tubes are characterised by having a single contact pin at each end of the tube. The design of the lamp is similar to T12 fluorescent tubes, but the single pin connection prevents the X type lamps from being used in normal 'cathode preheat' circuits.

These lamps are only for use in special fully enclosed light fittings that are used to provide illumination in dangerous explosive atmospheres such as encountered on gas and oil rigs. The fact that the cathodes have no means of being electrically heated means that they pose no risk of being a source of ignition in an explosive atmosphere (should the light fitting be accidentally broken open, breaking the tubes and exposing the lamps’ cathodes to potentially explosive gases).

3.3.7.5 Induction fluorescent tubes

Induction fluorescent lamps operate on the principle of induction. Unlike incandescent or conventional fluorescent lamps, they have no electrical connection going inside the glass bulb; the energy needed to generate light is transferred through the glass envelope solely by electromagnetic induction. Typically they are a closed rectangular tube, 54mm in diameter, with a triphosphor coating. It employs amalgam technology because their high wattages (up to 150W) generate high operating temperatures.

**Operation**

Coils of wire around the short sides of the lamp carry a high frequency current (supplied by specialist electronic control gear). The magnetic field generated by these coils induces a current to flow through the gas around the inside of the closed tube. The current excites the mercury in the amalgam to emit ultraviolet which then causes the phosphor to fluoresce, in the same way as a normal fluorescent tube.

The luminous efficacy is around 80 lm/W - not quite as high as the T5 & T8 triphosphor tubes. However, the outstanding advantage of induction fluorescent tubes is that with no internal cathodes to fail, they will theoretically never fail. Their useful life is stated as 60,000 – 100,000 hours (more than 10 years continual use) and this is based on a lumen maintenance of 70%.

**Uses**

Induction fluorescent tubes are a truly 'fit and forget' light source - ideal for installations where accessibility for maintenance is difficult and costly, such as factories and road/rail tunnels. Lamps are available in 75W, 100W and 150W ratings. However, they can only be operated with specialist electronic control gear.

3.3.8 Characteristics of Tubes

3.3.8.1 T12 (38mm diameter) tubes

This is the original design from the 1930s, but in spite of being old technology, is still in use today, although the demand is declining in favour of more efficient T8 and T5 tubes. With a few exceptions, T12 tubes are 'basic' tubes using halophosphate phosphors. They are not recommended for applications where good quality
lighting is required or where energy saving lighting is specified. Their use is restricted to industrial and amenity lighting where good colour rendering is not of paramount importance.

### T12 Fluorescent tubes

<table>
<thead>
<tr>
<th>Sizes</th>
<th>Starts at 2ft (20W) and goes up to 6 ft (80W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficacy</td>
<td>Luminous efficacy is in the range of 61 to 86 lm/W</td>
</tr>
</tbody>
</table>

New installations rarely use T12 tubes. Modern T8 and T5 fluorescent tubes offer greater energy savings, as well as superior light output and quality. The only exception is when 8ft tubes are required.

#### 3.3.8.2 T8 (26mm diameter) tubes

These tubes were introduced in the 1970s in the halophosphate version. T8 fluorescent tubes are designed to replace similar wattage T12 tubes as they come in the same lengths and have the same G13 base connections. The only exception is the 8 ft T12 tubes for which there are no T8 equivalents. The maximum practical length for T8 (1 inch) diameter glass tube is 6 ft. as a 1 inch diameter glass tube in an 8 ft. length would be too 'bendy' and too easily broken during insertion or removal.

<table>
<thead>
<tr>
<th>Phosphors and sizes</th>
<th>Halophosphate phosphor (‘basic’) lamps from 18” (15W) to 6 ft (70W), CRI 50 - 60</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Triphosphor phosphor lamps from 19” (10W) to 6 ft (70W), CRI 85.</td>
</tr>
<tr>
<td></td>
<td>Multi-phosphor lamps from 18” (15W) to 5 ft (58W), CRI 93 - 98.</td>
</tr>
<tr>
<td>Efficacy</td>
<td>Halophosphate and multi-phosphor T8 fluorescent tubes have similar luminous efficacy to their T12 equivalents.</td>
</tr>
<tr>
<td></td>
<td>Triphosphor T8 tubes are 10-15% more luminous efficient, even when operated on conventional control gear, the improvement in luminous efficacy is then as high as 30%.</td>
</tr>
</tbody>
</table>

T8 triphosphor tubes are actively promoted as energy saving alternatives to T12 tubes. For example, by replacing a 40W (4 ft.) T12 tube with a 36W (4 ft.) T8 tube, the energy saved is 4W (i.e. 10%) and the light output from the triphosphor tube is also 10% more.

#### 3.3.8.3 T5 (16mm diameter) tubes

T5 fluorescent tubes can be divided into two technologies - ‘old’ and ‘new’.

**Old technology:** These first appeared in the early 1970s. They generally use halophosphate phosphors and have relatively low luminous efficacies (40 to 66 lm/W). Because of their small size and low wattage - ranging from 4W (6") to 13W (21"), they have restricted use. Their application is in small illuminated road signs, battery powered emergency lighting and domestically in under cupboard kitchen lighting.

**New technology:** The ‘new’ technology T5 fluorescent tubes were first introduced to the market (in Europe) in 1996. These tubes represent the latest developments in triphosphor fluorescent tube technology. They are currently the most luminous efficient of all fluorescent lamps. They are specifically designed to be operated only with high frequency electronic control gear, making ‘new’ T5 lighting systems the most energy efficient currently available.

They are not interchangeable with either T8 or T12 tubes. They have different pin base connections to T8 and T12, and are approximately 2” shorter than the standard imperial lengths. ‘New’ T5 tubes are for use only
The Basics of Efficient Lighting

in dedicated light fittings that have specially designed reflectors that take advantage of the narrower light source. Smaller light sources produce less obscuration of the reflected light, allowing more of the light generated by the lamp to come out of the fitting.

### T5 Fluorescent tubes

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lengths: 549 mm (21W) to 1449 mm (35W)</td>
<td>Use: HE tubes are used where the most energy efficient system is required.</td>
</tr>
<tr>
<td></td>
<td>HO (HO = High Output)</td>
<td>Same lengths as HE but in larger wattages for higher light output.</td>
</tr>
<tr>
<td></td>
<td>Wattages: 24W, 39W, 49W, 54W, 80W</td>
<td>Use: HO tubes are used where the requirement for high light levels is more important than energy efficiency.</td>
</tr>
<tr>
<td></td>
<td>Lengths: 549 mm (24W) to 1449 mm (80W)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FC (C = Circular)</td>
<td>Essentially HO tubes in circular format.</td>
</tr>
<tr>
<td></td>
<td>Wattages: 22W, 40W and 55W</td>
<td>Use: FC circular tubes are used in applications where more attractive, aesthetically designed light fittings are preferred to the conventional long narrow types</td>
</tr>
<tr>
<td>Efficacy</td>
<td>The HE version is highly efficient at 104 lm/W. About 20% more luminous efficient than T8 triphosphor tubes.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HO and FC versions have slightly lower luminous efficiency than HE</td>
<td></td>
</tr>
<tr>
<td>Colour</td>
<td>‘New’ T5 tubes are available in triphosphor with HO also available in Deluxe triphosphor.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>They are available in all the colour appearances - from Very Warm White at 2,700K to Sky White at 8,000K.</td>
<td></td>
</tr>
</tbody>
</table>

The advantage of using ‘new’ T5 lighting systems is that the light fittings are much smaller and compact. Also, because the fitting efficiency is higher, less are required (than T8 fittings) to provide the required illumination levels. This is a significant factor in keeping the installation and operating energy costs as low as possible, without sacrificing the level or quality of the light.

### 3.3.8.4 T2 (7mm diameter) tubes

These ‘pencil slim’ fluorescent tubes are only 1/4” (7 mm) in diameter. They have a unique base connection (referred to as W4.3) used only for this T2 tube. It needs special electronic control gear for its operation.

<table>
<thead>
<tr>
<th>Sizes</th>
<th>Available in 4 sizes: 219mm(6W), 321mm(8W), 423mm(11W) and 524mm(13W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td>Colour appearances in Warm White (3,000K), Cool White (4,000K) and Daylight (6,000K). All offer good colour rendering with CRI 70 - 79</td>
</tr>
</tbody>
</table>
The Basics of Efficient Lighting

FM (T2) tubes are not designed for general lighting as their wattages and hence their light outputs are too low. However, because of their very small diameter they are used extensively in display cabinets, for illuminating signs, picture lighting or any application where unobtrusive lighting is required.

3.3.9 Lamp Performance

For fluorescent tubes (and CFLs), the most important aspects of their performance are the following:

- Efficacy
- Lifetime - the average operating hours
- Lumen maintenance - how the light output changes over the lifetime of the lamp
- Frequent switching - how the life is reduced from the effect of being switched on and off
- Ambient temperature - how the ambient temperature around the lamp affects its light output

3.3.9.1 Lifetime

The industry states that fluorescent lamps will last for a 'rated average life', which is the time, in hours, when 50% of the lamps in a test batch would be expected to have failed. This is the same as saying when 50% are still surviving and is defined as the “mortality” rate of the lamp.

Manufacturers state a figure for 'rated average life' in their literature, such as 10,000 hours or 15,000 hours; but for the lighting designer and even the end user, it is important to know the rate at which lamps in an installation will fail so that the annual lamp replacement cost can be estimated. For this reason, the life performance of fluorescent lamps is expressed in the form of a 'survivor graph', which shows the percentage of surviving lamps relative to the cumulative burning hours. The time at which 50% of the lamps are still operating (i.e. when 50% have failed) is what is stated as the 'rated average life'.

3.3.9.2 Lumen maintenance

Knowing the rate at which the light output from a fluorescent lamp declines during its lifetime is quoted as 'lumen maintenance'. It is important in designing light schemes to be sure there is always enough illumination for the particular tasks being undertaken. Too much light can be uncomfortable, but not enough light can be stressful and potentially dangerous.

Lumen maintenance is always shown graphically, otherwise it would require a long list of lumen levels at different operating hours.

Triphosphor fluorescent tubes (T8 & T5 FH/HO/FC) all have excellent lumen maintenance, losing only about 10% of their initial output over their lifetime. Triphosphor CFLs perform less well, with about a 20% light loss.
over their lifetime. 'Basic' halophosphate tubes tend to suffer the largest light loss, with about 30% loss over their generally shorter lifetime.

3.3.9.3 Frequent switching

All fluorescent lamps (with the exception of certain specialist lamps), suffer from reduced life if subjected to abnormally frequent on / off switching. This is because the high starting voltage gradually erodes the cathodes, which fail sooner if the lamp is given frequent starts. The effect is more pronounced with lamps operated from conventional (magnetic) control gear. With electronic control gear the effect is less severe, but there can be still a reduction in lamp life.

The life reduction varies according to how frequently the lamp is switched. Life claims for fluorescent lamps are based on life testing with one switch cycle every 3 hrs (i.e. 2¾ hrs /¼ hr OFF). This equates to about 3 switching cycles in an average working day. More frequent switching can result in reduced lamp life.

This effect is very important to be aware of, especially with installations using presence detectors, where switch frequencies could be several hundred times a day. Under such conditions, the cost of having to frequently replace lamps would considerably outweigh any savings in energy costs by installing presence detectors.

3.3.9.4 Ambient temperature

The ambient temperature of the atmosphere surrounding an operating fluorescent lamp can significantly affect its luminous output. Both very low and very high ambient temperatures result in reduced light output - although amalgam technology has improved the high and low temperature performance.

For 'new' T5 FC, T8 and T12 tubes, the peak light output is achieved at an ambient temperature around 25°C. For 'new' T5 tubes, the peak light output is achieved at an ambient temperature of around 35°C. CFLs are sensitive to ambient temperature as well as their operating position. Mercury only CFLs give their peak light output in the 20° - 25°C region, with the lamp in either base up or horizontal position. In the base down orientation, the peak light output occurs at a much lower ambient temperature of 5° - 10°C. This is the recommended burning position for the CFL used outdoors, where the ambient temperature is lower, especially in winter.
Amalgam lamps have the advantage of maintaining more than 90% of the peak light output in an ambient temperature range of around 5° - 70°C.

3.4 Compact fluorescent lamps

**HEADS UP: Compact Fluorescent Lamps and Energy Efficiency**

Compact fluorescent lamps (CFLs) represent a very efficient choice for residential applications and where linear fluorescent tubes are not suitable. CFL quality has improved significantly in recent years and they have become popular in almost all Australian households. Once again, choice of colour temperature is critical to good lighting design.

Compact fluorescent lamps (CFLs) have all the benefits of fluorescent tubes but take advantage of the fact that fluorescent lamps will operate just as well even if the tube is bent double (or even treble). The electrical discharge follows the bore of the tube irrespective of its contour. This allows for all the electrical connections to be at one end of the lamp and they can be designed to fit into conventional bayonet or screw fitting light sockets, greatly extending the scope of CFL applications as a more energy efficient replacement for incandescent lamps in many light fittings.

The operation and performance characteristics modes of CFLs, are the same as for fluorescent lamps, as covered in the previous section.

### Performance summary

<table>
<thead>
<tr>
<th></th>
<th>Compact fluorescent integrated: 6 – 42 watt</th>
<th>Compact fluorescent non-integrated: 5 – 55 watt</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Range</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Colour temperature</strong></td>
<td>Compact fluorescent integrated: 2,700 – 6,500 Kelvin</td>
<td>Compact fluorescent non-integrated: 2,700 – 6,500 Kelvin</td>
</tr>
<tr>
<td><strong>Life</strong></td>
<td>800 – 16000 hours</td>
<td></td>
</tr>
<tr>
<td><strong>CRI</strong></td>
<td>Compact fluorescent integrated: 76 – 82</td>
<td>Compact fluorescent non-integrated: 80 – 92</td>
</tr>
<tr>
<td><strong>Efficacy</strong></td>
<td>Compact fluorescent integrated: 33 – 65 lm/watt</td>
<td>Compact fluorescent non-integrated: 46 – 82 lm/watt</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Pros</strong></th>
<th><strong>Cons</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Economical to operate</td>
<td>Expensive to purchase</td>
</tr>
<tr>
<td>Large colour range</td>
<td>Sometimes requires ballast and starter</td>
</tr>
<tr>
<td>Cool operation</td>
<td>Slow to full brightness</td>
</tr>
<tr>
<td>Long life</td>
<td>Often unattractive</td>
</tr>
<tr>
<td>Soft light</td>
<td></td>
</tr>
</tbody>
</table>

A new standard will be introduced for CFLs sold in Australia from November 2009. This standard will specify requirements for a range of efficiency and quality issues including lifetime requirements.

3.4.1 Types of CFLs

There are two types of CFLs:

- **Pin-based CFLs** - with pin base connections for operation from control gear that is separate from the lamp
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- **Integral ballast CFLs** - where the control gear is an integral part of the lamp and housed in the base of the CFL

3.4.1.1 Pin based CFLs

Pin-based CFLs have connections for operation from control gear that is separate from the lamp, i.e. the control gear is NOT housed within the lamp. They have bases with either 2 pins or 4 pins for making the electrical connections to the lamp. Pin-based CFLs cover a very large range of wattages from 5W to 120W increasing in size with increasing wattages.

CFLs with 2 pin bases are for operation only from conventional magnetic ballasts. The starter switch for striking the lamp is contained inside the base of the lamp. This circuit arrangement only needs two electrical connections to the lamp - hence the 2 pins. These CFLs will not operate from electronic control gear.

CFLs with 4 pin bases are usually for use only with electronic control gear (ECG). They do not have integral starter switches as the starting circuit is part of the separate electronic control gear. Both cathodes in the lamp each require 2 connections for their electrical heating during starting - hence 4 pins in total.

**Pin bases**

There are a variety of styles of CFL bases. Within each style there can be several variations that superficially all look the same, but in fact they are all slightly different from each other. Although they have the same pin positions, each base has two small flanges, the position of which is unique to that wattage of lamp. The flanges line up with corresponding slots in the lamp holder, preventing the CFL being put into the wrong light fitting where it would be operated incorrectly, causing possible damage to both lamp and control gear.

The following diagrams show some of the base variations and refer to the manufacturers’ lighting catalogues to see which lamp has which base.

2 pin bases:
4 pin bases:

3.4.1.2 Integral Ballast CFLs

CFLs with the control gear (usually electronic) built into the lamp base are generally referred to as 'integral ballast' CFLs - sometimes written in abbreviated form as CFLi. These CFLs are the well known 'energy saving lamps' used extensively in the home. They are fitted with normal Edison screw bases to enable them to be directly inserted into normal domestic lamp-holders. They can provide up to 80% energy saving over normal incandescent lamps (more details below).

The very first 'integral ballast' CFLs used magnetic control gear and appeared on the market in 1979. These lamps were big and heavy, but were superseded by the more compact lightweight versions using electronic control gear in 1984.

Most integral ballast CFLs sold in Europe use a triphosphor (2,700K) to produce a warm effect lighting with very good colour rendering - similar to the conventional lamps they are designed to replace.

Lamps are also manufactured with Cool White and Daylight triphosphors, but these are not popular in the Northern Hemisphere as the colour appearance is too 'cold'. However, they are more popular in tropical countries where a 'cold' effect light is preferred.

Since their introduction in the mid 1980s, integral ballast CFLs have continually improved. Not only has the range and variety increased, but they have become much smaller, with their life virtually doubling - from 8000 hours in 1984 to 15000 hours today. Integral ballast CFLs range from 3W (single turn) to 30W (quadruple turn).

Until the mid 1990s, these 'integral ballast' CFLs were all of the parallel tube design (and are sometimes called 'stick' lamps). The public preference has always been for CFLs to be the same size and shape as conventional incandescent lamps, but it was not until 1995 that the technology was able to produce energy saving lamps that looked like normal incandescent lamps. They are available in a range of wattages to replace conventional incandescent lamps and candle lamps.
"Double-envelope" CFLs are in essence the same as the tubular types but with an outer glass or plastic bulb to give them the familiar shape of conventional incandescent lamps.

Because of the enclosed design, the operating temperatures of the fluorescent tubes inside the outer bulb are much higher than normal, so these lamps use amalgam technology to maximise the light output.

**Special integral ballast CFLs**

Manufacturers have also developed some special 'integral ballast' CFLs with unique features for particular applications:

- Integral ballast CFLs with special electronic control gear that allows them to have a high and a low light output - controlled by the mains switch. This switch dimming feature is suited to mood lighting in living rooms or for low level night time lighting on stairs, landings or children's bedrooms.
- Integral ballast CFLs have infinitely variable light output, and as such can be introduced into all applications in combination with adequate phase control dimmers.
- Energy saving integral ballast CFLs that can provide automatic outdoor security lighting via a light sensor built into the base. They automatically switch on at dusk and off at dawn, without the need for a time switch.
- Integral ballast CFLs with special electronic control gear, gives the lamp a preheat 'boost' start so that it provides a high light output much quicker than other CFLs and prolongs the life of the cathodes. These lamps are ideal for installations that are frequently switched, e.g. for use on frequently operated timed switches in corridors, entrances and stairwells in multi-occupancy dwellings, as they can be switched on and off any number of times without reducing the lifetime of the lamp.
- Integral ballast CFLs enclosed in a large-bulb lamp. They are designed for use in luminaires where the lamp is visible. The outer bulb is made of plastic, which helps reduce weight and improve impact resistance.
- Integral ballast CFLs designed to replace conventional incandescent reflector lamps (e.g. R80, R95 or PAR 38). These can greatly reduce the thermal load on the objects they illuminate.

### 3.4.2 Amalgam Technology

When fluorescent lamps operate in conditions where the temperature of the lamp is much higher than normal, the fluorescence process becomes less efficient, making the lamp lose light output. This happens because the high operating temperature increases the mercury vapour pressure in the lamp and this results in reduced UV for the fluorescence process. This is very apparent where CFLs (especially the higher wattage versions that give out more heat) are operated in compact, often enclosed, fittings in interior installations.

The following graph shows how lumen output is affected by ambient temperature for both mercury and amalgam CFLs.
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The light output loss problem is most pronounced with interior lighting installations where room temperatures are generally high, especially at ceiling level. For this reason the industry has developed 'amalgam CFLs'.

Amalgam lamps use a low mercury content alloy (the amalgam), often in pellet form, to stabilise the mercury vapour pressure inside the lamp. This keeps the lamp efficacy high over a wider range of ambient temperatures and virtually eliminates the fluctuations of light output at varying temperatures. In addition, amalgam technology allows a reduction in the amount of mercury used in fluorescent lamps.

The disadvantage of amalgam technology is that there is a noticeable ‘warm-up time’ when the lamps are switched on.

3.5 High Intensity Discharge Lamps

HEADS UP: High Intensity Discharge Lamps and Energy Efficiency

High intensity discharge (HID) lamps are usually very efficient. The exception is high pressure mercury (or 'mercury vapour') lamps which are being phased out in various parts of the world due to their poor efficiency and high mercury content.

Electronic control gear for HID lamps will also reduce energy consumption and should be selected where feasible.

High-intensity discharge (HID) lamps are a type of electrical lamp that produces light by means of an electric arc between tungsten electrodes housed inside a translucent or transparent fused quartz or fused alumina arc tube. This tube is filled with both gas and metal salts. The gas facilitates the arc's initial strike. Once the arc is started, it heats and evaporates the metal salts forming a plasma, which greatly increases the intensity of light produced by the arc and reduces its power consumption. This is the same principle as lightning where the high voltage that builds up in the storm clouds discharges itself through to the ground. The passage of electrical current through the atmosphere (mainly nitrogen) 'excites' the nitrogen atoms to give out a bluish-white light during that split second of the discharge.

High intensity discharge lamps produce a range of visible radiation at specific wavelengths consistent with the metal used in the lamp. Typical metals are mercury, sodium and a combination of metal halides, which effect their colour appearance and colour rendering properties. Mercury and sodium lamps have their characteristic colours and are not renowned for their good colour rendition. They tend to be used where good colour rendering is not the main requirement. Metal halide lamps produce ‘daylight’ quality white light with extremely good colour rendering and so are used in applications where accurate colour reproduction is paramount.
The Basics of Efficient Lighting

Compared with fluorescent and incandescent lamps, HID lamps have higher luminous efficacy since a greater proportion (about 25%) of their radiation is in visible light as opposed to heat. Their overall luminous efficacy is also much higher as they give a greater amount of light output per watt of electricity input.

During the 1930s when fluorescent tubes were being developed, scientists also looked into ways of making sodium and mercury generate visible light. By the mid 1930s, the first commercial high pressure mercury and low pressure sodium lamps became available. Almost 30 years later, the high pressure sodium lamp was developed and about the same time the first metal halide discharge lamps appeared. There is also a type of discharge lamp that does not use metals to generate the light but relies on the excitation of xenon gas.

The high intensity discharge lamp has been adopted because all these discharge lamps produce light from a relatively small intense electrical discharge (i.e. compared with the larger discharge in a fluorescent tube). The table below summarises the key properties of the different types of HID lamps.

<table>
<thead>
<tr>
<th>Lamp type</th>
<th>Range (watts)</th>
<th>Colour temperature (Kelvin)</th>
<th>Life (Hours)</th>
<th>CRI</th>
<th>Efficacy (lm/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High pressure mercury</td>
<td>50 – 1,000</td>
<td>3,000 – 4,000</td>
<td>15,000 - 24,000</td>
<td>40 – 60</td>
<td>32 – 60</td>
</tr>
<tr>
<td>Low pressure sodium</td>
<td>18 – 180</td>
<td>Below 2,000</td>
<td>16,000</td>
<td>15</td>
<td>100 – 200</td>
</tr>
<tr>
<td>High pressure sodium</td>
<td>70 – 1,000</td>
<td>1,900 – 2,100</td>
<td>12,000 - 32,000</td>
<td>23 – 25</td>
<td>70 – 120</td>
</tr>
<tr>
<td>Metal halide</td>
<td>50 – 2,000</td>
<td>3,000 – 6,000</td>
<td>6,000 - 24,000</td>
<td>60 – 90+</td>
<td>65 – 120</td>
</tr>
<tr>
<td>Xenon discharge</td>
<td>6,000 – 6,500</td>
<td>&gt;90</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usually very economical to operate</td>
<td>Expensive to install and re-lamp</td>
</tr>
<tr>
<td>Long to extremely long life (up to 32,000 hours)</td>
<td>Control gear required for operation</td>
</tr>
<tr>
<td>Metal halide lamps give good colour rendition</td>
<td>Sodium lamps give poor colour rendition</td>
</tr>
<tr>
<td></td>
<td>May require the use of safety screens</td>
</tr>
<tr>
<td></td>
<td>Time delay before full light output &amp; re-strike</td>
</tr>
<tr>
<td></td>
<td>Not suitable for dimming</td>
</tr>
</tbody>
</table>

3.5.1 Performance of HID Lamps

Unlike fluorescent lamps, HID lamps are not adversely affected by either high or low ambient temperatures. In fact, high pressure sodium and metal halide lamps are frequently used to provide the permanent lighting in cold storage areas. Obviously, excessively high ambient temperatures will have a damaging effect by causing the lamps to overheat and fail prematurely.

The essential factors for the performance of HID lamps are:

- **Life** - how long do they last
- **Lumen maintenance** - how does the light output decline over operating hours
- **Luminous efficacy** - how much light is produced for the energy consumed

Like fluorescent lamps, the claimed 'rated average life' represents the operating time (in hours) to a 50% survival level (which is the same as a 50% failure level) for a large group of lamps on a pre-determined switching cycle (hours on and hours off). Survival levels and lumen depreciation of operating time are usually expressed graphically.
3.5.2 How HID Lamps Work

Apart from xenon discharge lamps, all HID lamps operate on the principle of light being generated from the excitation of atoms of certain metals in an electrical discharge between two electrodes, through inert gases such as neon, argon and xenon.

The bright discharge between the electrodes is not straight, but curved into an arc shape. This is due to the intense convection movement of the hot gas in the discharge tube.

3.5.2.1 Control Gear

As with fluorescent lamps, High Intensity Discharge lamps are not designed to be operated directly from the mains supply, but require control gear for their ignition and operation. HWL high pressure mercury lamps with their integral filament are the only exception.

It is usual to house the control gear in the light fitting. Sometimes, depending on the aesthetic requirements for the lighting system, the control gear is sited remotely and connected by cable to the light fitting. The remote location of the control gear requires specially designed ignitors and cabling in some cases to ensure an adequate starting voltage at the lamp.

3.5.2.2 Ballast

As with the fluorescent lamp operation, the ballast in an HID circuit can also be referred to as a choke and is defined as a current limiting device.

3.5.2.3 Ignitor

Switching devices for fluorescent lamps are always referred to as ‘starters’. For high intensity discharge lamps such as high pressure sodium and metal halide, the internal gas pressure is much higher and requires a much higher voltage to strike the lamp. Typically, this striking voltage is in the region of 3000V to 4500V and the striking pulse needs much more energy than for fluorescent lamps. For this reason the switching device is always referred to as the ‘ignitor’.

There are two types of ignitors used for high pressure discharge lamps.

**Impulse type ignitor** - this is a switching device that is connected to part of the ballast coil inducing it to operate as a high voltage transformer to generate sufficiently high voltage to strike the lamp. The ballast itself also experiences these very high voltages and requires strong insulation to prevent internal short circuiting. This type of ignitor is mainly used where the lamp is some distance from the control gear, such as tall lamp posts where the control gear is in the base of the column and the lamp is 20m – 30m up in the lamp-house. 2 wire impulse reactor - ignitor circuit shown below:
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- **Super-imposed pulse ignitor** - this is in essence a high voltage transformer, the voltage pulse of which is super-imposed on the mains voltage across the ballast. The ballast is not exposed to high voltages as in the case of impulse type ignitors, so ballast life is generally longer. Super-imposed pulse ignitors are not suitable for remote siting and must be within a 2m – 3m cable length from the lamp. 3 wire super-imposed pulse ignitor circuit shown below:

![Super-imposed pulse ignitor circuit](image1)

- **Internal Ignitor** - Some high pressure sodium and metal halide lamps have 'internal' ignitors that consist of a bi-metal switch inside the lamp envelope. At switch on, the mains voltage is across this switch and as the bi-metal contacts heat up, they spring apart. This rapid breaking of the circuit induces a high voltage across the ballast causing the lamp to strike. Once the lamp runs up, the ignitor stops operating. A typical circuit is shown below:

![Internal Ignitor circuit](image2)

3.5.3 Types of HID Lamp

3.5.3.1 High pressure mercury lamps

**HEADS UP: High Pressure Mercury Lamps and Energy Efficiency**

High pressure mercury (or 'mercury vapour') lamps are the least efficient of the HID lamps. They are being phased out in various parts of the world, due to their poor efficiency and high mercury content.

Developed in the 1930s, these lamps use mercury metal in an electrical discharge through argon gas at high pressure. Unlike the low pressure discharge in fluorescent tubes, the higher operating pressure makes the mercury produce proportionally more visible light (with a slight green tinge) and less ultraviolet. The residual ultraviolet is converted to visible light by a phosphor coating on the inside of the outer bulb.

High pressure mercury lamps are mostly elliptical in shape with Edison screw bases. Clear tubular and reflector versions are also available but have significantly declined in popularity over the last 10 years.
Some versions have both a tungsten filament and a mercury discharge tube. The filament has a dual role in that it provides instant light at switch-on, and acts as a current controlling device for the discharge tube. These types operate directly from the mains supply without the need for control gear.

Light is generated by exciting atoms of mercury in an electrical discharge through argon gas. The electricity is conducted through the argon gas between tungsten electrodes at each end of a quartz arc-tube. The electrodes are coated with electron emissive materials similar to those on fluorescent tube cathodes. The operating pressure in the arc-tube is about three times the atmospheric pressure (which is approximately 1,500 times higher than in fluorescent lamps, thus these lamps are called 'high pressure mercury'). At these operating pressures, mercury atoms produce most of the colours of the visible spectrum, but mostly in the blue and green regions. The light given out is white but with a bluish-green tinge.

The control gear consists of a ballast (also called a ‘choke’) which controls the current through the lamp. A high voltage igniter is unnecessary as these lamps will start at around 170V - well within the 230V peak mains supply voltage.

The self ballasted types (HWL) use the resistance of the series connected filament to control the current through the arc-tube. This means they can be used instead of incandescent lamps.

**Starting**

High pressure mercury lamps do not require starting aids as they will ignite at normal mains voltage, but to make the ignition process easier and more reliable, an auxiliary electrode (sometimes referred to as the starting electrode) is employed to initiate the arc.

The proximity of the auxiliary electrode to the main electrode (only a few millimetres apart) starts a small arc when the lamp is switched on. This starts off the ionisation of the argon gas so that the main discharge can quickly be struck between the electrodes. The current through the auxiliary electrode is kept very small by means of a series resistor in the lamp so that most of the current is carried by the main discharge.
**Construction**

The arc-tube has to be made from quartz (fused silica) because glass would soften and distort under the high operating temperature and pressure. The construction of the quartz arc-tube uses the same pinch-seal technology as for tungsten halogen lamps.

The quartz arc-tube is mounted inside an elliptical glass bulb which is filled with inert nitrogen gas which not only conducts away some of the heat from the arc-tube but also prevents damaging oxidation of the nickel framework supporting the arc-tube. The outer bulb of lamps 250W or greater are made from ‘pyrex’ type heat-resistant glass. Below 250W, the outer bulbs are made from soda-lime glass - the same type of glass used for normal light bulbs.

Approximately 10% of the radiant output from high pressure mercury lamps is ultraviolet. Though it would be safely absorbed by the outer glass bulb, it is not wasted but converted to visible light. The inside of the outer bulb is coated with yttrium vanadate phosphor to convert the ultraviolet to red light which improves the spectral output of the lamp by making the light less dominant in the blue-green region. The white phosphor powder also serves to give the lamp a softer, more diffuse appearance.

**De luxe and super de luxe versions**

De luxe versions of these lamps have additional yttrium vanadate phosphor to further increase the red output, making the light have a slightly 'warmer' appearance.

Super de luxe versions have an internal golden-yellow powder coating as well as additional phosphor. This gives the lamps an almost 'incandescent light bulb' appearance, but at the expense of a noticeable loss in light output.

**HWL - Mercury Tungsten Blended Lamps**

Versions of high pressure mercury lamps that operate directly from the mains supply without the need for control gear have a coiled tungsten filament connected in series with the mercury arc-tube. These are the HWL lamps and are referred to as 'blended' lamps as they blend together incandescent lighting with mercury discharge lighting. The high resistance of the filament acts as the current limiting device for the arc-tube (taking over the function normally performed by the external ballast).
When these lamps are switched on the filament lights begin to dims as the arc-tube warms up to its full light output. This is a useful combination, as these lamps give instant light and, because they don't need separate control gear, can be used as long life replacements for high wattage incandescent lamps. They have an yttrium vanadate phosphor.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated average life</td>
<td>Up to 24,000 hours</td>
</tr>
<tr>
<td>Lumen maintenance at 24,000 hours</td>
<td>60%</td>
</tr>
<tr>
<td>Luminous efficacy:</td>
<td></td>
</tr>
<tr>
<td>HQL</td>
<td>35 – 58 lm/W</td>
</tr>
<tr>
<td>De lux</td>
<td>40 – 60 lm/W</td>
</tr>
<tr>
<td>Super de luxe</td>
<td>32 – 46 lm/W</td>
</tr>
</tbody>
</table>

Common notation exists for high pressure mercury lamps, for example Osram notation is HQL or HWL, where:

- $H = Hg$ (chemical symbol for mercury)
- $Q =$ quartz discharge tube
- $L =$ leuchtstofflampe (German for fluorescent coating)
- $W =$ $W$ (the chemical symbol for tungsten) i.e. tungsten filament
Applications

High pressure mercury lamps find applications where white light is preferred, colour rendering is of secondary importance but long service life is necessary to avoid the expense of frequent lamp replacement. Typical applications include:

- Industrial lighting
- Sign illumination e.g. motorway signs
- DIY store lighting (though being gradually superseded by metal halide lamps)
- Warehouse lighting
- HWL versions for longer life replacements for high wattage incandescent lamps

3.5.3.2 Metal halide lamps/ceramic discharge metal halide (CDM) lamps

First developed in the 1960s, metal halide lamps are essentially an improvement on high pressure mercury lamps. The addition of other metal (in the form of halides) to the mercury discharge tube improved the spectral output to give daylight quality white light. The use of quartz for the discharge tube is gradually being overtaken by a ceramic material, which improves the overall performance of the lamps.

They have the greatest luminous efficacy of all HID lamps. Where incandescent (including tungsten halogen) lamps are upgraded to metal halide lamps, there is usually a 75% improvement in luminous efficacy, giving the user both energy saving and improved illumination.

Most metal halide lamps use the same control gear as equivalent wattage high pressure sodium lamps only for operation on phase-to-phase supplies (440V) in some cases. Electronic control gears have been developed for the lower wattage metal halide lamps (up to 150W). These units are small lightweight electronic devices that ignite the lamps and operate them at their optimum performance.

Metal halide lamps come in a variety of shapes and sizes with 2-pin or Edison screw bases. Linear types with contacts at each end are also widely available. Smaller types have quartz outer bulbs whereas the bigger versions employ glass outer bulbs.

Metal halide lamps are essentially high pressure mercury lamps but with the addition of other metals. When electrically excited, they give a good mix of the primary colours (red, green and blue) across the visible spectrum, to produce white light that is more like natural daylight.

A whole range of different metals are used to ‘fill the gaps’ in the spectral output of mercury. They are excited in an electrical discharge through argon gas operating at a pressure of several atmospheres. The metals are
introduced into the arc-tube in the form of halide compounds (usually iodides and bromides). This is done deliberately in order that these halides, when released in the heat of the discharge, take part in a halogen cycle to keep the walls of the arc-tube clear of any deposits of metals, including the tungsten from the electrodes.

**Metal used in metal halide lamps**

Mercury is the basis of metal halide lamps. Added to the mercury are a ‘cocktail’ of different metal iodides and bromides. Depending on the requirement for different colour appearances (colour temperatures), different combinations of metals are used in the discharge. For example, sodium, thallium and caesium produce more red light and are used for the ‘warmer’ colour appearances. Tin, scandium and indium produce more blue light and are used for the ‘colder’ colour appearances.

**Lamp characteristics**

The smaller, lower wattage versions also use quartz outer bulbs, but the larger, higher wattage types (>250W), tend to have glass outer bulbs - either tubular or elliptical shaped. Most of these have clear outer bulbs, but some of the elliptical versions have internal white coatings (not phosphors), to produce diffuse lighting.

Those types with quartz outer bulbs employ 2-pin bases (single ended) or end contacts (double ended). All the glass outer bulb versions have Edison screw bases.
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Colour shift

Metal halide lamps were the first discharge lamps to produce daylight quality white light. They are superior to all other discharge lamps as regards their colour rendering capabilities. However, this first generation with its quartz arc-tubes suffers from the problem of changing colour though life - referred to as 'colour shift'. This is because the quartz arc-tubes are chemically attacked by alkali metal such as sodium and caesium, causing discolouration of the arc-tube well before the natural end of life of the lamp. The discolouration (browning effect) of the arc-tube and the chemical combination of sodium and caesium with the quartz, alters the spectral output from the lamp. The end result is that the colour appearance of the light changes, usually to a blue-green white light that no longer retains its outstanding colour rendering qualities.

Ceramic technology

The latest technology of metal halide lamps has arc-tubes made from the same material as used in high pressure sodium lamps i.e. ceramic polycrystalline alumina. This material is unaffected by alkali metals and has effectively overcome the problem of 'colour shift'. This new technology of lamps is known collectively as 'ceramic metal halide' lamps.

The first generation of ceramic metal halide lamps uses short cylindrical shaped ceramic arc-tubes. The ends of the arc-tube have thick ceramic plugs to seal in the tungsten electrodes. These plugs absorb much of the light directed towards the ends of the arc-tube, giving the lamp a relatively high radial light output but with little light along the lamp axis.
The Basics of Efficient Lighting

The second generation of ceramic metal halide lamps use a spherical or ball shaped arc-tube. This still retains the excellent colour stability benefit, as well as offering further improvements in light output, lumen maintenance and colour rendering. This later design doesn't have the thick end plugs of the cylindrical arc-tube, which means it produces very uniform light distribution in all directions - making it ideal for use in accurate optical systems.

Ceramic arc-tubes are also incorporated into integral reflector designs to give precisely controlled beam patterns without the need for expensive ‘optical control’ light fittings.

Nominal Mortality and Lumen Maintenance Curves

Metal halide lamps are the best of the HID lamps as regards light quality, but their lifetimes and lumen maintenance, though continually improving, are not as good as those of high pressure sodium and high pressure mercury lamps. The introduction of ceramic arc-tube technology has given some increase in both lamp life and lumen maintenance.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated average life</td>
<td>2,000 – 15,000 hours (dependent on type and wattage)</td>
</tr>
<tr>
<td>Lumen maintenance at rated average life</td>
<td>60 – 80%</td>
</tr>
<tr>
<td>Luminous efficacy</td>
<td>74 – 100 lm/W</td>
</tr>
</tbody>
</table>
### The Basics of Efficient Lighting

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated average life</td>
<td>12,000 hours</td>
</tr>
<tr>
<td>Lumen maintenance at rated average life</td>
<td>Exceeds 80%</td>
</tr>
<tr>
<td>Luminous efficacy</td>
<td>80 lm/W and above depending on lamp type</td>
</tr>
</tbody>
</table>

The most common notation for metal halide lamps are HQI and HCI, where:
- H = Hg (the chemical name for mercury)
- Q = quartz discharge tube
- C = ceramic discharge tube (cylindrical or spherical)
- I = iodide

### Applications

With their daylight quality white light and excellent colour rendering capabilities, metal halide lamps find more uses than any of the other HID lamps. Typical applications include:
- Display lighting (shops, showrooms, museums, exhibitions etc.)
- Stadium lighting (ideal for televised sports events)
- Floodlighting of buildings (especially modern structures with large areas of glass)
- DIY sheds
- Warehouse lighting
- Amenity lighting
- Road lighting (being assessed for lighting of accident black-spots)

Coloured metal halide lamps, with a special halide content to produce green, blue or magenta-coloured light, give an intense and saturated light that is particularly effective for attractive floodlighting and special display applications.
3.5.3.3 High pressure sodium lamps

These lamps use an alloy of sodium and mercury (called sodium amalgam) in a discharge through xenon gas at a much higher pressure than in SOX lamps. The influence of mercury and xenon is to moderate the deep orange light from the sodium, making it a more whitish orange light. They have clear tubular or elliptical glass bulbs, the latter having a diffuse white coating. All have Edison screw bases. There are also linear versions with contacts at each end (similar to linear tungsten halogen floodlight lamps).

The light from high pressure sodium lamps is produced from the excitations of atoms of both sodium and mercury (from the sodium amalgam), as well as from the atoms of the xenon filling gas. The operating pressure inside the arc-tube is about 80% of ‘high pressure sodium’.

At the higher operating pressure, the mercury produces some blue and red light. Xenon also contributes some blue light, and the combination added to the characteristic orange light from the sodium gives the lamp a whitish orange appearance.

![Diagram of high pressure sodium lamp](image)

The small arc-tube is made from polycrystalline alumina which is aluminium oxide in ceramic form. This material is transparent to the whitish orange light and resistant to chemical attack from molten sodium.

Tungsten electrodes impregnated with electron emissive material is sealed in at the ends of the arc-tube which is mounted inside a tubular or elliptical shaped outer glass bulb.

All high pressure sodium lamps require an ignition voltage between 3000V - 4500V and a series ballast to control the lamp current. Some high pressure sodium lamps have an internal igniter inside the outer bulb. This igniter operates within a second or two after switch on, and through the ballast induces a series of very high voltage pulses to ignite the lamp. Once the lamp has started, the internal igniter stops operating.
Lamp types

All single ended types have Edison screw bases.

Tubular types always have clear bulbs and the elliptical types generally have a white diffuse coating on the inside. This is not a phosphor coating as these lamps produce very little ultraviolet in the discharge. There are also linear versions using quartz outer bulbs and contacts at each end (similar to linear tungsten halogen lamps).

High pressure sodium lamps come in two grades - standard and super. The ‘super’ versions offer higher luminous efficacy and improved lumen maintenance compared with the ‘standard’ versions. The improvement is achieved from having higher xenon gas pressure, but the drawback is that ‘super’ lamps can be more difficult to start and require good quality igniters.

Nominal Mortality and Lumen Maintenance Curves

High pressure sodium lamps with greatly improved reliability now exist. This offers the user longer service life without the annoying premature failures that require expensive re-lamping before the scheduled group replacement. The service life of these lamps has been increased from 12,000 hours (typically 3 years use) to 16,000 hours (typically 4 years use).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated average life:</td>
<td></td>
</tr>
<tr>
<td>50 – 100 W</td>
<td>28,000 hours</td>
</tr>
<tr>
<td>150 – 400 W</td>
<td>32,000 hours</td>
</tr>
<tr>
<td>Lumen maintenance at:</td>
<td></td>
</tr>
<tr>
<td>28,000 hours (50 – 100 W)</td>
<td>79%</td>
</tr>
<tr>
<td>32,000 hours (150 – 400 W)</td>
<td>82%</td>
</tr>
</tbody>
</table>
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Luminous efficacy:

<table>
<thead>
<tr>
<th>Power Range</th>
<th>Luminous Efficacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 – 100 W</td>
<td>70 - 118 lm/W</td>
</tr>
<tr>
<td>150 – 400 W</td>
<td>84 – 120 lm/W</td>
</tr>
</tbody>
</table>

The important point is that at 16,000 hours (typically 4 years’ service life), there are only 5 - 8% failures and more than 90% lumen maintenance.

The common notation for these lamps is SON (a variant of ‘sun’ because of their better colour rendition). They are also referred to by the acronym ‘HPS’ lamps.

Applications

Having longer service life and better (though not good) colour rendering, high pressure sodium lamps find a greater variety of uses than SOX lamps. Typical applications include:

- Road and street lighting (gradually replacing SOX lamps)
- Amenity lighting (public areas, car parks etc.)
- Floodlighting of buildings and monuments (the whitish orange light is particularly effective for floodlighting historic buildings)
- Warehouse and cold storage lighting

High pressure sodium lamps with a slightly larger blue component in the spectral output (though this is not discernable to the human eye) are made specifically for horticultural light to promote the growth of plants.

3.5.3.4 Low pressure sodium lamps

Low pressure sodium lamps generate their light by the excitation of sodium metal in a discharge through a mixture of neon and argon gas at very low pressure. With their characteristic deep orange light, these lamps are the most luminous efficient of all HID lamps. All have clear tubular outer bulbs with a bayonet base. However, they have additional insulation between the contact plates to protect against the very high voltages needed to start these lamps.

SOX lamps require a high voltage to start them (sometimes in excess of 600V). They also need to have ballast in series with the lamp to control the lamp current. The normal control gear for SOX lamps is a special transformer that provides the initial high voltage to ignite the lamp and then changes the way it operates to act as a series ballast for controlling the lamp current.

Low pressure sodium (SOX) lamps produce light from the excitation of sodium atoms in an electrical discharge through a mixture of neon and argon gas at very low operating pressure of only about 1% of atmospheric pressure - hence the description ‘low pressure’. Because molten sodium is extremely corrosive to both quartz and normal glass, a special sodium-resistant glass has to be used for the arc-tube which is U-shaped and contained in a tubular glass outer bulb - the lengths of which varies according to wattage of the lamp.

Efficiency and heat loss

Heat loss in a SOX lamp is a major consideration. Only about 33% of the input power comes out as visible light, the rest being potentially lost as heat (infrared radiation). To conserve this heat, the inside of the outer
The Basics of Efficient Lighting

glass bulb is coated with a thin film of indium oxide (InO), which has the property of reflecting heat whilst transmitting the orange sodium light.

Special SOX economy (SOX-E) versions have a more efficient indium oxide reflecting film, so less heat is lost and more is reflected back onto the arc-tube. With the aid of special control gear, these lamps are the most luminous efficient of all artificial light sources - up to 200 lm/W.

Practical considerations

All SOX and SOX-E lamps use the same bayonet base - BY22d. It is similar but not identical to the one used on conventional incandescent lamps in some countries. The difference is that the BY22d base has a part of the insulation between the contact plates raised up to provide the additional electrical insulation that is required during ignition when voltages in excess of 600V can be generated.

Applications for SOX lamps include economical lighting for arterial roads and motorways, tunnels, car-parks, canals etc. An added advantage is that their monochromatic yellow light attracts few insects (about 5% compared to mercury vapour lamps).

Nominal Mortality and Lumen Maintenance Curves
The Basics of Efficient Lighting

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated average life</td>
<td>16,000 hours</td>
</tr>
<tr>
<td>Lumen maintenance at 16,000 hours</td>
<td>85%</td>
</tr>
<tr>
<td>Luminous efficacy:</td>
<td></td>
</tr>
<tr>
<td>SOX</td>
<td>100 – 175 lm/W</td>
</tr>
<tr>
<td>SOX-E</td>
<td>158 – 200 lm/W</td>
</tr>
</tbody>
</table>

The universal notation for these lamps used by all lamp manufacturers is SOX, where:

- SO = sodium
- X = low pressure discharge

They are sometimes also referred to by the acronym 'LPS' lamps.

Applications

Because of their high luminous efficacy but poor colour rendering abilities, SOX lamps are only used where energy efficient lighting is required, without the need for good colour reproduction. This includes:

- Road lighting (especially motorways)
- Industrial lighting (e.g. heavy industry maintenance areas)

3.5.3.5 Xenon discharge lamps

These lamps produce a very intense bluish-white light from an electrical discharge in xenon gas at extremely high pressure.

The light is produced by an electrical discharge through xenon gas at extremely high operating pressure (20 to 30 times atmospheric pressure). They give out a bright bluish white light at the instant of switch on. They use a very thick wall quartz arc-tube to withstand the very high operating pressure but have no outer bulb.

They are not long life lamps (last only a few hundred hours) and are used for very special applications such as medical endoscopes, searchlights and cinema projectors. Instant high light output, XBO lamps are for very special use. Their life and lumen maintenance are less important as they are not used for general lighting.

Applications

The instant crisp blue-white light give xenon discharge lamps certain advantages over other HID lamps in their ability to produce high intensity light immediately at switch on. They are only used for very special applications, including:

- Light source for commercial cinema projectors
- Effect lighting (discos and pop concerts)
- Military searchlights
- Surveillance lighting (on police helicopters)
- Film studio lighting (to simulate daylight in the studio)
- Strobe lighting (strobe lamps are basically xenon discharge lamps)
- Medical endoscopes

3.5.4 HID lamp Run Up Times

Apart from xenon discharge lamps which have instant ignition, all HID lamps take several minutes to reach full light output (although high pressure mercury lamps which have both a tungsten filament and a mercury
The Basics of Efficient Lighting

discharge tube give high immediate incandescent light from the filament). This time is necessary in order that metals in the arc-tube reach the temperature at which they give out their full light output.

The run-up times depend upon the type of lamp and its size. Generally, the smaller lower wattage lamps run-up fastest, and the larger higher wattage versions take longer.

<table>
<thead>
<tr>
<th>Lamp type</th>
<th>Run-up times (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xenon discharge</td>
<td>Instant</td>
</tr>
<tr>
<td>Metal halide</td>
<td>5 – 8</td>
</tr>
<tr>
<td>High pressure mercury</td>
<td>4 – 6</td>
</tr>
<tr>
<td>High pressure sodium</td>
<td>2 – 4</td>
</tr>
<tr>
<td>Low pressure sodium</td>
<td>12 – 14</td>
</tr>
</tbody>
</table>

3.5.5 HID Lamp Re-strike

Unlike incandescent lamps, HID lamps do not respond to being quickly switched off and on again. Once switched off, they have to cool down to allow the pressure in the arc-tube to fall back to the level that enables the lamp to be re-ignited. This ‘re-strike’ time can be quite long, especially for the larger lamps that take longer to cool down.

Re-strike times vary from about 30 to 90 seconds for high pressure sodium lamps to 5 to 8 minutes for small metal halide and mercury vapour lamps. For the large high wattage metal halide lamps there can be up to 15-20 minute delay. Low pressure sodium lamps have an instant re-strike.

It is possible to ‘hot re-strike’ some metal halide and high pressure sodium lamps, but special control gear is necessary as the ignition voltage required has to be in the region of 25,000V -30,000V. This can only be performed safely on linear double ended lamps, and even then only in light fittings with additional insulation to withstand such high voltages. It may also have an adverse effect on the lamp life.

HID lamps are very sensitive to brief interruptions in the power supply. Whereas incandescent and fluorescent lamps will momentarily go out and come back on again immediately, a break in the power supply of even less than 0.02 sec will cause HID lamps to permanently extinguish. They have to cool down for several minutes, as noted above, before the igniter will start to operate again.

3.5.6 Dimming of HID Lamps

To dim HID lamps it is necessary to run them underpowered. However, HID lamps are designed to be operated within a narrow tolerance of a specific voltage and current to give the claimed light output, power consumption and lamp life. Operating HID lamps outside this tolerance makes them unstable and they are likely to extinguish. Such operation can also damage the electrodes in the arc-tube, which in turn causes the lamp to suffer short life.

The demand for dimming is mainly directed to metal halide lamps. Attempting to dim metal halide lamps causes the arc-tube to operate at a temperature that is too low, which in turn results in the condensation of some of the metal halides. The consequence is a loss of colour from the condensed halides and the overall spectral output of the lamp is changed. The colour temperature changes (usually increases) and the colour rendering index falls significantly. For this reason, dimming of metal halide lamps is not recommended, as the colour and life performance of the lamps cannot be guaranteed.
3.5.7 Safe Operation of HID Lamps

Only high pressure mercury and metal halide lamps have arc-tubes that operate well in excess of atmospheric pressure. Occasionally this can lead to the arc-tube exploding (usually at the end of life).

Sometimes an exploding arc-tube can cause the outer bulb to shatter, dangerously projecting fragments of hot glass and quartz from the light fitting if the latter is 'open', i.e. not enclosed by a toughened glass safety screen. Most light fittings are not equipped with safety screens as these make the light fitting very expensive.

Note: The arc-tubes of high and low pressure sodium lamps operate at much lower pressures and are not prone to explosive failure.

The use of metal halide lamps in areas such as conference rooms, shopping malls, DIY stores, etc is becoming more popular. Because many of the light fittings used in these areas are the 'open' types (i.e. no safety screen), a range of metal halide lamps has been developed, that are self-protecting and can be safely used in 'open' light fittings.

Inside, the arc-tube is contained in a wire reinforced open ended quartz tube. If the arc-tube should explode, the surrounding quartz tube absorbs the energy of the explosion and slows down the fast moving fragments of the shattered arc-tube, preventing these fragments from destroying the outer bulb. In fact, all the fragments from the arc-tube and the surrounding quartz are safely retained in the outer bulb and none are expelled from the light fitting.

3.5.8 Ultraviolet from HID Lamps

High and low pressure sodium lamps produce small amounts of ultraviolet light which is virtually all absorbed by the outer glass bulbs. They are not classed as being of any serious concern as regards ultraviolet radiation.

High pressure mercury and metal halide on the other hand, do produce relatively high levels of ultraviolet from their arc-tubes. Those versions with glass outer bulbs have the ultraviolet significantly reduced by the filtering effect of the glass and do not pose any health hazard. They can, however, produce a bleaching effect on colour sensitive materials over long periods of exposure.

Metal halide lamps with quartz outer bulbs produce levels of ultraviolet that could be a health hazard, because normal quartz does not filter out ultraviolet radiation. It was always necessary to use ultraviolet filters on light fittings with these lamps. However, some manufacturers now use a special ‘ultraviolet filter’ quartz for their range of metal halide lamps. From a health point of view, these can be used without the need for additional ultraviolet filters on light fittings. However, it may still be prudent to use ultraviolet filters on the light fittings to eliminate the effect of bleaching if the illuminated objects are particularly sensitive (e.g. valuable paintings).

3.6 LEDs

HEADS UP: LEDs and Energy Efficiency

LEDs are an emerging technology and are often claimed to be very efficient. However recent experience shows that LEDs have a range of efficiencies, thus great care should be taken in selecting LEDs for any lighting purpose.

Light emitting diodes are semiconductor devices which emit light. They can potentially have a very long life, (up to 50,000 hours), offer reasonably high efficiencies (around 40 to 60 lm/W in a luminaire) and are compact and tough. A range of LED halogen replacements are available, the most powerful at this stage use a 3 watt
LEDs produce heat which must be managed to allow a high light output. Experience to date has required good heat sinks to be designed to keep the junction temperature of the LED low within a luminaire. Assembly of and connections made to the LED are critical in the successful operation of the units. At this stage of their development, LED luminaires are quite expensive.

LEDs operate very differently to filament lamps, discharge lamps and fluorescent tubes via a process known as 'injection electroluminescence'. This phenomenon first observed in 1907 by H. J. Round experimenting with silicon carbide. However, as he was really looking for new ways of radiolocation in seafaring, his discovery was completely forgotten and it wasn't until 1962 that the first red LEDs were invented. By the mid-70s other colours had joined red, including yellow, orange and green. However, the efficiency and light output was still very poor.

Between 1970 and 1995, the light output of red LEDs increased by a factor of approximately 45 and between 1995 and 2003 the efficiency of LEDs increased by an average factor of 16 and the light output per LED package by a factor of 430. The net result is that today LEDs have the efficiency and light output to be considered for many varied applications including traffic signals and signs, large area video displays and car instrument and switch illumination.

Since 2005, further developments have seen a rapid growth in the use of LEDs for higher levels of illumination. For example, LEDs are already used for general effect lighting applications and decorative lighting and will replace some conventional light sources in the near future.

3.6.1 Structure of LEDs

A light emitting diode (LED) is a ‘solid state’ electronic component with the characteristics of a diode i.e. it only allows electrical current to flow through it in one direction. When the current flows through an LED in the correct direction, the LED produces light of a specific colour.

LEDs can be thought of as mini-luminaires. The packaged product can contain a built-in reflector and lens, coloured filters and scattering materials.
3.6.1.1 Discrete LEDs

Individual LEDs are called discrete LEDs. To be of practical use, discrete LEDs are assembled (mounted) onto printed circuit boards (PCBs), usually with additional electronic components to control the current flowing through the LED.

Through hole or radial LEDs

There are different types of discrete LEDs. Some have legs that pass through holes on a circuit board and are fixed in place by soldering underneath the circuit board. These are called ‘through hole’ or ‘radial’ type LEDs.

The package of a radial LED has a lens on the top so that it produces a higher intensity beam. However, this means this type of LED projects a spot of light onto a surface. Uniform illumination of an area cannot be achieved with radial LEDs.

Surface mount LEDs

The more modern type of LED sits on the top of the circuit board and is soldered automatically so that the solder joint is on the top of the circuit board. These are called ‘surface mount’ LEDs. Surface mount LEDs range in size from tiny LEDs that measure only 0.5 x 1.5 x 0.3mm (used in space efficient equipment like mobile phones) to ‘power’ LEDs measuring 20 x 20 x 2.5mm or larger.

Surface mount LEDs are assembled onto circuit boards very quickly and accurately by machines. So that the machine can use the LEDs, they are supplied sealed into a plastic ‘tape’ and wound onto reels. This method of supply is called ‘tape and reel’ and a reel of LEDs can be between 800 pieces and 8000 depending on the size of the LED and the reel.

Unlike most radial LEDs, the majority of surface mount LEDs do not have lenses and produce a more even illumination on a surface. Depending on the application, LEDs with lenses or accessory lenses for LEDs are useful.

3.6.1.2 LED Modules

An assembly of one or more discrete LEDs in a unit for lighting or display is a modular LED. Although it is possible to construct a module using radial LEDs, they are usually made using surface mount LEDs with automated techniques.

Depending on the application, lenses for the LEDs may be used.

3.6.2 Operation

At the heart of every LED there is a very small piece of semi-conducting material called the LED ‘die’. The die can be considered in the same way as the filament in a lamp, because it is the die that produces the light. The size of a high power LED die is approximately a 1mm cube and for other LED types much smaller.
The base of the die is glued or soldered into a fine metal framework (the lead frame). A very fine wire called a bond wire is attached to the top of the LED die, which has a very fine conductive metal pattern. The wire is attached to the other side of the lead frame.

When electricity of the correct voltage and polarity is applied to the LED via the lead frame contacts, current flows through the die.

The different properties of the layers in the die cause between 50 and 90% of this electrical energy to be converted into light at the junction by a process called ‘injection electroluminescence’. This process is significantly more efficient than virtually any other light source.

Injection electroluminescence does not require heat like a filament lamp (incandescence) or chemicals that glow like those used for a fluorescent tube (fluorescence). It is a phenomenon that is caused entirely by atomic differences in the material caused by doping.

3.6.3 Efficiency

Unfortunately, a large proportion of the light produced at the junction does not escape from the die and is reabsorbed, the remainder being converted to heat. As this is an ongoing development process efficiency is increasing continuously. Even so, the LED is very efficient compared to conventional light sources. For
example, an LED traffic signal consumes only 25 to 30% of the energy of a halogen lamp to achieve the same performance.

3.6.4 LED Manufacture

An LED die is manufactured in a ‘wafer fabrication plant’. In the plant, different chemicals called dopants are passed over circular wafers of very pure semiconducting material (the substrate) as gasses or liquids at high temperatures. Two different sets of dopants diffuse into the wafer to form two distinct layers with different atomic and therefore different electrical properties. The boundary between these two layers is called a junction, and it is at this boundary that the electroluminescence occurs.

When the diffusion process is complete, the surface of the die can then be shaped to help light escape from it by masking and etching the surface. This is followed by the formation of a very fine metal pattern on the top of the die (metallisation) which will be used to carry electrical current.

Finally, the wafer is sawn into individual LED die, sometimes with a shaped saw blade. The sawn wafer is transferred to another facility (backend production) where the LED die are mounted individually with a glue or solder that conducts electricity onto one side of a fine metal ‘framework’, the lead frame of the LED. One end of a very fine wire called a bond wire is then attached to the metal pattern on the top of the LED, the other end being attached to the other side of the lead frame.

The lead frame is then moulded into a solid epoxy block to give the whole assembly strength and a final casting protects the die. The LEDs are then automatically tested and grouped before being packaged and sent to the warehouse.

3.6.5 LED Colours

The light emitted by an LED is of a specific colour and wavelength respectively, depending on the dopant chemicals that were diffused into the die and is a virtually monochromatic saturated colour.

Indium, gallium and nitrogen dopant chemicals produce LEDs that emit light in bands ranging from blue through to green. These are called ‘InGaN’ LEDs after the chemical symbols for the dopants (In, Ga and N).

Indium, gallium, aluminium and phosphor dopants produce LEDs that emit light in bands ranging from green to red. These are often called ‘InGaAlP’ LEDs after the chemical symbols for the dopants (In, Ga, Al, P).

At present, commercially available LEDs produce light of certain specific colour. White light is generated by using light of a blue LED and a yellow phosphor which converts a part of the blue light into yellow light. Depending on the ratio between blue and yellow light different colour temperatures can be achieved.
3.6.5.1 Multi-colour LEDs

The light from individual LEDs, particularly the primary colours red, green and blue, can be mixed together to produce a wider range of colours than even the highest quality TV. Manufacturers produce a number of LED packages that contain three die rather than one. By incorporating a red, green and blue LED die into the same package, the LED can be used for applications ranging from large area video screens using up to 50,000 LEDs per square metre, to colour changing luminaries for lighting whole buildings.

3.6.5.2 White LEDs

An LED die emits coloured light that is virtually monochromatic, so to produce white light a technique is used that is similar to that used in fluorescent tubes. In a fluorescent tube, a gas discharge produces ultraviolet light which causes a phosphor coating mix on the inside of the glass tube to fluoresce and emit usable white light.

Structure of a single chip white LED:

- A phosphor is added to the normally clear epoxy covering the LED die. Alternatively the latest technology provides a more homogeneous white light using chip level conversion (CLC), applying a thin phosphor layer on top of the die
- A blue LED die stimulates the phosphor
- The phosphor emits a yellowish light
- The light from the phosphor and the blue LED combine to produce white light of different colour temperatures
3.6.5.3 Colour temperature

Because the white light is produced by mixing the light from two sources (die and phosphor) and the proportions of light from the two sources can vary, the colour temperature of a white LED can lie between 2,700K and 11,000K. Grouping of these LEDs is therefore essential to ensure that there is little perceived difference in colour between individual discrete LEDs or LED modules. Manufacturers offer their LED modules in colour temperature groups so that customers can ensure consistency.

3.6.6 Use of LEDs for Lighting

LEDs are very small light sources. It takes large quantities of the highest output white LEDs to produce the same amount of light as a 100 Watt GLS lamp. But their small size can actually be advantageous in the design of small compact light sources and this is one of the many reasons why LEDs are beginning to be used for general lighting applications. The other key factors are:

- Reliability
- Efficiency
- Safe low voltage operation

Care should be taken when selecting LEDs for general purpose lighting, as research in Australia and the US has shown that many LED products tend to over-state their performance.

Reliability

Unlike the majority of lamps, LEDs do not suffer ‘catastrophic failures’ (i.e. stop producing light in normal operation). With an LED, the light output gradually reduces over time, the rate of light output reduction being dependent primarily on the average operating temperature of the LED die (the junction temperature).

The time that the light output of an LED takes to decline to a level where it is no longer usable, could be tens of years, thus, the agreed method for specifying LED lifetime, is the time after which the light output falls to 50% of its original value. Even with this method, the lifetime for LEDs under the right conditions can be as much as 150,000 hours (17 years) continuous operation and the LED is still emitting usable light!

As LEDs are solid in their construction and are not made from fragile materials they have a high immunity to shock and vibration.

For example, LED traffic lights have capabilities including:

- Having multiple colour LEDs within one unit - i.e. a lamp that changes colour.
- Turning off several of the individual LED elements with a lamp to allow patterns and shapes to be displayed. For example, it is easy to have one LED lamp showing green, a left turn arrow, a right turn arrow etc.

Efficiency

As mentioned above, numerous white LEDs would be required to duplicate the light output of a 100 watt GLS lamp, although the power consumption of the LEDs would be around 45 watts. However, a fluorescent lamp would consume in the region of 20 to 25 watts to produce the same amount of light. Thus white LEDs can offer energy efficient alternatives in some, but not all applications.

In applications where colour is needed, LEDs often offer a higher efficiency than filtered white light sources, including fluorescent tubes which reduces heat dissipation, energy costs and the size and cost of power supplies. This in turn reduces the design and construction cost of luminaires as there is no need to accommodate LED replacement or to deal with very high temperatures.
The Basics of Efficient Lighting

Safe low voltage operation

LED modules operate at either 10V, 24V or 350mA or 700mA - well within the limit for safe low voltage operation.

3.6.7 LED Modules

An LED has a turn-on (threshold) voltage between 1.3 and 2 Volts, depending upon the die type. LEDs can be stacked in series like batteries, the threshold voltages will add up e.g. six LEDs in series each with a threshold voltage of 2V gives a total voltage requirement of 6 x 2 = 12V.

Once the threshold voltage of the individual LED or string of LEDs has been reached, the LED(s) will draw current and begin to light. There are very few situations where discrete LEDs can be used reliably without at least one other electronic component to control the flow of current, and this task is usually performed by another simple electronic component, a resistor. A resistor in line (series) with the LED will also allow operation from higher voltages than the threshold voltage(s).

Another and more accurate alternative to control the LED current is to use a small integrated circuit (IC) to control the LED current. LED modules with built in ICs provide users with a ‘ready to use’ LED lighting solution. The circuit boards that form the basis of the LED modules contain strings of LEDs together with the ICs to control the current and operate from 10V, 24V or 350mA and soon 700mA power supplies.

3.6.7.1 Types of LED modules

Manufacturers produce a wide range of LED products for the architectural, industrial, automotive and electronic markets. This includes LEDs mounted on rigid strips of board, flexible strips or board units that can be interconnected in many different arrangements. These are all available in either single or multi colours.

3.6.8 Control Gear

Special control gear is available for LEDs. The voltage and wattage information is obviously important when choosing control gear to match a particular LED module. LED control gear also protects against short circuit, thermal and overload protection. This ensures safe ongoing operation of the LED modules. It is available in various shapes and sizes.
The Basics of Efficient Lighting

Taken from Osram material, this is a typical naming convention for an LED driver

The output voltage in the naming system above is sometimes followed by one or two characters, which denote the case style (E for external use, CE for compact external, L for long, S for square).

3.6.8.1 Standard for LED control gear

CEN EN 62384, ‘DC or AC supplied electronic control gear for LED modules - Performance requirements’

3.7 Applications for conventional control gear

Conventional control gear has the advantage of being cheaper than electronic control gear (ECG), but recent EU legislation has started to prohibit the sale of many fluorescent lamp ballasts on the grounds of poor energy efficiency. As the price differential between CCG and ECG narrows and energy efficiency requirements become legally enforced, CCG will be completely superseded by ECG over the coming years.

At present, conventional ballasts and transformers are used only in the ‘cheaper’ fluorescent light fittings - mainly for the domestic market. Commercial and industrial users almost exclusively specify only light fittings with ECG.

For HID lamps, local authorities are the main users of high and low pressure sodium lamps (for road lighting). They do not have the financial resources to change over to more efficient ECGs, so manufacturers are less inclined to invest in developing ECGs for these HID lamps.

The less expensive metal halide lamp fittings will use CCG to keep the cost down, but the ‘top end’ of the market will use the more efficient ECGs. In fact most of the development of ECGs for HID lamps has been directed to metal halide lamps, as this is where the HID market is seen to be expanding most rapidly.

3.8 Electronic Control Gear

<table>
<thead>
<tr>
<th>HEADS UP: Electronic Control Gear and Energy Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic control gear allows the lamp to run more efficiently and has lower losses than conventional (wire-wound) control gear.</td>
</tr>
</tbody>
</table>

Electronic Control Gear (ECG) is a one-piece unit that combines starting (or igniting), operating the lamp at the correct voltage and current, has virtually unit power factor and safely shuts down the lamp as it approaches the end of its useful life.
The Basics of Efficient Lighting

The use of miniaturised electronic circuits instead of large heavy pieces of iron wound around with 'miles' of copper wire, make ECGs very compact in size and lightweight.

3.8.1 ECG operation – fluorescent lamps

For fluorescent lamps, the electronic starter circuit first provides the cathode preheat current for a defined time (between 0.5 and 2 seconds), and then a high voltage is applied to strike the lamp. Once the lamp starts up, the current and voltage are adjusted for the correct operation of the lamp. The cathodes carry both the preheat current and the lamp current, except with 'cut-off' type ECGs where the preheat current is cut-off once the lamp has run-up.

Good quality ECGs have electronic circuits that monitor the mains voltage (which can be quite variable). They continually adjust the lamp voltage and current to keep the lamp power constant, (hence the light output) irrespective of the variation in the supply voltage.

As the lamp approaches the end of its useful life, it needs an increasing higher voltage to keep it operating. Special electronic circuits in the ECG monitor this progress and shut off the supply to the lamp before it starts to become unstable and exhibit annoying flashing or flickering. The ECG will automatically start the replacement lamp.
Unlike CCGs which are designed to operate at the mains frequency of 50Hz, ECGs for fluorescent lamps operate at very high frequency - typically at 45,000 Hz for non-dimmable types, and up to 70,000Hz for dimmable versions. High frequency operation not only improves the luminous efficacy of the lamp, but also allows for the current restricting ballast to be made so small that it becomes one of the miniaturised components on the ECG’s printed circuit boards.

3.8.2 ECG operation – metal halides

For metal halide lamps, preheating of the cathodes is not necessary, so the ECGs for these lamps provide the very high ignition voltage (3000-4500 V) to strike the lamp. As the lamp runs up, the ignitor part of the ECG switches off. These ECGs operate the lamps at about double the mains frequency.

3.8.3 High Frequency Operation

Operating ballast at a higher frequency means that the current through the coil alternates more rapidly. This greatly enhances the current ‘choking’ effect of the ballast, so it becomes possible to achieve the same current restricting effect with a very small coil wound around a tiny iron core.

By operating the ballast at a frequency of around 30,000Hz, it can be reduced to the size of a small sugar cube and weigh just a few grams. This makes it possible for it to be easily integrated onto the ECG's printed circuit board. Special transistors are used to convert the mains frequency to these very high levels.

(The diagram compares a frequency of 50Hz (mains) with 250Hz. It isn't possible to show diagrammatically an ECG's operating frequency of 30,000Hz).

3.8.4 Luminous efficiency

The other advantage of high frequency operation is that the fluorescent lamp improves its luminous efficacy. Typically, at 30,000Hz operation, a fluorescent lamp is about 10% more luminous efficient compared with 50Hz operation. All ECG manufacturers have taken advantage of this benefit by designing their products to make the lamp give the same light output as with 50Hz operation, but at about 10% lower power. Power loss in the ECG is much less than in CCG and together with the reduced lamp power, the overall power consumption can be 20 – 25% less compared with CCG operation.
For example, a 58W T8 fluorescent tube operated on CCG and ECG:

<table>
<thead>
<tr>
<th></th>
<th>Conventional control gear</th>
<th>Electronic control gear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamp power</td>
<td>58W</td>
<td>50W?</td>
</tr>
<tr>
<td>Light output</td>
<td>5,200 lm</td>
<td>5,100 lm</td>
</tr>
<tr>
<td>Luminous efficacy</td>
<td>89.9 lm/W</td>
<td>102 lm/W</td>
</tr>
<tr>
<td>Control gear losses</td>
<td>13W</td>
<td>5W</td>
</tr>
<tr>
<td>Total circuit power</td>
<td>58W + 13W = 71W</td>
<td>50W + 5W = 55 W</td>
</tr>
<tr>
<td>Power saving</td>
<td>71W − 55W = 16W (23%)</td>
<td></td>
</tr>
</tbody>
</table>

### 3.8.5 Electronic Transformers

Electronic transformers also operate low voltage lamps at high frequency (typically 30,000-50,000Hz). The lamps do not run more efficiently, but it allows the transformer to be small and lightweight and have much lower power losses compared with conventional transformers.

Electronic transformers from reputable manufacturers are designed to optimise the performance of low voltage lamps. Output voltage is kept constant irrespective of the loading of the transformer. Even small increases in voltage on the lamps can cause marked reductions in lamp life.

![Electronic Transformers Image]

For example, a typical 12V halogen lamp has a claimed life of 2000 up to 4000hrs at 12V. An electronic transformer will ensure that the voltage to the lamp never exceeds 12V, so the expected lamp life will always be attained. On the other hand, a conventional transformer would not be able to control the output voltage as the mains voltage increases or decreases. Even at just 5% extra, the lamp life would be halved. Some low voltage transformers are designed to supply direct current (DC) which is required for optimum output of light emitting diodes (LEDs).

The best quality electronic transformers also have built-in safety features:
- Shut down if short circuited - but comes on again once the short is removed.
- Shut down if severely overloaded - but comes on again on restoring the correct load.
- Shut down if over heated - but comes on again after cooling down.

### 3.8.6 HID Lamps

High intensity discharge lamps such as high pressure mercury (HQL) and low pressure sodium (SOX) are the old technology lamps and are never considered for new lighting installations. For this reason, they have not been considered for ECG operation.
The Basics of Efficient Lighting

Metal halide lamps (and to a lesser extent high pressure sodium lamps) are the newer technology HID lamps, and have many makes of ECGs available for their operation. The majority of these ECGs are for the lower wattage range of metal halide lamps, as these are currently the most popular of the range and the prospective users are prepared to pay the higher cost of ECG operation to get the best lighting quality and performance.

ECGs for metal halide lamps are one piece units that provide the high ignition voltage, run the lamp at the correct power, and safely shut down the lamp at the end of its useful life before it starts to flash or flicker. These ECGs generally operate the metal halide lamps at only 120Hz, as very high frequency operation results in an unstable arc and makes the lamps give out a high pitched whistling noise (technically referred to as ‘acoustic resonance’).

3.8.7 Hot re-strike

Some ECGs for metal halide lamps can be operated with an additional electronic ignitor to provide a striking voltage of 25,000 – 40,000V. This high voltage enables hot lamps to be quickly re-ignited (known as ‘hot re-strike’).

This can be very useful in applications like security lighting where momentary interruptions in the mains supply can extinguish discharge lamps, and so avoids delays of 15-20 minutes before the lamps are cool enough to be re-ignited normally. The light fittings, however, must have additional electrical insulation in order to withstand such high voltages.

3.8.8 Induction fluorescent

All makes of fluorescent induction lamps are designed to operate only on special, extra high frequency ECG. The lamp and ECG have to be purchased as a complete system. The ECGs are dedicated to the particular lamps and are not interchangeable with each other. In some case, the ECG is integrated into the lamp.

3.8.9 Multiple fluorescent

Many fluorescent lamp fittings have more than one lamp. Twin lamp fittings are very common and there are even fittings that operate 3 or 4 lamps simultaneously.

To have individual ECGs to operate each lamp in a multi-lamp fitting would be prohibitively expensive. ECG manufacturers have therefore developed single unit ECGs to operate two, three and even four lamps together and which are only marginally more expensive than a one-lamp ECG.

3.8.10 Fluorescent multi-wattage

Until very recently, all wattages of fluorescent lamps required a dedicated ECG. With the ever increasing number of new fluorescent lamps (tubes and CFLs) coming onto the market, the range of different ECGs has greatly increased over the last few years.

However, new electronic technology has met this challenge with the introduction of ‘multi-wattage’ ECGs. These devices operate at the correct power to give the correct light output. One ECG will operate a range of tubes and CFLs of different wattages, and twin lamp ECGs allows different types and wattages of lamps to be operated together.

To be able to have different types and wattages of fluorescent lamps operating in the same light fitting from a single ECG gives the designer much greater scope for more aesthetic light fittings. Just as important is that the fittings manufacturer and the electrical wholesaler will need to stock far fewer ECG types - greatly reducing stock levels and hence the amount of capital tied up.
3.8.11 Dimmable ECG – Low Voltage

Normal good quality electronic transformers can be controlled with special dimmer switches to regulate light output. These dimmer switches are similar, but not identical to those used in the home to dim ordinary incandescent lamps. Because ordinary incandescent lamps only have a resistance (i.e. the filament), domestic dimmer switches are designed to operate only on lighting circuits with a resistive load and are unsuitable for operating electronic transformers.

Virtually all makes of electronic transformers have a load and need dimmer switches that are suitable for such a load. If a domestic dimmer switch was used, it would cause the lamp(s) to flicker - quite severely at low dimming levels.

All the major electronic transformer manufacturers have agreed on a convention to mark transformers with a symbol to indicate the type of dimmer that should be used:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Symbol" /></td>
<td>Trailing edge phase control dimmer suitable for capacitive loads.</td>
</tr>
<tr>
<td><img src="image2.png" alt="Symbol" /></td>
<td>Leading edge phase control dimmer suitable for inductive loads.</td>
</tr>
<tr>
<td><img src="image3.png" alt="Symbol" /></td>
<td>Leading-edge and trailing-edge phase control dimmer suitable for either inductive and capacitive loads.</td>
</tr>
</tbody>
</table>

3.8.11.1 Phase control dimmer types

Phase control dimmers come in two versions:

- **Leading edge phase control** - these are the versions that 'chop' the mains voltage waveform on the leading (or rising) part of the alternating cycle.

![Leading Edge Phase Control](image4.png)

- **Trailing edge phase control** - these are the versions that 'chop' the mains voltage waveform on the trailing (or falling) part of the alternating cycle.

![Trailing Edge Phase Control](image5.png)

The symbols marked on the transformer indicate the type of phase control that is compatible with that transformer.
3.8.11.2 **Use with fluorescent lighting schemes**

Low voltage tungsten halogen lamps are often incorporated into fluorescent lighting schemes. The control system for dimming the fluorescent lamps, is not directly compatible with electronic transformers. Special conversion units are used to convert the fluorescent dimming control signals into phase control signals suitable for the particular transformers being used.

3.8.12 **Dimmable ECGs – LEDs**

Light emitting diodes (LEDs) do not dim significantly if their operating voltage is reduced. If the voltage drops too much, the LED just goes out - so a different method of dimming control has to be employed.

In this case, it is not the input to the transformer, but the output that is controlled. The technique used is called ‘pulse width modulation’ (PWM). The output is switched on and off at such a high frequency, the eye does not register a flicker but sees a reduced light output. By varying the time of the ‘on’ pulse to the ‘off’ time, the LED appears to alter its light output.

![Pulse Width Modulation](image)

Dimming can also be achieved by connecting a PWM module between the electronic transformer and the LEDs. It is controlled by the same dimming control as used for fluorescent lamps.

3.8.13 **Dimmable ECG – HID Lamps**

Because of their daylight quality white light, only metal halide lamps are required to be dimmed. There has been no commercial interest in dimming requirements for any other HID lamp.

There are dimming systems on the market that claim to dim metal halide lamps. These devices work on the principle of reducing the lamp power in order to reduce light output. However, under-powering metal halide lamps, causes the arc-tube temperature to decrease and some of the less volatile metal halides condense from vapour form back to the inactive solid form. This effectively removes their colour contribution from the overall spectral output and upsets the colour balance, significantly changing the colour temperature and colour rendering of the lamp.

For this reason, most of the major lamp manufacturers do not recommend dimming their metal halide lamps as they cannot guarantee the colour performance of the lamps in a dimmed state. Hopefully, future technology will permit metal halide lamps that can be dimmed without any loss of light quality.

3.8.14 **Dimmable ECG – Fluorescent**

Virtually all commercial and industrial lighting worldwide is now fluorescent. Whether for comfort or energy saving, the demand for dimming fluorescent lighting systems has increased enormously over the last decade.
Modern fluorescent dimming systems are controlled either manually (rotary knob or slider) or automatically, for instance by a light sensor that can detect the natural daylight coming in through the windows and signal the fluorescent lighting system to dim down to a more appropriate level.

To dim fluorescent lamps requires special dimmable ECGs as normal ECGs are not capable of being dimmed. These dimmable ECGs operate on the principle of controlling the lamp current to regulate the power and hence the light output. The dimming control circuits are built into the dimmable ECGs, so it is necessary to have only a simple controlling device connected by cable to the ECG to control the dimming.

Modern dimmable ECGs are available for single, double and now for multi-wattage lamp operation. They can dim lamps to as low as 1% light output and are capable of switching on lamps at any preset dimmed level without first having to come on at full light output and be dimmed to the required level. There are two types of dimmable ECGs for fluorescent lamps characterised by the method of dimming control - analogue and digital.

3.8.14.1 Analogue dimming control

The current and voltage of the dimming control into the dimmable ECG is a low voltage DC signal (referred to as an analogue signal).

- **Current source** dimming control is an external device which produces a varying DC voltage signal (0-10V) which is sent into the dimmable ECG to regulate the light output.
- **Current sink** dimming control is an external device which takes a varying DC voltage signal (1-10V) from the dimmable ECG to regulate the light output. In essence, the device is a potentiometer (i.e. a variable resistance). It is the most popular means of fluorescent dimming control. The two types of analogue dimming control are NOT interchangeable.

The 1-10V dimming control units can operate from 1 to 50 dimmable ECGs, either single or twin lamp versions. For controlling more than 50 dimmable ECGs, an additional amplifier is required to amplify the control signal. It is imperative that the polarity (i.e. positive and negative connections) of the control lines is correct for each and every dimmable ECG. If only one dimmable ECG has the wrong polarity, the whole of the dimmable lighting system will fail to operate correctly e.g. for 50 ECG a bigger relay will be required, with a special contact to switch the start current of all the ECGs.
3.8.14.2 Other dimming control types

Daylight sensors can be incorporated into the dimming control to automatically dim lights if there is sufficient daylight coming into the room.

Presence detectors (often combined with daylight sensors), can also be installed into the dimming control to either switch off the lights or dim to minimum level when there is no activity in the lit area.

Special converters to change from 1-10V control to phase control are also available. These allow the same 1-10V dimming control to also dim incandescent lamps, either mains voltage or low voltage via electronic transformers.

3.8.14.3 Digital dimming control

The latest technology for dimming control is by the use of digital signals and requires special dimmable ECGs. The protocol for the digital signalling system has been agreed by all the major ECG manufacturers and has become known by the acronym DALI (digital addressable lighting interface). This universal agreement ensures the inter-changeability of the DALI ECGs irrespective of manufacturer. The DALI protocol was implemented into the international standard IEC60929, which is the established standard covering the performance requirements of ECGs.

The advantages of the DALI dimming system over the 1-10V system, are that the DALI ECGs are not polarity sensitive and are unaffected by the resistance of long control cables. Built-in memory chips means that data on pre-set dimmed levels can be stored and instantly reproduced simply by pressing a switch. This facility enables DALI ECGs to be individually programmed to memorise several different dimmed levels so that several different light scenes can be created and easily changed from one to another depending upon the type of activity in a lit area.

DALI is an extremely flexible dimmable control system that does not require complex wiring arrangements. It is relatively easy to install compared with the 1-10V control system and with its microprocessor controlled ECGs, it can also provide feedback information to alert the user of faults in the ECGs, failure of the power supply to the light fittings and lamp failures. DALI is ideal for integration into building management systems (BMS) which are the computer systems that control and monitor the heating, ventilation and lighting in large buildings.

Daylight sensors and presence detectors can be incorporated into the DALI network and special converter units are available that convert the digital signals to 1-10V analogue signals so the two dimming systems can be combined.

The more advanced forms of DALI dimming control have the capability to programme and store 16 different light scenes. Ancillary units such as photocells, presence detectors and control switches communicate with the central control unit by radio, obviating the need for any cable connections. Even the initial programming of the system can be carried out by radio transmission.

3.8.15 ECG – Circuit Protection

All electrical circuits, including lighting, have to be protected against fault conditions such as overload or short circuit.

The devices used for this protection are miniature circuit breakers (MCBs). They are essentially a switch that is sensitive to the circuit current and breaks the circuit if the current is too high. They are the modern replacement for fuses.
The Basics of Efficient Lighting

The problem with lighting using ECGs is that the initial surge of current at switch on can be very high, causing the MCB to trip, switching off all the lights in the process. This is known as ‘nuisance tripping’.

For this reason, MCBs are classified in terms of their switch-on sensitivity. It is normal practice with lighting circuits to select an MCB that has low switch-on sensitivity so it does not trip out during the switch on phase (which lasts for only a few thousandths of a second).

All ECG manufacturers provide information on the maximum number of ECGs that can be used with the different current ratings and in-rush current sensitivity of the MCBs.

4 Lighting design

HEADS UP: Lighting Design and Energy Efficiency

Good lighting design is often the most overlooked aspect of lighting efficiency, and vice versa. A lighting installation cannot be efficient AND attractive, without careful consideration of ALL the aspects of lighting design. This includes choice of lamp, control gear and luminaire, along with luminaire placement, use of day lighting and intelligent control such as motion detectors and automatic dimming.

Irrespective of whether you are designing a lobby or dining room for a 6-star hotel, an office, or an industrial facility, lighting design must take an holistic approach that not only provides illumination, but creates a comfortable, stimulating and interesting environment.

An efficient and effective lighting system will:
- Provide a high level of visual comfort
- Make use of natural light
- Provide the best light for the task
- Provide controls for flexibility
- Have low energy requirements

Simply achieving the required illuminance does not guarantee a satisfactory lighting installation, and over illumination will not necessarily act as a safety margin. As long as there is adequate illuminance to perform a task, some variation in the level will not generally make a significant change to the level of visual performance. Other aspects of the visual environment such as glare, contrast and user satisfaction will have greater impact on whether a lighting installation is perceived to be successful.
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It is therefore important that the quality aspects of the space are addressed in parallel with the illuminance level, namely:

- Correct luminance distribution on the vertical surfaces
- Rational glare control
- Careful treatment of the task surround luminance
- Colour rendering
- Visual interest

Therefore, designing a lighting installation to provide a successful visual environment is a balancing act between multiple requirements which are often conflicting. Add to this the practical limitations of the performance of the light sources and lighting equipment available, energy efficiency, running costs, maintenance and available funds.

Regrettably, the lighting installation is sometimes among the last items to be considered when budgeting a building project, with the result that often cheaper alternatives are chosen just to keep total expenses within financial limits. The outcome may then be less than adequate, giving sub-optimal lighting conditions and low user satisfaction. Proper initial investment in a well designed lighting installation usually repays itself not just in higher return-of-investment but also in lower total cost of ownership during its lifetime.

4.1 Lighting design process

To achieve the best overall outcome in a lighting installation, it is important to avoid the tendency of rushing straight into luminaire selection before determining more broadly what is required from the system. The use of a structured design process helps to avoid this. The key steps in the design process are:

1. Identify the requirements
2. Determine the method of lighting
3. Select the lighting equipment
4. Calculate the lighting parameters and adjust the design as required
5. Determine the control system.
6. Check that the fittings to be installed are those that the design was based on
7. Inspect the installation upon completion and, if possible, a few months after occupation, to determine what worked and what didn’t. This is the only way to build up experience to apply to future designs.

The five initial stages are considered in more detail in the following sections.

4.1.1 Identifying the requirements

This involves gaining a full understanding of what the lighting installation is intended to achieve. This includes the:

- Task Requirements
  - Illuminance
  - Glare
- Mood of the space
- Relation to shape of space
- Things to be emphasised
- Things to hide
- Direction of light
- Interaction of daylight
4.1.2 Determine the method of lighting

At this stage, consideration is given to how the light is to be delivered, e.g. will it be recessed, surface mounted, direct or indirect, or will up-lighting be used, and its primary characteristics, e.g. will it be prismatic, low brightness or mellow light. Consideration should be given at this stage to the use of daylight to minimise the need for artificial light.

4.1.3 Select the lighting equipment

Once the method of lighting has been selected, the most appropriate light source can then be chosen followed by the luminaire. The following attributes should be studied when choosing the light source:

- Light output (lumens)
- Total input wattage
- Efficacy (lumens per Watt)
- Lifetime
- Physical size
- Surface brightness / glare
- Colour characteristics
- Electrical characteristics
- Requirement for control gear
- Compatibility with existing electrical system
- Suitability for the operating environment

A number of factors also affect luminaire choice:

- Characteristics of the light source and control gear (see above)
- Luminaire efficiency (% lamp light output transmitted out of the fixture)
- Light distribution
- Glare control
- Finish and appearance
- Size
- Accessibility of components for maintenance
- Ability to handle adverse operating conditions
- Aesthetics
- Thermal management

4.1.4 Calculate the lighting parameters

Lighting calculation methods fall into three broad categories:

- Manual calculation methods
- Three dimensional modelling
- Visualisation

Photometric data for light sources and luminaires is commercially available to contribute to these calculations.

4.1.4.1 Manual calculation methods

There are a wide range of manual computation methods for the calculation of different lighting aspects. These include complex methods for calculating the illuminance from a wide variety of shapes of luminous objects. The majority of these have now been superseded by computer programs.

The Lumen Method was the mainstay for interior lighting and has remained in use as a quick and relatively accurate method of calculating interior illuminance. The Lumen Method calculates the average illuminance at a specific level in the space, including an allowance for the light reflected from the interior surfaces of the
The Basics of Efficient Lighting

room. The calculation method has a set of assumptions that, if followed, gives a reasonable visual environment. Inadequate attention to the assumptions will produce poor results. The basic assumptions are:

- All the luminaires in the room are the same and have the same orientation
- The luminaires do not have a directional distribution and are aimed directly to the floor
- The luminaires are arranged in a uniform array on the ceiling and have the same mounting height
- The luminaires are spaced less than the maximum spacing to mounting height ratio nominated in the coefficient of utilisation tables

The average illuminance produced by a lighting installation, or the number of luminaires required to achieve a specific average illuminance, can be calculated by means of utilization factors, a UF being the ratio of the total flux received by a particular surface to the total lamp flux of the installation.

4.1.4.1.1 Lumen method formula

The average illuminance \( E(h) \) over a reference surface \( s \) can be calculated from the "lumen method" formula.

\[
E(h) = \frac{F \times n \times N \times LLF \times UF(s)}{\text{area of surface } s}
\]

where:

- \( F \) = the initial bare lamp flux (lumens)
- \( n \) = the number of lamps per luminaire
- \( N \) = the number of luminaires
- \( LLF \) = the total light loss factor
- \( UF(s) \) = the utilisation factor for the reference surface \( s \) of the chosen luminaire

Utilization factors can be determined for any surface or layout of luminaires. The "UF" symbol is normally shown followed by an extra letter in brackets, to denote the surface, for example, \( UF(F) \) is the utilisation factor for the floor cavity and \( UF(W) \) is the utilisation factor for the walls.

Utilization factors are, in practice, only calculated for general lighting systems with regular arrays of luminaires and for three main room surfaces. The highest of these surfaces, the \( C \) surface (for ceiling cavity), is an imaginary horizontal plane at the level of the luminaires having a reflectance equal to that of the ceiling cavity. The lowest surface, the \( F \) surface (for floor cavity), is a horizontal plane at normal working height (i.e. table height), which is often assumed to be 0.85m above the floor. The middle surface, the \( W \) surface (for walls), consists of all the walls between the \( C \) and \( F \) planes.

Although the lighting designer can calculate utilization factors, lighting companies publish utilization factors for standard conditions for their luminaires. The standard method of presentation is shown below. To use this table, it is only necessary to know the Room Index and the effective reflectance of the three standard surfaces (floor cavity, walls and ceiling cavity).
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4.1.4.1.2 Room Index

The Room Index is a measure of the angular size of the room, and is the ratio of the sum of the plan areas of the F and C surfaces to the area of the W surface. For rectangular rooms the room index is given by:

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

Where:
L = the length of the room
W = the width of the room
Hm = the height of the luminaire plane above the horizontal reference plane.

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

4.1.4.1.3 Spacing to Mounting Height Ratio

The Spacing to Mounting Height Ratio (SHR) is the spacing between luminaires divided by their height above the horizontal reference plane. It affects the uniformity of illuminance on that plane. When the UF tables are determined, for a nominal spacing to height ratio SHR NOM, the maximum spacing to height ratio SHR MAX of the luminaire is also calculated, and is a value that should not be exceeded if the uniformity is to be acceptable.

4.1.4.2 Three dimensional modelling

Although it was possible to calculate the luminance of all the surfaces in a room, the calculations were extremely laborious and could only be justified in the most special cases. However, the advent of computer modelling enabled a more flexible approach to lighting design and significantly increased the information available to the designer.
In contrast to the Lumen Method, lighting programs enable the lighting designer to broaden the assumptions:

- A mixture of luminaires can be used
- The luminaires no longer have to be arranged in a regular array
- Directional luminaires can be modelled
- A large number of calculation points can be considered to give a meaningful uniformity calculation
- The illuminance and luminance of all surfaces can be calculated

This gives the lighting designer a much greater understanding of what is happening in the room. However, there has been considerable research, experience and documentation over the past 80 years that has developed the current thinking in the adequacy of various illuminance levels for various tasks and functions. Although there is some general understanding of the need for appropriate luminance distribution in the vertical plane, there is little information, experience or understanding for many designers to determine:

- What the luminance of surfaces should be in varying situations
- What is an acceptable luminance uniformity
- Whether there should be a maximum luminance uniformity
- What is the desired graduation in luminance
- At what point is the luminance distribution of the wall unacceptable

It is important in using a lighting calculation program that the output records the type of luminaire used, the location of the luminaires, the assumed lumen output of the lamp, the light loss factor and the aiming points. If this is not recorded you have a pretty picture of the installation and no way of making it a reality.

4.1.4.3 Visualisation

These are programs that create a perspective rendering of the space in levels of detail that vary from a block representation of the space, to photographic quality renderings, depending on the sophistication of the program and the level of detail of the interior to be entered. The programs fall into two basic types:

- Flux transfer or radiosity calculations
- Ray tracing calculations

The major difference being in how they interpret light from reflective surfaces. A Lambertian surface is a perfect diffuser, where light is reflected in all directions, irrespective of the angle of incidence of the light such that irrespective of the viewing angle the surface has the same luminance. A specular surface is a mirror like surface, where the angle of reflection of the light is the same as the angle of incidence.

A real life surface is a combination of both surfaces (semi-specular) and has both specular and diffuse characteristics. Some materials are more specular while others are more diffuse.
A flux transfer or radiosity program treats all surfaces as diffuse or Lambertian surfaces, as a result their rendering tends to appear flat with soft shadow details. It will tend to overestimate the uniformity.

Ray tracing traces the individual rays of light from the source to the eye as it reflects from surface to surface around the room. As a result ray tracing can allow for the specular component of the surfaces.

Some programs calculate the entire lighting by ray tracing while others calculate the space on a flux transfer basis and have an overlay of ray tracing of specific areas to improve the quality of the rendering. When ray tracing is added, reflections are added in polished surfaces and shadows become sharper.

Visualisation programs are a useful tool in the presentation of a design, as a tool for the designer to check that the design is consistent with his own visualisation of the space, and to model specific lighting solutions. The programs are still calculation tools and not design programs. The programs can show the designer how a specific design will perform but that they cannot reliably be used to assess the acceptability of a design.

Irrespective of the form of the visualisation output, it is important that the program provides adequate information to enable the construction and verification of the lighting design. The output should include:

- **Installation information** - the type and location of all luminaires and the aiming information. The lamp details should be included as well as the specific catalogue number of photometric file that has been used.
- **Light technical parameters** – the illuminance, uniformity and other parameters that have been calculated to achieve the design.
- **Verification information** – adequate details to enable the lighting calculation to be verified. This should include the luminaire type, the photometric file, surface reflectances that were assumed, light loss factors, lumen output of lamps and mounting and aiming locations.

### 4.1.5 Determine the control system

The effectiveness and efficiency of any lighting installation is affected as much by the control system as by the light sources and fixtures chosen. Give consideration to:

- Providing multiple switches to control the number of lights that come on at any one time. Using one switch to turn on all the lights in a large room is very inefficient.
- Placing switches at the exits from rooms and using two-way switching to encourage lights to be turned off when leaving the room.
- Using ‘smart’ light switches and fittings which use movement sensors to turn lights on and off automatically. These are useful in rooms used infrequently where lights may be left on by mistake, or for the elderly and disabled. Make sure they have a built-in daylight sensor so that the light doesn’t turn on unnecessarily. Models which must be turned on manually and turn off automatically, but with a manual over-ride, are preferable in most situations. Be aware that the sensors use some power continuously, up to 5W or even 10W in some cases.
- Using timers, daylight controls and motion sensors to switch outdoor security lights on and off automatically. Controls are particularly useful for common areas, such as hallways, corridors and stairwells, in multi-unit housing.
- Using solar powered lighting for garden and security lights.
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- Using dimmer controls for incandescent lights (including halogens). This can save energy and also increase bulb life. Most standard fluorescent lamps cannot be dimmed, but special dimmers and lamps are available. If lamps are to be dimmed it is important to ensure that the correct equipment is used, especially when retrofitting more energy efficient lamps.

4.1.6 Choice of Luminaire

The performance of a luminaire should be considered just as carefully as its cost. In the long term a well designed, well constructed luminaire will be cheaper than a poor quality unit; and the salient features of a good quality luminaire are:
* Sound mechanical and electrical construction and a durable finish
* Adequate screening of high luminance lamps to minimise discomfort and glare
* Adequate heat dissipation to prevent over-heating of the lamp, wiring and ancillary equipment
* High light output ratio with the appropriate light distribution
* Ease of installation, cleaning and maintenance

4.2 Standards, Codes and Regulations

When designing lighting systems, there are some specific standards and codes that must be taken into account. These provide useful advice and guidance as well as specifying any mandatory requirements.

Minimum Energy Performance Standards (MEPS) already apply to certain pieces of equipment in the lighting industry. This ensures that when these items are manufactured they meet the performance standards.

In May of 2006 the Australian Government introduced a mandatory section for maximum energy requirements in new buildings through the Building Code of Australia. The particular reference to lighting is in Section J6 and details the maximum values of lumens per watt (lm/w) and watts per square metre (w/m²) allowable for certain building classes and tasks performed.

Building classes are listed below

- **Class 1a** — single dwelling, row house, terrace house, townhouse or villa
- **Class 1b** — boarding house or guest house < 300m² or 12 persons
- **Class 2** — sole-occupancy units
- **Class 3** — residential, boarding house, hostel, motel, residential part of aged care, school or health care
- **Class 4** — caretakers dwelling
- **Class 5** — office
- **Class 7a** — carpark
- **Class 7b** — wholesale warehouse or storage facility
- **Class 8** — laboratory or factory
- **Class 9a** — health-care building
- **Class 9b** — assembly building
- **Class 9c** — aged care facility
- **Class 10a** — non-habitable private garage, shed, carport or the like
- **Class 10b** — swimming pool, mast, antenna, fence, retaining wall

The Deemed-to-Satisfy provisions are based on a maximum power density for different lighting tasks.

- Classes 2, 3 and 9c are Lamp Power Density (LPD) and defined as watts /m² (lamp wattage only)
The Basics of Efficient Lighting

Classes 5, 6, 7, 8, 9a & 9b are Illumination Power Density (IPD) and defined as watts/m² (lamp wattage and control gear losses included). The brief précis below from the BCA shows some of the IPD’s required:

Exterior Artificial Lighting must:

i. Be automatically switched off when daylight is available; and

ii. When the total external lighting load exceeds 100 watts
   A. Have an average light source efficacy of not less than 60 lumens per watt; or
   B. Be controlled by a motion detector in accordance with Specification J6

iii. When for decorative purposes, such as façade lighting or signage lighting, have a separate time switch

The requirements of the code do not apply to artificial lighting used for the purposes listed in J6.2 (d) i.e.

- Emergency Lighting in accordance with part E4
- Signage and Display lighting within cabinets and display cases
- Safe movement in accordance with part F4.4
- Accommodation and Residential section of a detention centre
- Bathroom heating
- Lighting of theatrical or musical performances
- The permanent display and preservation of works of art or objects in a museum or gallery but not for retail

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### Table J6.2a: Maximum Lamp Power Density

<table>
<thead>
<tr>
<th>Location</th>
<th>Lamp power density (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within a Class 3 and Go aged care building sole-occupancy unit</td>
<td>10</td>
</tr>
<tr>
<td>Within a dormitory of a Class 3 building used only for sleeping</td>
<td>5</td>
</tr>
<tr>
<td>Within other areas of a Class 2, 3 or 3&amp; aged care building that are frequently occupied such as a lounge room, a dining room, restaurant or gymnasium</td>
<td>8</td>
</tr>
<tr>
<td>Within public corridors and the like</td>
<td>3</td>
</tr>
<tr>
<td>Within stairways</td>
<td>5</td>
</tr>
<tr>
<td>Services areas such as a plant room or store room</td>
<td>6</td>
</tr>
<tr>
<td>Employees’ work areas such as a reception</td>
<td>10</td>
</tr>
</tbody>
</table>

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### Table J6.2b: Maximum Illumination Power Density

<table>
<thead>
<tr>
<th>Space</th>
<th>Maximum illumination power density (lm/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry lobby</td>
<td>15</td>
</tr>
<tr>
<td>Factory, industrial tanks and processes</td>
<td>17</td>
</tr>
<tr>
<td>Laboratory</td>
<td>15</td>
</tr>
<tr>
<td>Office – artificially lit to an ambient level ≥ 200 lux</td>
<td>10 (7 if &lt; 200 lux)</td>
</tr>
<tr>
<td>Restaurant, café, bar, hotel lounge (food/beverages)</td>
<td>20</td>
</tr>
<tr>
<td>Retail space including sales area of museum/gallery</td>
<td>25</td>
</tr>
<tr>
<td>School – general purpose learning area</td>
<td>10</td>
</tr>
<tr>
<td>Storage – shelving height ≥ 76% aisle lighting height</td>
<td>10 (8 if &lt; 76%)</td>
</tr>
<tr>
<td>Service area, locker, staff, tea and cleaner’s rooms</td>
<td>3</td>
</tr>
</tbody>
</table>

---

The requirements of J6.2(a) and (b) do not apply to:
- Emergency and exit lighting
- Signage and display lighting within cabinets and display cases
- Lighting of specialist processes (theatre, sport, art, turn cupboard, operating theatre)
As this reference manual was being completed, the BCA had released an update for public comment to be incorporated into the 2010 release of the BCA. This update includes requirements for class 1a single dwellings.

4.3 Australian Lighting Standards and Their Relevance

The human eye will adapt to an enormous range of illumination levels. The untrained eye cannot easily detect a 20% change in illumination levels. In a general office or home environment we read under levels ranging from 50 lux to 1000 lux. We can also read at night on the railway station platform with only 15 lux and conversely outside on a sunny day in illumination levels of 100,000 to 150,000 lux.

However there is an optimum level which will produce the greatest "task efficiency" with the lowest practical illumination level. To ascertain the 'correct' illumination level for any given task extensive research has been carried out comparing various illumination levels with a person's task efficiency or work output under the different illumination levels. The results of these studies are the basis of the Australian/New Zealand Standard for Interior Lighting AS/NZS 1680 series. The illumination levels recommended in this standard are the minimum recommended illumination levels to be maintained that will permit consistently high task efficiency with comfortable intensity levels.

As previously discussed, the first step in providing the correct solution is to identify the needs of the site. Minimum illumination levels for various applications should be checked with the Australian Standard and the type of luminaire which best suits the glare control limits required can be selected. The Standard generally recommends **MINIMUM** maintenance illumination levels only. It is also accepted that Corporate requirements, or unusual circumstances, may require higher levels in various situations.

It is worthy of note that the highest recommended illumination level in the Interior Lighting Standard is 1600 lux, which is recommended for minute instrument workings inspection such as watch making.

The key standards are:

- AS1680.1-2006, ‘Interior and workplace lighting - general principles and recommendations’
- AS/NZS 1680.2 series, ‘Interior and workplace lighting - specific applications’

A brief overview of the Australian Standards for lighting is given in Appendix 1.

4.4 Building in efficiency

As lighting accounts for a significant percentage of energy use there is an increasing requirement to achieve the required visual environment while minimising energy use and consequential greenhouse gas emissions.

Energy efficient lighting is not simply minimising the energy input through higher equipment efficiency, or reducing illuminance levels to the minimum that is tolerable. If user comfort is poor, then there a likelihood that occupants will increase illuminance levels (for example with desk lamps) to compensate.

Compact fluorescent and linear or tubular fluorescents lamps are the most energy efficient form of lighting for households. Fluorescent lamps use only about one quarter of the energy used by incandescent lamps to provide the same light level.

Although more expensive to buy they are much cheaper to run and can last up to twenty thousand hours. With careful design they can replace incandescent and halogen lights in most situations.
4.5 Use of daylight

The most energy efficient light is natural light. The science of day lighting involves the deliberate use of daylight to displace electric light. Large savings are possible in offices and other non-residential buildings when the relative amounts of daylight and artificial light are regulated by sensors and a control system. Done correctly, there will be a net saving of energy consumed by the building. Done incorrectly, the heat load on the building will increase and there will be a net increase in cooling energy consumption. If the daylight control system is poorly implemented, building occupants deal with glare and/or thermal discomfort using the most expedient means at hand, which in turn usually cancels out any of the benefits that day lighting might have offered.

In a residential setting, well designed north-facing windows, skylights and light tubes let in light without adding to summer heat and winter cold. Light coloured interior surfaces, especially in south-facing rooms and hallways, reflect more light and reduce the level of artificial lighting required.

Effective use of daylight depends on many factors including:

- The sun’s altitude and azimuth
- The relative occurrence of overcast versus sunny weather
- The season
- Levels of air pollution and haze

Australian cities are not afflicted by heavy air pollution as much as many overseas locations, except on isolated occasions such as during severe bushfires or dust storms. Therefore it is possible to predict average sky conditions with good accuracy, including relative amounts of clear and overcast sky, for most populated locations.

An essential starting point in day lighting design is to determine the distribution of sunlight and shadow on the site. Phillips (1983) provides solar charts for latitudes from Darwin to Hobart, together with a useful shadow-angle protractor. Several well-known references provided tabulated data for sky conditions for major Australian centres and how to use the knowledge to design effective sky lighting. Good day lighting designers must also be mindful of reflected glare from neighbouring buildings; Hassall (1991) gives extensive advice and methods for predicting and avoiding 'rogue reflections' from nearby buildings, etc.

Locations with a high incidence of cloudy skies are better served by roof windows or conventional skylights with large areas and diffuse glazing systems. On the other hand, sunny locations can exploit tubular day lighting devices – tubular skylights – which send direct-beam sunlight into the space below and are capable of delivering very high illumination levels provided the sky is clear.

5 Selling efficiency and replacement technologies

HEADS UP: Selling Efficiency

The trend toward energy efficiency has taken a quantum leap in recent years, with the demand for energy efficient equipment and appliances being largely consumer driven. The objective of this manual is to give electricians, salespeople and anyone involved in lighting, a range of tools to specify and install efficient, high quality lighting systems. The benefits to consumers are lower running costs, reduced environmental impact and often improved lighting quality which comes from thoughtful lighting design, rather than adherence to out-dated (yet easy) lighting practices.
5.1 Issues for consideration

With the ongoing phase out of incandescent lamps in Australia it will soon become necessary to replace all general service lamps with a more energy efficient alternative. In the residential sector this will normally be a direct replacement with CFLs or halogen IRC technology. In other situations, alternative energy efficient lamps may be a more appropriate choice. In new build installations, there is greater freedom of choice and flexibility and the opportunity to further minimise energy consumption by good lighting designing. In both instances, consideration should be given to a few key points.

5.1.1 Lamp compatibility

At a basic level, when selecting lamps it is important to ensure that they are compatible with the fixtures and circuits that are already in place (or that are included in the design). For example, do you need a particular lamp base (pin base, Edison screw base, bayonet) or does the linear fluorescent tube chosen require a particular fitting (e.g. T5 fluorescent tubes are not interchangeable with T8 or T12 tubes). More generally, several other points should be considered.

5.1.1.1 Point source – non-point source

The nature of the task that the lamp is required to perform is an important consideration. If an object or a location specific task is to be illuminated, a point source is recommended (halogen IRC or some of the better LEDs). However, for more general lighting a more diffuse (non-point source) should be used which will light the entire space (linear fluorescent or CFLs).

5.1.1.2 Directional – non directional

If more control the area being illuminated is required this can be achieved by using a directional light source. These lamps use either an integral reflector or a reflector built into the luminaire to restrict the passage of light backwards from the lamp and reflect it forwards.

5.1.1.3 Size

Although energy efficient lamps are increasingly becoming available in a wide range of shapes and sizes, care should still be taken when selecting replacement lamps to ensure that they are a suitable size for the luminaire or fixture in which they are being used. With integral ballast CFLs, the extra required for the ballast can result in a lamp with an equivalent bulb size to the one that is being replaced failing to fit the luminaire.

5.1.1.4 Colour temperature

The colour temperature of a lamp determines the colour that the light source appears. There are several reasons for selecting a particular colour of lamp.

Atmosphere – incandescent lamps have traditionally been used in homes and hotels. As a result the warmth and reddish appearance tends to be associated with comfort and relaxation. In these types of installations and areas where people are to be encouraged to relax, a lamp with a colour temperature of 2,700K to 3,000K would be preferable. As low colour temperature lamps give an atmosphere of warmth, they are often preferred for cooler climates. In areas that are hot or humid and not air conditioned, moving to a cooler lamp, around 4,000K or higher, can reduce the oppressive feeling.
**Colour Scheme** – irrespective of the colour rendering of the lamps, the correlated colour temperature needs to be co-ordinated with the colour scheme of the room. In many colour schemes it has little effect, however where warm lamps are used with a cool colour scheme or vice versa, the general feeling of space can be incongruous. It can be a particular problem where mid greys are used, as the spectral difference between a warm grey and a cool grey can be slight.

Matching with other sources – There is a general preference to match the colour of light sources throughout an installation, as significant variations in the colour appearance draws attention to the light fittings. However, changes in the colour appearance of lamps can be used to advantage. When highlighting an object a subtle shift in colour appearance to the cooler temperature can help draw attention, thereby requiring a smaller contrast in luminance. Also, a reduction in colour temperature when moving from a work area to a relaxation area can increase the contrast in the atmospheres and reinforce the change in role.

5.1.2 Retrofit

Retrofitting more energy efficient lamps introduces some additional considerations.

5.1.2.1 Thermal issues – over heating

When introducing new lamps into an existing lighting system, the space around the lamp is fixed. This therefore means that the space available for heat dissipation is also restricted. Care should therefore be taken when choosing replacement lamps to ensure that they do not generate more heat during operation than can easily be dissipated in the space available.

The LED has enormous difficulties with heat dissipation. The hotter the LED gets the worse it performs.

5.1.2.2 Dimmability

Over recent years there has been an increase in the popularity of dimmable lighting. This can pose constraints on the choice of lamps to replace normal incandescent lamps as some of the newer technologies require specific controls to allow dimming that would normally be fitted at the time of installation.

Some compact fluorescent lamps are not compatible with existing dimming circuits – the lamp will not work properly and the electronics in the dimmer switch could be damaged. It is recommended that you refer to product packaging at the time of purchase, or alternatively contact the manufacturer for product specific information. However, specialised integral ballast CFLs which are compatible with dimming circuits are available and more dimmable compact fluorescent lamps are expected to become available as the phase-out of incandescent lamps progresses.

Mains voltage halogen lamps provide a more efficient dimmable alternative to common incandescent lamps and are readily available in the market place.

The demand for dimming of HID lamps is mainly directed to metal halide lamps. Attempting to dim metal halide lamps causes the arc-tube to operate at too low a temperature, which in turn results in the condensation of some of the metal halides. The consequence is a loss of colour from the condensed halides and the overall spectral output of the lamp is changed. The colour temperature changes (usually increases) and the colour rendering index falls significantly. For this reason, dimming of metal halide lamps is not recommended, as the colour and life performance of the lamps cannot be guaranteed.
5.1.2.3 Compatibility with control devices (basic circuits, power supply)

As the newer technologies have different control requirements, it is important to ensure that any replacement lamp is compatible with the control devices that are already present. For example:

- Fluorescent lamps are not designed to be operated directly from the mains supply as they require specific control gear to generate a high voltage to initiate the discharge and control the discharge current.
- Integral ballast compact fluorescent lamps should not be operated from other electronic switches, such as electronic timers and light sensors, as the electronics in the switches could be damaged.
- Mains voltage halogen lamps must be operated with a separate fuse in the system because the size of the lamp does not allow an effective fuse system to be built into the lamp.
- Low voltage lamps must never be operated directly off the mains supply, even through a phase control dimmer, as they are liable to explode. They should always be operated through an appropriately rated transformer or battery.

5.2 Understanding labelling and packaging

With the proliferation of new lamp styles and technologies, it is important to be able to understand the designation codes that are used for the different types of lamps.

5.2.1 Marking of Fluorescent Lamps

Fluorescent lamps are identified by a standardised code that reveals valuable information about operating characteristics and physical dimensions. Manufacturers' codes, found on the lamps and in catalogues, may vary slightly from the generic designations. However all major lamp manufacturers base their codes closely on the identification system discussed below.

The coding system provides the user with the three essential parameters of the tube: Lamp power (wattage), colour rendering (CRI value) and colour temperature (K). Some examples are shown below:

**Rapid-start (40 watts or less) and preheat lamps**

Rapid-start lamps are the most popular fluorescent lamp type used in commercial applications such as office buildings.

<table>
<thead>
<tr>
<th>F30T12/CW/RS</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>T</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>CW</td>
</tr>
<tr>
<td>RS</td>
</tr>
<tr>
<td>Preheat lamps do not have “RS” as a suffix</td>
</tr>
</tbody>
</table>

Note: Some lamps may be designated F40T12/ES, but the lamp draws 34 instead of 40 watts; the ‘ES,’ a modifier which stands for ‘energy-saving,’ indicates this. ES is a generic designation; actual manufacturer designations may be ‘SS’ for Supersaver, ‘EW’ for Econ-o-Watt, ‘WM’ for Watt-Miser and others.

---

1 [www.lightsearch.com/resources/lightguides/fllampid.html](http://www.lightsearch.com/resources/lightguides/fllampid.html)
After the mode of starting, another number may be added to indicate colour rendering and colour temperature if the lamp's colour (CW, WW, WWX, etc.) is not indicated. The number will often be three digits, the first indicating colour rendering (a ‘7’ standing for ‘75,’ for example) and then the next two indicating colour temperature (a ‘41’ standing for ‘4,100K,’ for example).

### High-output rapid-start lamps

<table>
<thead>
<tr>
<th>F48T12/WW/HO</th>
</tr>
</thead>
<tbody>
<tr>
<td>F Fluorescent</td>
</tr>
<tr>
<td>48 Rated nominal wattage</td>
</tr>
<tr>
<td>T Shape - <em>this lamp is shaped like a tube</em></td>
</tr>
<tr>
<td>12 Diameter in eighths of an inch; this lamp is 12/8 (1.5) inches in diameter</td>
</tr>
<tr>
<td>WW Colour - <em>this lamp is a warm white lamp</em></td>
</tr>
<tr>
<td>HO High output lamp operating on 800mA current</td>
</tr>
</tbody>
</table>

### Very high-output rapid-start lamps

<table>
<thead>
<tr>
<th>F72T12/CW/VHO</th>
</tr>
</thead>
<tbody>
<tr>
<td>F Fluorescent</td>
</tr>
<tr>
<td>72 Nominal length of the lamp in inches</td>
</tr>
<tr>
<td>T Shape - <em>this lamp is shaped like a tube</em></td>
</tr>
<tr>
<td>12 Diameter in eighths of an inch; this lamp is 12/8 (1.5) inches in diameter</td>
</tr>
<tr>
<td>CW Colour - <em>this lamp is a cool white lamp</em></td>
</tr>
<tr>
<td>VHO Very high output lamp operating on 1500mA current</td>
</tr>
</tbody>
</table>

Note: Instead of VHO, lamps may use brand names such as ‘1500’ or ‘PowerGroove’

### Instant-start lamps

<table>
<thead>
<tr>
<th>F96T12/WWX</th>
</tr>
</thead>
<tbody>
<tr>
<td>F Fluorescent</td>
</tr>
<tr>
<td>96 Nominal length of the lamp in inches</td>
</tr>
<tr>
<td>T Shape - <em>this lamp is shaped like a tube</em></td>
</tr>
<tr>
<td>12 Diameter in eighths of an inch; this lamp is 12/8 (1.5) inches in diameter</td>
</tr>
<tr>
<td>WWX Colour - <em>this lamp is a deluxe warm white lamp</em></td>
</tr>
</tbody>
</table>

### Other fluorescent lamps

- ‘FC’ instead of ‘F’ means the lamp is circular.
- ‘FB’ or ‘FU’ instead of ‘F’ means the lamp is bent or U-shaped. The suffix ‘U’ may also be followed by a ‘/’ and a number that indicates the distance between the lamp’s legs in inches
- ‘FT’ instead of ‘F’ is used for twin-tube T5 lamps

### 5.2.2 Compact Fluorescent Lamp Identification

Compact Fluorescent lamps are either pin-based (they plug into a socket) or they are medium screw-based (they screw into the same socket as common incandescent lamps). The following describes the National Electrical Manufacturers Association (NEMA) generic designation system for pin-based compact fluorescent lamps. The NEMA generic designation system for pin-based compact fluorescent lamps consists of four parts:

\[
\text{CF + shape + wattage / abbreviated base designation}
\]
• The prefix ‘CF’ is used for all types of compact fluorescent lamps that comply with the American National Standards Institute (ANSI) definition of a self-supporting lamp with a single base.
• The ‘shape’ designator is chosen from the following:
  o T - twin parallel tubes
  o Q - four tubes in a quad formation
  o TR - triple tube (including three twin tubes in a delta formation or three tubes in an arch). This is new shape designator to address the increased use of this lamp type. Some publications may refer to triple tube using their former ‘M’ designator
  o S - square shaped
  o M - a combination of tubes (multiple) not covered by any of the above shape designators
• The ‘wattage’ is the nominal wattage, followed by ‘W’.
• The ‘abbreviated base designation’ after the ‘/’ separator, is the ANSI/IEC (International Electrotechnical Commission) designation which includes the number of pins, but excludes any keyway information. The base designation, which can be determined from lamp catalogues, is essential to differentiate between lamps of the same wattage, but which have different pin configurations (as described in the section on CFLs).
• Additional information, such as colour, may be added after a further ‘/’ separator.

For example:

<table>
<thead>
<tr>
<th>Identification mark</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFT9W/G23</td>
<td>9 watt twin tube with G23 base</td>
</tr>
<tr>
<td>CFQ26W/G24d</td>
<td>26 watt quad tube with 2 pin G24 base</td>
</tr>
<tr>
<td>CFQ26W/G24q</td>
<td>26 watt quad tube with 4 pin G24 base</td>
</tr>
<tr>
<td>CFTR32W/G24q/835</td>
<td>32 watt triple tube with 4 pin G24 base, &gt;80CRI, 3,500K</td>
</tr>
</tbody>
</table>

5.2.3 Halogen lamp identification

The designation system for halogen lamps consists of four parts

\[
\text{wattage} + \text{MR} + \text{diameter} / \text{beam angle}
\]

• The ‘wattage’ is the nominal wattage
• MR – coded designation which stands for ‘multifaceted reflector’ The ‘shape’ designator is chosen from the following:
  • Diameter – as number of eighths of an inch the front is in diameter. In the case of MR16, this is 16 x 1/8 i.e. 2 inches
  • Beam angle – in degrees

For example:

<table>
<thead>
<tr>
<th>Identification mark</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>20MR16/10°</td>
<td>20 watt, 10 degree beam</td>
</tr>
<tr>
<td>20MR16/40°</td>
<td>20 watt, 40 degree beam</td>
</tr>
<tr>
<td>50MR16/15°</td>
<td>50 watt, 15 degree beam</td>
</tr>
<tr>
<td>50MR16/25°</td>
<td>50 watt, 25 degree beam</td>
</tr>
<tr>
<td>65MR16/25°</td>
<td>65 watt, 25 degree beam</td>
</tr>
<tr>
<td>65MR16/40°</td>
<td>65 watt, 40 degree beam</td>
</tr>
<tr>
<td>75MR16/15°</td>
<td>75 watt, 15 degree beam</td>
</tr>
<tr>
<td>75MR16/25°</td>
<td>75 watt, 25 degree beam</td>
</tr>
</tbody>
</table>

Halogen reflectors are available in many other power and beam combinations. For this reason, MR16 lamps are also often labelled according to beam spread abbreviations. While these abbreviations are commonly
used, the angles associated with these abbreviations vary slightly from manufacturer to manufacturer. Typical beam angles for these beam spread abbreviations are shown overleaf:

<table>
<thead>
<tr>
<th>Identification mark</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VNSP (Very narrow spot)</td>
<td>Less than 8 degrees</td>
</tr>
<tr>
<td>NSP (Narrow spot)</td>
<td>8-15 degrees</td>
</tr>
<tr>
<td>SP (Spot)</td>
<td>8-20 degrees</td>
</tr>
<tr>
<td>NFL (Narrow flood)</td>
<td>24-30 degrees</td>
</tr>
<tr>
<td>FL (Flood)</td>
<td>35-40 degrees</td>
</tr>
<tr>
<td>WFL (Wide flood)</td>
<td>55-60 degrees</td>
</tr>
<tr>
<td>VWFL (Very wide flood)</td>
<td>60 degrees or more</td>
</tr>
</tbody>
</table>

5.3 Energy Saving Calculations

At a simplistic level, the cost of running a light is directly related to the wattage of the globe plus any associated ballast or transformer. The higher the wattage, the higher the running cost and it is a straightforward calculation to work out the running cost of lamp over its lifetime:

Running cost = cost of electricity in $/kWh x wattage of lamp x lifetime in hours

Because the purchase price of more energy efficient lamps is currently higher than that of the normal incandescent lamps, it is also useful to consider the total lifetime cost of the replacement lamp. This demonstrates that although it costs more to buy the lamp, significant savings are still made over its lifetime as a result of the reduced energy use.

CFLs are the cheapest form of household lighting when the life cycle cost is considered. The type of lighting you choose will affect the amount of electricity used, your lighting bill, and greenhouse gas emissions.

As an example, the table below compares the cost to the user of a standard incandescent lamp, a long-life CFL and an ELV tungsten halogen. It illustrates the large savings in electricity costs from using the CFL.

<table>
<thead>
<tr>
<th></th>
<th>Long life CFL</th>
<th>ELV Tungsten Halogen</th>
<th>Incandescent lamp</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lamp Wattage</strong></td>
<td>15W</td>
<td>50W</td>
<td>75W</td>
</tr>
<tr>
<td><strong>Quantity</strong></td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Hours burned</strong></td>
<td>15,000 hours</td>
<td>15,000 hours</td>
<td>15,000 hours</td>
</tr>
<tr>
<td><strong>Average life</strong></td>
<td>15,000 hours</td>
<td>4,000 hours</td>
<td>1,000 hours</td>
</tr>
<tr>
<td><strong>Lumens</strong></td>
<td>900</td>
<td>900</td>
<td>900</td>
</tr>
<tr>
<td><strong>Power Input</strong></td>
<td>15W (integral ballast)</td>
<td>65W (incl transformer)</td>
<td>75W</td>
</tr>
<tr>
<td><strong>Total power consumption</strong></td>
<td>225kWh</td>
<td>975kWh</td>
<td>1,125kWh</td>
</tr>
<tr>
<td><strong>Electricity cost at $0.17 /kWh</strong></td>
<td>$38.25</td>
<td>$165.75</td>
<td>$191.25</td>
</tr>
<tr>
<td><strong>+ Lamp price</strong></td>
<td>$9.95</td>
<td>4 x $2.50 = $10.00</td>
<td>15 x $0.90 = $13.50</td>
</tr>
<tr>
<td><strong>= Total Costs</strong></td>
<td>$48.20</td>
<td>$175.75</td>
<td>$204.75</td>
</tr>
<tr>
<td><strong>Savings per lamp (vs. incan)</strong></td>
<td>$156.55</td>
<td>$48.20</td>
<td></td>
</tr>
</tbody>
</table>
5.3.1 Energy Efficiency Index

The Energy Efficiency Index (EEI), also known as the Energy Label, is a classification system for the lamp/ECG combination (it does not relate to luminaires). In Australia, all ballasts used with linear fluorescent lamp between 15 and 70W, are required to meet a Minimum Energy Performance Standard (MEPS) where the EEI = B2. Details of MEPS and EEI are contained in AS/NZS 4783.2: 2002, ‘Performance of electrical lighting equipment - Ballasts for fluorescent lamps - Energy labelling and minimum energy performance standards requirements’.

From 1 October 2004, linear fluorescent lamps manufactured in or imported into Australia must comply with Minimum Energy Performance (MEPS) requirements which are set out in AS/NZS 4782.2: 2004, ‘Double-capped fluorescent lamps - Performance specifications - Minimum Energy Performance Standard (MEPS)’.

The scope of linear fluorescent lamps MEPS covers FD and FDH lamps ranging from 550mm. The intention of MEPS is to improve end-use energy efficiency by eliminating lower efficiency fluorescent lamps from the market and to encourage the sale and purchase of higher efficiency fluorescent lamps.

The standard also sets out the requirements for voluntary energy labelling which is the same as the European Energy labelling scheme. The label can be used on product packaging and in promotional or advertising materials. This labelling scheme extends to all lamp types including linear fluorescent lamps, compact fluorescent lamps, quartz halogen lamps and incandescent lamps.


![European energy label](image)
The EEI classification systems, set out below with examples, are defined by certain limit values in lamp or system performance and range from A to G, with Class A being the best in terms of energy efficiency and Class G the worst.

<table>
<thead>
<tr>
<th>Rating system for Household Lamps</th>
<th>Rating system for Control component</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: Very Efficient</td>
<td>A1: Dimmable ECGs</td>
</tr>
<tr>
<td>B: &gt;50 lm/W</td>
<td>A2: ECGs with low loss</td>
</tr>
<tr>
<td>C</td>
<td>A3: ECGs with higher losses</td>
</tr>
<tr>
<td>D: Mostly Halogen - &gt; 16 lm/W</td>
<td>B1: Good low-loss control gear</td>
</tr>
<tr>
<td>E: Incandescent - GLS</td>
<td>B2: Poor low-loss control gear</td>
</tr>
<tr>
<td>F: Incandescent - &lt; 10 lm/W</td>
<td>C: Conventional control gear</td>
</tr>
<tr>
<td>G: Least efficient - Coloured lamps</td>
<td></td>
</tr>
<tr>
<td>(Calculated according to specified formula)</td>
<td>(Determined by test)</td>
</tr>
</tbody>
</table>

The interim standard, AS/NZS 4847.2(Int):2008, ‘Self-ballasted lamps for general lighting services - Minimum Energy Performance Standards (MEPS) requirements’ specifies Minimum Energy Performance Standards (MEPS) requirements and related attributes for self-ballasted compact fluorescent lamps (CFLs) with integrated means for controlling starting and stable operation that are intended for domestic and similar general lighting purposes in Australia and New Zealand. It applies to self-ballasted lamps of all voltages and wattages irrespective of the type of lamp cap. It applies performance standards to the following attributes:

- Starting time
- Run-up time
- Efficacy
- Lumen maintenance
- Premature lamp failure
- Life
- Power factor
- Colour appearance
- CRI
- Mercury content
- Switching withstand
- Harmonics and immunity

6 Sustainability

As discussed in the introduction, sustainability is about sensibly and effectively using the resources currently available and thereby helping to ensure that the ability of future generations to meet their needs is not compromised.

6.1 Electricity

Electricity consumption during operation is by far the biggest issue relating to the sustainability of lighting systems. Lighting accounts for between 5 and 15% of residential energy use and up to 30% of commercial building energy use. The phase-out of inefficient incandescent lamps will deliver considerable savings to the environment and the economy. Across the country, the move to more efficient lighting, such as CFLs, is expected to save around 30 terawatt hours of electricity and 28 million tonnes of greenhouse gas emissions between 2008 and 2020. This is equivalent to permanently decommissioning a small coal-fired power station or taking more than 500,000 cars off the road permanently. It is expected to result in savings to the Australian economy of around $380 million per
year by 2020 and result in net savings of more than $50 per year for each household that changes all of its incandescent light globes to CFLs.

In addition to the obvious benefits in terms of reduction in energy use and production of greenhouse gases from the use of more energy efficient lamps, good lighting design that considers lighting zoning, lighting power densities, lighting ballasts, sub-metering, and lighting controls also contributes to overall sustainability. Conversely, poor lighting design can actually increase the energy consumption as users seek to improve their visual environment by using additional lighting and may increase the energy required to cool the building because of the higher level of heat generation.

6.2 Materials

6.2.1 Recyclability

Another consideration determining the sustainability of a product is whether it is possible to recycle its component parts (including the packaging).

There are already specialty recyclers who are able to the mercury, glass, phosphor and aluminium contained in lamps. The main driver for this is currently the concern over mercury contamination from mercury containing lamps (the recovered mercury is commonly sold to the dental industry, where it is used in amalgam for fillings).

Several states have household chemical collection programs and/or drop-off points that accept CFLs and fluorescent tubes for recycling. Other states are considering introducing similar schemes.

Several states have household chemical collection programs and/or drop-off points that accept CFLs and fluorescent tubes for recycling. Other states are considering introducing similar schemes. Detailed information about disposal and recycling, developed with the assistance of the states and territories is available at [www.environment.gov.au/settlements/waste/lamp-mercury.html](http://www.environment.gov.au/settlements/waste/lamp-mercury.html).

In an effort to reduce mercury emissions even further, the Australian Government, in conjunction with the Environment Protection and Heritage Council, has launched the *Fluoro-cycle* project in order to begin addressing this issue.

*Fluoro-cycle* is a voluntary partnership between the Australian Government and industry to increase recycling of mercury containing lamps by the commercial and public lighting sectors. These lamps currently account for approximately 90 per cent of all lighting waste. The scope of the program is expected to be eventually broadened to include lamps from the domestic or household sector. This may be necessary to address the increasing volumes of waste lamps as the CFLs currently being installed to replace incandescent globes reach end of life.

Less mercury is released into the environment from the use of Compact Fluorescent Lamps (CFLs) than incandescent lamps despite the fact that CFLs contain a small amount of mercury. The reason for this is that burning coal to produce electricity also produces emissions of mercury. As CFLs use significantly less electricity than incandescent lamps, their use also results in lower overall emissions of mercury.

6.2.2 Embodied energy

Embodied energy is defined as the available energy that was used in the work of making a product. Minimising resource and energy usage, as well as waste (particularly hazardous waste) in the manufacturing and disposal of lighting equipment is also an important aspect of sustainability. However embodied energy in lighting equipment is generally insignificant compared to the energy used during the life of the equipment.
Selecting energy efficient lighting equipment is far more important than considering the embodied energy contained in the lighting equipment.

For example, CFLs are a more complex technology than traditional incandescent lamps, and so have a higher embodied energy, but this additional embodied energy will be offset many times over in the energy savings achieved from replacing an incandescent lamp with a CFL.

In this example we have a clear picture of the energy generated to make, and then operate two lamp types over an equal time period. If this energy is from fossil fuels, apart from the release of ‘greenhouse effect’ gases in related proportions, similar proportions of mercury are also released into the atmosphere. There is now only a small amount of mercury in all commonly used low-pressure gas discharge lamps and hence the threat from mercury pollution, via fossil fuel energy production associated with the incandescent lamp usage, is far greater than that imposed by many of the newer discharge lamps.

Different materials have a different embodied energy. Aluminium has a high embodied energy (170 MJ/kg as opposed to 12.7 MJ/kg in glass). Unless lamps of aluminium construction are required because of the environment in which the lamp will be operating, choosing one of plastic construction instead provides a more sustainable option.

7 Health consideration and lighting

As the phase-out of standard incandescent lamps and replacement with more energy efficient products progresses, questions have arisen over possible health issues. In particular, these concerns are associated with:

- Flicker
- Ultraviolet emissions
- Mercury
- Electromagnetic radiation (EMR)
7.1 Flicker

As part of their normal operation, fluorescent lamps, both linear and compact fluorescent lamps (CFLs) ‘flicker’ (i.e. flash on and off very rapidly). Compact fluorescent lamps (CFLs) flicker at a rate of more than 20,000 times per second, modern linear fluorescent tubes at a rate of more than 5,000 times per second and older style linear fluorescents at 100 times per second. These rates of flickering are not detectable by the human brain (studies suggest that 1% of people can detect a flicker rate of up to 60 times per second). If a linear fluorescent light has a noticeable flicker it is likely to have developed a fault and should be replaced. If a CFL has a noticeable flicker it could be the result of a poor quality product or may occur in situations where the lamp has been incorrectly fitted i.e. in a dimmer switch, touch lamp or another electronic device.

However, some concern has been raised regarding the possible health implications associated with flicker. In particular for sufferers of:

- Photosensitive epilepsy
- Ménière's disease
- Migraines

7.1.1 Photosensitive epilepsy

Photosensitive epilepsy is the name given to epilepsy in which all, or almost all, seizures are provoked by flashing or flickering light, or some shapes or patterns. Both natural and artificial light may trigger seizures. Photosensitive epilepsy is rare and only 5% of epileptics are diagnosed with this form of epilepsy.

Some known triggers for people with photosensitive epilepsy are:

- Watching television or playing video games
- Having a faulty lamp or television that flickers
- Strobe lights
- Driving at dawn or dusk with sun shining through a line of trees
- Sun flickering on water
- Looking out of the window from a fast moving vehicle
- Geometric patterns.

Although the frequency of flashing light most likely to trigger seizures varies from person to person, it is between 8 and 30 Hz or flashes per second. CFLs and linear fluorescent lamps flicker at a rate well above this sensitive range and do not pose a hazard to sufferers of photosensitive epilepsy. Researchers have concluded that compact fluorescent lamps (CFLs) are no more likely to be a greater risk to people with photosensitive epilepsy than other lamps. The small number of cases of reactions to linear fluorescent tube flicker that have been recorded were almost certainly triggered by old technology which operated at a much lower frequency on a copper-iron magnetic controller, rather than an electronic controller which all modern fluorescent lamps use.

7.1.2 Ménière's disease

Ménière's disease afflicts about 0.2% of the population. It is a condition where excess fluid in the inner ear upsets the ear's balance and hearing mechanisms producing symptoms such as vertigo (dizziness), tinnitus (ringing in the ears) and hearing loss. The disorder usually affects only one ear and is a common cause of hearing loss.

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There is no scientific evidence to suggest compact fluorescent lamps (CFLs) (or any fluorescent lights) can exacerbate or initiate symptoms of Ménière's disease. However, there are anecdotal reports that sufferers of Ménière's disease are more sensitive to flashing lights than others (because of their impaired balance systems), and so may be more susceptible to a phenomenon known as flicker vertigo (which can reportedly affect anyone).

Flicker vertigo may arise from flicker rates in the range of 4 to 30Hz or flashes per second. Symptoms range from vague and non-specific feelings of unease through to nausea, dizziness, migraines, unconsciousness, and even photosensitive epileptic seizures. Triggering events can be as simple as viewing fast moving objects, (such as fan, helicopter blades or a tree line from a moving car), that intermittently obscures the sun, creating a flickering effect.

CFLs and linear fluorescent lamps flicker at a rate well above that detectable by the human brain and so should not affect Meniere's sufferers.

### 7.1.3 Migraines

Migraine is one of the most common diseases of the nervous system. In developed countries migraine affects about 10-15% of people. Migraines can be triggered by many different things, including stress, exercise, certain foods, bright light, flickering light, loud noises, strong smells, lack of sleep or too much sleep. In women, attacks may be triggered by hormonal changes, for example during menstruation.

If light is suspected as the triggering event for migraines, ordinary headaches, or even eyestrain, the primary cause is likely to be glare, highly contrasting or inappropriate light levels. These problems are a result of poor lighting design rather than a feature of fluorescent lamps and can occur with any lighting technology if used inappropriately. Light fittings that enclose lamps and distribute light evenly without compromising light output and efficiency can help avoid these problems.

The UK migraine action association (www.migraine.org.uk) recommends:

- Ensuring that lighting is adequate and well positioned
- Fluorescent lighting should be properly maintained to minimise flicker
- Fluorescent lamps should be fitted with the correct type of diffuser to imitate natural daylight as much as possible
- Avoid reflected glare from shiny/polished surfaces, plain white walls etc, opt for matt finishes and break up surfaces with pictures, posters or plants
- Fit adjustable blinds to windows

While light sources with a detectable flicker can trigger migraines in susceptible individuals, CFLs and linear fluorescent lamps flicker at a rate well above that detectable by the human brain and so should not affect migraine sufferers.

### 7.2 Ultraviolet emissions

As mentioned in previous sections, ultraviolet radiation occurs naturally from the sun, sitting just beyond the violet end of the visible range of the electromagnetic spectrum.

Ultraviolet radiation is categorised into three bands - UVA, UVB and UVC:

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>UVA</td>
<td>Long wave ultraviolet</td>
<td>400 to 320nm</td>
</tr>
<tr>
<td>UVB</td>
<td>Medium wavelength ultraviolet</td>
<td>320 to 280nm</td>
</tr>
<tr>
<td>UVC</td>
<td>Short wavelength ultra violet</td>
<td>280 to 100nm</td>
</tr>
</tbody>
</table>
Exposure to UV can have beneficial effects. A small amount of radiation is essential to the body as it stimulates the production of vitamin D, which plays a crucial role in food absorption, skeletal development, immune function and blood cell formation. However, only 5 to 15 minutes of casual sun exposure of hands, face and arms two to three times a week during the summer months is necessary to keep your vitamin D levels high\(^3\).

On the other hand, too much solar ultraviolet exposure (especially at shorter wavelengths) can be very damaging to skin and eyes. It is well-known that it is responsible for skin cancer - which has dramatically increased over the last two decades with more people enjoying both holiday sunbathing and the use of sun beds.

UV radiation also has the effect of colour bleaching (e.g. the fading of coloured curtains by sunny windows).

### 7.2.1 Artificial light sources

Ultraviolet radiation is produced to various degrees by all artificial light sources. The common household lamps such as incandescents, halogens and CFLs all produce some UV.

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) conducted a study\(^4\) into a range of CFLs, incandescent lamps and halogen lamps. Of the tested lamps, those with the highest UV levels, measured at a distance of 10cm over a period of 8 hours was equivalent to spending approximately 6 minutes in the midday summer sunshine in Brisbane and 7 minutes in Melbourne.

The study found that UV emissions from all lamps decreased rapidly with distance. If people are concerned about UV exposure they should minimise the time spent closer than 25cm from these lamps or use ‘double envelope’ or ‘covered’ CFLs (these types of lamps look similar to ‘pearl’ incandescents).

#### 7.2.1.1 Fluorescent lamps

Fluorescent lamps, by the nature of their operation, give out low levels of UV. The amount is quite small and does not pose a health hazard to people who are exposed to it. The amount of UV given out by fluorescent tubes in a typically lit office is only a small proportion of that in average daylight. While some CFLs do emit slightly more UV light than equivalent incandescent light bulbs, these emissions are not significant if the CFLs are installed more than 25cm away from people, such as in ceiling fittings.

#### 7.2.1.2 High intensity discharge lamps

High and low pressure sodium lamps produce small amounts of UV which is virtually all absorbed by the outer glass bulbs. They are not classed as being of any serious concern as regards UV radiation.

High pressure mercury and metal halide on the other hand, does produce relatively high levels of UV from their arc-tubes. Those versions with glass outer bulbs have the UV significantly reduced by the filtering effect of the glass and do not pose any health hazard. They can, however, produce a bleaching effect on colour sensitive materials over long periods of exposure.

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3 World Health Organisation
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Metal halide lamps with quartz outer bulbs produce levels of UV that could be a health hazard, because normal quartz does not filter out UV radiation. It was always necessary to use UV filters on light fittings with these lamps. However, most manufacturers now use special ‘UV filter’ quartz, for their range of metal halide lamps. From a health point of view, these can be used without the need for additional UV filters on light fittings. However, it may still be prudent to use UV filters on the light fittings to eliminate the effect of bleaching if the illuminated objects are particularly sensitive (e.g. valuable paintings).

7.2.1.3 Halogen lamps

The quartz envelope used for halogen lamps allows the transmission of ultraviolet electromagnetic waves in addition to the visible spectrum. Therefore lamp manufacturers now offer a range of tungsten halogen lamps that use a ‘doped’ material that effectively cuts off the ultraviolet radiation. These ultraviolet absorbing chemicals are usually added during the molten phase of manufacture.

7.2.2 Light sensitivity conditions

With the increased use of compact fluorescent lamps (CFLs), some concern has been raised that these lamps can have an adverse impact on the health of individuals who are affected by ultraviolet (UV) light, specifically sufferers of Systemic Lupus Erythematosus (SLE) or Lupus.

Lupus, in its many forms, is an autoimmune disorder characterised by chronic inflammation of body tissues. People with Lupus produce antibodies that target their own healthy tissues and organs. The cause of Lupus is not clear but genetics, viruses, UV light, and medication all appear to play some role. Lupus is up to eight times more common in women than men. Exacerbations or flare ups of Lupus can be induced by exposure to any source of UV emissions including sunlight.

There can be a great deal of variation in the UV output of different bulbs, even within the same class (i.e. incandescents, halogens and CFLs). The slightly elevated levels of UV produced by CFLs may pose a problem for sensitive sufferers of Lupus, if not ameliorated. For example, there are rare instances recorded of prolonged exposure to bare linear (tubular) fluorescent lamps provoking Lupus in hypersensitive individuals.

Some double envelope CFLs - designed to have a similar appearance to traditional incandescent lamps - emit lower UV than the single envelope CFLs – however, this not always the case with all models.

Traditionally, light covers, light fittings and light diffusers have been used in homes for both aesthetic reasons and to reduce glare from bare light bulbs. If used correctly acrylic light covers can also reduce UV light levels by as much as 94 per cent. Available in a range of styles, light covers should be positioned between the light source (light bulb) and yourself to reduce the level of UV light. It is important that you cannot see the light bulb once the cover is fitted.

7.3 Mercury

Mercury is a naturally occurring element and a potent neurotoxin. Emissions in the air can come from both natural and man-made sources. Coal-fired power plants are the largest man-made source because mercury that naturally exists in coal is released into the air when coal is burned to make electricity.

As has been discussed in earlier sections, a variety of lamp types require mercury to operate. Generally the higher the power usage the more mercury is required in the operation of the lamp. Mercury containing lamps include:

- High pressure discharge (HID) lamps such as mercury vapour lamps, which typically contain about 30 milligrams (mg) of mercury, as used for street and road lighting

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- Linear fluorescent tubes, which are required by an Australian standard to contain less than 15mg, as used in most commercial and public buildings
- Compact fluorescent lamps (CFLs), which will be required to contain less than 5mg of mercury under a new Australian standard to be introduced in 2009, mostly used in homes.

As the number of CFLs in use increases so has awareness of the hazards and health impacts associated with exposure to the element, leading to questions about whether they are safe to use. However, the amount of mercury in domestic lamps is very small (in many cases, less than the mandatory 5mg), roughly equivalent in size to the tip of a ballpoint pen, and it is sealed within the CFL glass tubing. By comparison, there is up to five times that amount of mercury in a watch battery; between 60 to 200 times that in a single ‘silver’ dental filling in people’s mouths; 100 to 200 times that amount in the old-style thermometers many people still have in their medicine cabinets; 200 times that amount per switch in the light switches of certain freezers; and about 500 times that amount in thermostats on the walls of people’s homes.

The mercury contained in CFLs and these household products pose no threat during use, unless the device is broken. Therefore, these products should always be handled carefully and properly disposed.

In addition, CFLs use around one-quarter the energy of incandescent lamps, so they last longer, require less electricity, and avoid some of the mercury emissions from coal-fired power plants.

7.3.1 Disposal

CFLs can generally be disposed of in regular garbage bins - where the garbage goes to landfill. However, it is best to check with the local authority who manages garbage collection, as different local authorities may have different arrangements. If disposing of CFLs this way, it is best to wrap them in newspaper to prevent them from breaking.

Where possible, it is preferable to have them recycled by specialty recyclers. Recycling can safely recover and reuse the mercury, glass, phosphor and aluminium. The recovered mercury is commonly sold to the dental industry, where it is used in amalgam for fillings. Most lamp recyclers will collect large quantities of lamps from capital cities and selected regional areas and several states have household chemical collection programs or drop-off points that accept CFLs for recycling. Other states are considering introducing similar schemes. Detailed information about disposal and recycling, developed with the assistance of the states and territories is available at [www.environment.gov.au/settlements/waste/lamp-mercury.html](http://www.environment.gov.au/settlements/waste/lamp-mercury.html).

CFLs should not be placed in kerbside recycling collections because they can break during transport and contaminate recyclable items. Rubbish dumps do not have the facilities to recycle fluorescent lamps.

In an effort to reduce mercury emissions from lamps, the Australian Government, in conjunction with the Environment Protection and Heritage Council, has launched the *Fluoro-cycle* project in order to begin addressing this issue.

*Fluoro-cycle* is a voluntary partnership between the Australian Government and industry to increase recycling of mercury containing lamps by the commercial and public lighting sectors, which currently accounts for approximately 90 per cent of all lighting waste. The scope of the program is expected to eventually be broadened to include lamps from the domestic or household sector. This may be necessary to address the increasing volumes of waste lamps as the CFLs currently being installed to replace incandescent globes reach end of life.
7.3.2 Breakages

The short term nature of the potential exposure (particularly after effective clean-up of broken CFL material) does not constitute a significant health risk to exposed adults (including pregnant women) or children. However, following these simple and straightforward clean up and disposal instructions as a precautionary approach, will further reduce risk:

- Open nearby windows and doors to allow the room to ventilate for 15 minutes before cleaning up the broken lamp. Do not leave air conditioning or heating equipment on, as this could re-circulate mercury vapours back into the room.
- Do not use a vacuum cleaner or broom on hard surfaces because this can spread the contents of the lamp and contaminate the cleaner. Instead scoop up broken material (e.g. using stiff paper or cardboard), if possible into a glass container which can be sealed with a metal lid.
- Use disposable rubber gloves rather than bare hands.
- Use a disposable brush to carefully sweep up the pieces.
- Use sticky tape and/or a damp cloth to wipe up any remaining glass fragments and/or powders.
- On carpets or fabrics, carefully remove as much glass and/or powdered material using a scoop and sticky tape; if vacuuming of the surface is needed to remove residual material, ensure that the vacuum bag is discarded or the canister is wiped thoroughly clean.
- Dispose of cleanup equipment (i.e. gloves, brush, damp paper) and sealed containers containing pieces of the broken lamp in your outside rubbish bin - never in your recycling bin.
- While not all of the recommended cleanup and disposal equipment described above may be available (particularly a suitably sealed glass container), it is important to emphasise that the transfer of the broken CFL and clean-up materials to an outside rubbish bin (preferably sealed) as soon as possible is the most effective way of reducing potential contamination of the indoor environment.

7.4 Electromagnetic compatibility

CFLs, like all electrical appliances, will produce 50 Hz magnetic fields from the currents drawn from the supply. Both the lamp and the associated household wiring will produce these fields. The magnetic fields from the wiring should theoretically be lower with CFLs than incandescent globes because of their lower power consumption. Magnetic fields from the lamps themselves may be higher than from incandescent lamps very close to the fittings but preliminary tests undertaken on a small range of CFLs tested at the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) did not find any cases where the 50 Hz magnetic fields, at distances greater than 30 cm, were elevated above typical residential levels.

The high frequency electrical currents produced within the base of the lamp will cause some localised electric and magnetic fields. The radiofrequency emissions are constrained by the need to avoid producing electrical interference to well below the limits known to be associated with any health effects.

Normally electromagnetic interference isn’t a significant issue, especially if lamps comply with the relevant electromagnetic compatibility (EMC) standards and appropriate installation procedures are followed. In the rare instances, where problems do occur consult the lamp ballast and/or the control gear supplier.

The key international standards related to electromagnetic compatibility are:

- IEC 61000, ‘Electromagnetic compatibility (EMC)’
- IEC 61547, ‘Equipment for general lighting purposes – EMC immunity requirements’
8 Myths and Tips

This section busts some of the public myths and misconceptions regarding lighting, and gives some useful tips to consider when designing or specifying lighting installations.

Fluorescent lighting DOES NOT require a large amount of energy to start

There is a very common myth that fluorescent lights should not be switched off, as they require more energy to start than can be saved by turning them off. This is not the case. fluorescent lights may use up to 300% more power to start, but this is only for around 3 milliseconds.

Low voltage DOES NOT mean energy efficient

There is a common misconception that low voltage incandescent lamps are also energy efficient. This is misleading. Due to the fact that their filament runs at higher current and therefore hotter, low voltage lamps are slightly more efficient than mains voltage incandescent lamps. However, they do require a transformer which has a power loss (particularly magnetic transformers).

Thus a standard 12 volt 50 watt halogen downlight with an iron core transformer uses 50 watts for the lamp and up to 15 watts for the transformer = 65 watts per fixture.

Low voltage halogen reflector lamps (dichroic lamps) are often inappropriately used for lighting of large spaces. These lamps are essentially spot lights - they emit light in a narrow beam. This means that many lamps are required to light a large space. Examples have been found where a room that would have traditionally been lit with one or two GLS lamps or CFLs are now lit with 12 or more dichroics.

To replace 50W low voltage lamps, there are now 30W and 35W IRC versions which have equivalent light output. When combined with electronic transformers, these can result in significant energy savings.

Thus a standard 12 volt 35 watt IRC halogen downlight with an electronic transformer uses 35 watts for the lamp and around 3 watts for the transformer = 38 watts per fixture.

However, fluorescent lighting represents the most efficient solution for general purpose illumination.

Incandescent lamps and fire risk

New wiring regulations have set tight restrictions on the clearances from flammable materials when installing halogen and incandescent lamps for reasons of fire risk.

Downlights and insulation

Downlights require multiple holes in the ceiling and the insulation above it, thus reducing ceiling insulation performance.

CFL colour temperature

CFLs are available in a wide range of colour temperatures, from warm white (suitable for homes) through to daylight colours which are more suited to commercial applications.
CFLs and mercury

CFLs contain a small amount of mercury. However, less mercury is released into the environment from the use of CFLs than from the use of inefficient incandescent lamps. This is because burning coal to produce electricity releases mercury into the environment. The new minimum energy performance standards (MEPS) for CFLs includes a maximum mercury level of 5mg per lamp.

CFLs on dimmers and other control circuits

Certain CFLs are not compatible with certain dimmers, movement sensors, sunset switches, touch lamps and other such circuits. Refer to CFL manufacturer’s specification for circuit compatibility.

Residential lighting controls

“Smart house” cabling and related systems can make use of sensors and smart controls to improve lighting efficiency in homes.

LED does not necessarily mean efficient

LEDs are an emerging technology and are often claimed to be very efficient. However recent experience shows that LEDs have a range of efficiencies, thus great care should be taken in selecting LEDs for any lighting purpose.

9 Case Studies

This chapter contains a number of simple case studies that serve as a guide to what can be achieved for both new installations and retrofits.

9.1 Office Lighting

This case study contains a number of different fluorescent office lighting designs. Three “standard” designs and one “high efficiency” design are presented in the table below. The “high efficiency” design is suitable for new installations or for retrofitting existing installations.
The lighting design was undertaken with the aid of a lighting design software package. The 200m² office space is lit to 320 lux in all designs. The first two “standard” designs utilise a basic “project” recessed luminaire. The “standard+” and “high efficiency” designs utilise efficient luminaires which have a higher light output ratio (as discussed in the Design chapter). All designs utilise T8 triphosphor fluorescent lamps.

<table>
<thead>
<tr>
<th></th>
<th>Standard</th>
<th>Standard</th>
<th>Standard+</th>
<th>High Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. lamps per luminaire</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Lamp lumens</td>
<td>3200</td>
<td>3200</td>
<td>3200</td>
<td>3200</td>
</tr>
<tr>
<td>Lamp Watts</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Ballast Type</td>
<td>magnetic</td>
<td>electronic</td>
<td>electronic</td>
<td>electronic</td>
</tr>
<tr>
<td>Luminaire Power</td>
<td>83W</td>
<td>72W</td>
<td>72W</td>
<td>36W</td>
</tr>
<tr>
<td>No. Luminaires</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>36</td>
</tr>
<tr>
<td>Calculated Illuminance</td>
<td>380</td>
<td>380</td>
<td>510</td>
<td>400</td>
</tr>
<tr>
<td>Total Power</td>
<td>2075W</td>
<td>1800W</td>
<td>1800W</td>
<td>1296W</td>
</tr>
<tr>
<td>Lighting Power Density</td>
<td>10.4 W/m²</td>
<td>9.0 W/m²</td>
<td>9.0 W/m²</td>
<td>6.5 W/m²</td>
</tr>
<tr>
<td>Approximate running cost p.a.</td>
<td>$900</td>
<td>$780</td>
<td>$780</td>
<td>$560</td>
</tr>
</tbody>
</table>

The above comparison shows that using a single-lamp luminaire can be significantly more efficient than using a twin lamp luminaire to produce the recommended illumination level (320 lux in this case). Whilst the high efficiency option uses more luminaires, it uses fewer lamps to achieve the same light levels at significantly less cost and energy consumption.

Note that the use of a high efficiency twin-lamp luminaire does not result in significant power savings in this case, due to the need to over-light the space in order to achieve uniformity of light.

The high efficiency option might result in a slight increase in costs (primarily for high quality luminaires). For the 200m² office, an additional cost of $2500 has been estimated, which would pay back in less than 4.5 years.

Greenhouse gas emissions savings of around 2.3 tonnes per annum would result from the high efficiency option compared to the standard option.

**Use of motion detectors and daylight controllers will achieve further significant energy savings.** Ideally, each motion detector should be fitted to no more than 6 luminaires (i.e. to suit the lighting needs of a single occupant). At least 10 luminaires in close proximity to natural lighting could also be controlled by daylight controllers in this example. These additions could reduce running costs to as little as $300 p.a. compared to $900 p.a. for the standard installation.
9.2 Factory Lighting

This case study contains a “standard” and a “high efficiency” design for a 500m² factory or warehouse. The “high efficiency” design is suitable for new installations or for retrofitting of existing installations. The lighting design was undertaken with the aid of a lighting design software package. The “high efficiency” designs utilises efficient luminaires which have a higher light output ratio (as discussed in the Design chapter).
The Basics of Efficient Lighting

<table>
<thead>
<tr>
<th></th>
<th>Standard</th>
<th>High Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highbay luminaire type:</td>
<td>Budget</td>
<td>High efficiency</td>
</tr>
<tr>
<td>Lamp type</td>
<td>Coated mercury vapour</td>
<td>Ceramic metal halide</td>
</tr>
<tr>
<td>Lamp CRI</td>
<td>45</td>
<td>80+</td>
</tr>
<tr>
<td>Lamp Watts</td>
<td>400</td>
<td>250</td>
</tr>
<tr>
<td>Luminaire utilisation factor</td>
<td>0.62</td>
<td>0.8</td>
</tr>
<tr>
<td>Total Watts per luminaire</td>
<td>425</td>
<td>270</td>
</tr>
<tr>
<td>Initial lumens</td>
<td>22,000</td>
<td>25,800</td>
</tr>
<tr>
<td>System efficacy (lm/W)</td>
<td>51.8</td>
<td>95.5</td>
</tr>
<tr>
<td>No. of lamps for 400 lux maintained over 500m²</td>
<td>21</td>
<td>14</td>
</tr>
<tr>
<td>Total Power</td>
<td>8,925W</td>
<td>3,780</td>
</tr>
<tr>
<td>Lighting Power Density</td>
<td>17.9 W/m²</td>
<td>7.6 W/m²</td>
</tr>
<tr>
<td>Approximate running cost p.a. (24hr operation)</td>
<td>$11,400</td>
<td>$4,800</td>
</tr>
</tbody>
</table>

The high efficiency option would result in a slight increase in costs (primarily for high quality luminaires). For the 500m² factory/warehouse, an additional cost of $5000 has been estimated, which would pay back in less than 1 year.

Greenhouse gas emissions savings of around 44 tonnes per annum would result from the high efficiency option, which is the equivalent of taking 11 cars off the road.

Use of daylight dimming will achieve further significant energy savings. Note that motion detectors are not suitable for HID lamps, due to the long re-strike time.

9.3 Residential Living Room

For a 6m x 6m living room, this case study compares a poor standard design to an efficient new design, as well as a simple retrofit for the poor design.

<table>
<thead>
<tr>
<th></th>
<th>Poor</th>
<th>Simple Retrofit</th>
<th>New – High Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamps</td>
<td>16 x 50W ELV halogen</td>
<td>12 x 35W IRC halogen</td>
<td>6 x 23W CFL</td>
</tr>
<tr>
<td>Control gear</td>
<td>Magnetic transformer</td>
<td>Electronic transformer</td>
<td>Integral</td>
</tr>
<tr>
<td>Luminaire type</td>
<td>MR16</td>
<td>MR16</td>
<td>3 x oyster and 3 x CFL downlight</td>
</tr>
<tr>
<td>Average illuminance (lux)</td>
<td>220</td>
<td>200</td>
<td>150</td>
</tr>
</tbody>
</table>
This case study shows that considerable savings are achievable in residential lighting design, particularly by moving from 50W down lights to appropriate CFLs.

Note that there is a slight reduction in light level, which is considered acceptable as ELV halogen lamps tend to over-light most applications in order to provide uniformity.

The cost of the simple retrofit has been estimated at $500, which would pay back in around 3 years.

### 9.4 Outdoor Security Lighting

This case study examines a single outdoor luminaire. Poor, good and high efficiency options are considered.
The Basics of Efficient Lighting

<table>
<thead>
<tr>
<th></th>
<th>Poor</th>
<th>Good</th>
<th>High Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamps</td>
<td>Budget tungsten halogen floodlight</td>
<td>High efficiency 250W high pressure sodium</td>
<td>High efficiency 250W high pressure sodium</td>
</tr>
<tr>
<td>Power per luminaire</td>
<td>1000W</td>
<td>270W</td>
<td>166W</td>
</tr>
<tr>
<td>Lumens</td>
<td>22,000</td>
<td>33,200</td>
<td>17,500</td>
</tr>
<tr>
<td>Lamp life (hours)</td>
<td>2,000</td>
<td>20,000</td>
<td>20,000</td>
</tr>
<tr>
<td>Approximate running cost p.a. (per fitting)</td>
<td>$640</td>
<td>$173</td>
<td>$106</td>
</tr>
</tbody>
</table>

The high efficiency option results in less light output, although it is considered anecdotally that the halogen floodlight will tend to over light most security applications. The Good option still results in significant power and cost savings.

The cost of the good and high efficiency options have been estimated at $500, which would pay back in the first year.

9.5 Case Studies from Sustainability Victoria

The following case studies were sourced from Sustainability Victoria, based primarily on lamp retrofits.
The Wilderness Shop
Eco Lighting Case Study

Above and Beyond Expectations!

Case Study Key Findings
- A 60.7% reduction in electricity for lighting.
- A saving of over $4,240 each year on electricity.
- A reduction of 34 tonnes of CO₂ emissions per year.
- On top of that, there are savings of $1,499 each year in maintenance costs.
- A return on investment in two years and one month.

About The Wilderness Shop
For over 25 years, The Wilderness Shop has long been meeting the needs of Victorian bushwalkers, cross country skiers and rock climbers.

The Wilderness Shop, located at 969 Whitehorse Road, Box Hill, Victoria, offers specialised service from experienced staff and quality equipment at competitive prices.

Before the Eco Lighting Retrofit
Prior to the eco lighting retrofit, the Wilderness Shop’s annual electricity bill for lighting was $6,985. The light globes were so inefficient that the staff at the Wilderness Shop were often reticent to fully utilise the lights because of the high electricity cost.

After the Eco Lighting Retrofit
After conducting a systematic lighting audit, the energy consumption for lighting at the Wilderness Shop was reduce by 60.7%. Table One on the next page shows the lights that were replaced during the retrofit, including the details about the globes replaced and the wattage per globe.
After the Eco Lighting Retrofit - Cont

<table>
<thead>
<tr>
<th>Location</th>
<th>Original Item</th>
<th>No.</th>
<th>Consumption</th>
<th>Total Power (W)</th>
<th>Original Item</th>
<th>No.</th>
<th>Consumption</th>
<th>Total Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Window</td>
<td>36w T8 Fluoro</td>
<td>11</td>
<td>40</td>
<td>440</td>
<td>28w T5 Fluoro</td>
<td>6</td>
<td>30</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>50w MR 16</td>
<td>13</td>
<td>55</td>
<td>715</td>
<td>6w MR LED</td>
<td>13</td>
<td>6</td>
<td>78</td>
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<tr>
<td>Shop Higher Black Ceiling</td>
<td>36w T8 Fluoro</td>
<td>41</td>
<td>40</td>
<td>1640</td>
<td>28w T5 Fluoro</td>
<td>30</td>
<td>30</td>
<td>900</td>
</tr>
<tr>
<td>Shop Lower Ceiling</td>
<td>36w T8 Fluoro</td>
<td>100</td>
<td>40</td>
<td>4000</td>
<td>28w T5 Fluoro</td>
<td>80</td>
<td>30</td>
<td>2400</td>
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<tr>
<td>Counter Area</td>
<td>36w T8 Fluoro</td>
<td>5</td>
<td>40</td>
<td>200</td>
<td>28w T5 Fluoro</td>
<td>5</td>
<td>30</td>
<td>150</td>
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<td></td>
<td>50w MR 16</td>
<td>17</td>
<td>55</td>
<td>935</td>
<td>6w MR LED</td>
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<td>102</td>
</tr>
<tr>
<td>Upstairs</td>
<td>100w GLS B22</td>
<td>11</td>
<td>100</td>
<td>1000</td>
<td>18w CLA CLF</td>
<td>1</td>
<td>18</td>
<td>118</td>
</tr>
<tr>
<td>Safe Storeroom</td>
<td>36w T8 Fluoro</td>
<td>4</td>
<td>40</td>
<td>160</td>
<td>28w T5 Fluoro</td>
<td>4</td>
<td>30</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>15w CFL</td>
<td>2</td>
<td>15</td>
<td>30</td>
<td>15w CFL</td>
<td>2</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Ski Workshop</td>
<td>36w T8 Fluoro</td>
<td>5</td>
<td>40</td>
<td>200</td>
<td>28w T5 Fluoro</td>
<td>5</td>
<td>30</td>
<td>150</td>
</tr>
<tr>
<td>Rear Storeroom</td>
<td>36w T8 Fluoro</td>
<td>5</td>
<td>40</td>
<td>200</td>
<td>28w T5 Fluoro</td>
<td>5</td>
<td>30</td>
<td>150</td>
</tr>
<tr>
<td>Office</td>
<td>36w T8 Fluoro</td>
<td>4</td>
<td>40</td>
<td>160</td>
<td>28w T5 Fluoro</td>
<td>4</td>
<td>30</td>
<td>120</td>
</tr>
<tr>
<td>Rear Entry</td>
<td>100w GLS B22</td>
<td>1</td>
<td>100</td>
<td>100</td>
<td>18w CLA CLF</td>
<td>1</td>
<td>18</td>
<td>118</td>
</tr>
<tr>
<td></td>
<td>36w T8 Fluoro</td>
<td>1</td>
<td>40</td>
<td>40</td>
<td>28w T5 Fluoro</td>
<td>1</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>2B0</td>
<td>280</td>
<td>2B0</td>
<td>280</td>
<td>2B0</td>
<td>246</td>
<td>246</td>
<td>5118</td>
</tr>
</tbody>
</table>

Table One: Original and efficient lighting replacements during the retrofit

“Our first thoughts regarding the new lighting, said Glenn Robbins, Manager, The Wilderness Shop, were that the overall brightness seemed to be quite dull and perhaps cold for the first two days...until the staff began to grow accustomed to the change”. Glenn Robbins added “We have all grown up with the thought that light should have tones of warming yellow or orange - suggesting warmth (as in a fire). These are no doubt primal notions”.

“After a number of days, however, we noticed that the light appeared to be more even and less stark, leaving us a little less drained at the end of very long days”.

The Wilderness Shop has reduced its lighting costs by **$5,740** a year, with substantially less impact on the environment with a saving of **34** tonnes of CO² emissions per annum.

“My ultimate appreciation for all your efforts in establishing a lighting system that, without a doubt, meets our needs as a retail establishment, at a fraction of the energy costs” said Glenn Robbins.

About the Eco Lighting for Victorian Businesses Project

The Eco Lighting for Victorian Businesses Project aims to demonstrate the latest energy saving lighting technologies to business and organisations. The Project is funded by the Victorian Government’s Sustainability Fund.

Who is Behind the Project?

The Eco Lighting for Victorian Businesses project is supported by the Victorian Government Sustainability Fund, managed by Sustainability Victoria.

The project is funded by the Sustainability Fund with the management being conducted from the Environment Shop. Other partners including the Alternative Technology Association, the Cities of Darebin, Banyule and Hume, the Moreland Energy Foundation (MEFL), the Northern Area Greenhouse Alliance (NAGA), VECCI Grow Me the Money, Megaman Australia, CLA and Low Energy developments.
Melissa Cake Shop
Eco Lighting Case Study

The pastries are great, the coffee is excellent, a shining example of a cafe!

Case Study Key Findings
- A 58% reduction in electricity for lighting.
- Savings of over $3,687 per annum on electricity.
- A reduction of 30 tonnes of CO² emissions per year.
- On top of that, there are savings of $750 per annum in maintenance costs.
- A return on investment in just under a year (11 months)!

About Melissa Cake Shop
Melissa’s in Smith Street, Fitzroy, is an institution.

Melissa’s, as the name implies, is a family run business that offers a great line of cakes and pastries.

Melissa’s is particularly famous for its spanakopita, a savoury delight consisting of spinach and feta cheese wrapped in layers of filo pastry. They have sold over 500 pieces of spanakopita a day for the last three decades.

In 2003 the Katakis family opened another Melissa Cake Shop, offering exactly the same menu in more modern surrounds, at 661 High Street, Thornbury.

Before the Eco Lighting Retrofit
Prior to the eco lighting retrofit, Melissa’s was filled with 113 Halogen 50 watt downlights and four Linear Fluoro 40 watt lights. The annual electricity bill for lighting was $6,329.
After the Eco Lighting Retrofit

After conducting a systematic lighting audit at Melissa’s, the eco lighting experts at the Environment Shop reduced the energy consumption of the lighting by 58%. Table One below shows the lights that were replaced during the retrofit, including the details about the globes replaced and the wattage per globe.

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Original No.</th>
<th>Consumption (Power W)</th>
<th>Total</th>
<th>Efficient Lighting Replacement</th>
<th>New No.</th>
<th>Consumption (Power W)</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>Fluorescent 36w</td>
<td>4</td>
<td>40</td>
<td>160</td>
<td>T5 Adapter</td>
<td>4</td>
<td>28</td>
<td>112</td>
</tr>
<tr>
<td>Halogen Lamps 50w</td>
<td>113</td>
<td>55</td>
<td>6215</td>
<td>T5 Halaogen IRC 35w</td>
<td>16</td>
<td>34</td>
<td>1190</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>T5 Halaogen IRC 20w</td>
<td>6</td>
<td>20</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CLA Downlight</td>
<td>65</td>
<td>15</td>
<td>975</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LED 6w</td>
<td>8</td>
<td>6</td>
<td>48</td>
</tr>
</tbody>
</table>

Table One: Original and efficient lighting replacements during the retrofit

“I was slightly sceptical when I was first approached to retrofit the lights in my business. I focussed first on the up front costs, but quickly moved my attention to the long term savings in electricity and maintenance bills” said Ange Katakis, Owner, Melissa Cake Shop.

Ange Katakis added “Melissa’s is open 7 days a week, 12 hours a day, so we arranged for the retrofit team to work overnight. This worked well, as it did not disrupt my business.”

“I am very pleased with the lighting design, in particular the CLA downlights with the frosted glass over the lamp fitting” said Ange Katakis. In addition to looking great, the CLA downlights are 27% more efficient and last 4 times longer (lamp life for CLA 15 watt Spiral Energy Saving Lamp is 8,000 hours) than the original Halogen downlights they replaced.

The ambience at Melissa’s is warmer and more inviting than ever, with substantially less impact on the environment (a saving of 30 tonnes of CO₂ emissions per annum).

Ange Katakis added “Now I look forward to my next electricity bill – but now can you help me reduce the electricity used in my ovens!” Melissa’s has reduced its lighting costs by $4,439 a year.

About the Eco Lighting for Victorian Businesses Project

The Eco Lighting for Victorian Businesses Project aims to demonstrate the latest energy saving lighting technologies to business and organisations. The Project is funded by the Victorian Government’s Sustainability Fund.

Who is Behind the project

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The Building Display Centre

Eco Lighting Case Study

The Shining Building Display Centre

Case Study Key Findings

- A 26% reduction in electricity for lighting.
- Savings of over $1,657 a year on electricity.
- A reduction of 13.5 Tonnes of CO² emissions per year.
- On top of that, there are savings of $1,007 a year in maintenance costs.
- A return on investment in one year and 5 months!

About the Building Display Centre

The Building Display Centre was originally based in Albert St East Melbourne, where building products and services were on display to both the public and the building industry, 7 days a week.

In early 2009, the Building Display Centre was re-established at the ex Collingwood Football Club house in Victoria Park. Prior to the retrofit, the building was awash with footy atmosphere and energy intensive Halogen downlights.

The Building Display Centre, which is highly regarded for its role in showcasing water and energy saving products, combined with developments in renewable energy technology, was keen to retrofit the lighting in the Victoria Park building with state of the art efficient lighting technology.

Before the Eco Lighting Retrofit

Prior to the retrofit, the board room and general areas at the Building Display Centre featured 50 watt Halogen down lights and 40 watt Linear Fluoro lights. The annual electricity bill for lighting was $6,340. The old lights were dull and aged through poor maintenance.
After the Eco Lighting Retrofit

After conducting a systematic lighting audit, the eco lighting experts at the Environment Shop reduced the energy consumption of the lighting by **26%**. The table below shows in detail the lights that were replaced during the retrofit at the ex Collingwood Football Club:

<table>
<thead>
<tr>
<th>Location</th>
<th>Item</th>
<th>No.</th>
<th>Consumption Power (W)</th>
<th>Total</th>
<th>Item</th>
<th>No.</th>
<th>Consumption Power (W)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Room</td>
<td>Halogen 50W</td>
<td>37</td>
<td>55</td>
<td>2035</td>
<td>IRC Lamps 35w</td>
<td>37</td>
<td>35</td>
<td>1295</td>
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<tr>
<td>Reception</td>
<td>Halogen 50W</td>
<td>8</td>
<td>55</td>
<td>440</td>
<td>IRC Lamps 35w</td>
<td>8</td>
<td>35</td>
<td>290</td>
</tr>
<tr>
<td>Entry Lobby</td>
<td>Halogen 50W</td>
<td>7</td>
<td>55</td>
<td>385</td>
<td>IRC Lamps 35w</td>
<td>7</td>
<td>35</td>
<td>245</td>
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<tr>
<td>Lift</td>
<td>Halogen 20W</td>
<td>4</td>
<td>20</td>
<td>80</td>
<td>IRC Lamps 20w</td>
<td>4</td>
<td>20</td>
<td>80</td>
</tr>
<tr>
<td>Room 1</td>
<td>Halogen 50W</td>
<td>28</td>
<td>55</td>
<td>1540</td>
<td>IRC Lamps 35w</td>
<td>28</td>
<td>35</td>
<td>980</td>
</tr>
<tr>
<td>Coffer – display</td>
<td>Linear Fluoro</td>
<td>16</td>
<td>50</td>
<td>800</td>
<td>T5 Fluorescent Kit</td>
<td>16</td>
<td>50</td>
<td>448</td>
</tr>
<tr>
<td>Window sealing</td>
<td>Linear Fluoro</td>
<td>4</td>
<td>50</td>
<td>200</td>
<td>T5 Fluorescent Kit</td>
<td>4</td>
<td>28</td>
<td>112</td>
</tr>
<tr>
<td>Between Rooms</td>
<td>Halogen 50W</td>
<td>6</td>
<td>55</td>
<td>330</td>
<td>IRC Lamps 35w</td>
<td>6</td>
<td>35</td>
<td>210</td>
</tr>
<tr>
<td>Room 2</td>
<td>Halogen 50W</td>
<td>23</td>
<td>55</td>
<td>1265</td>
<td>IRC Lamps 35w</td>
<td>23</td>
<td>35</td>
<td>805</td>
</tr>
<tr>
<td>Coffer</td>
<td>Linear Fluoro</td>
<td>13</td>
<td>50</td>
<td>650</td>
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<td>13</td>
<td>28</td>
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<tr>
<td>Kitchen</td>
<td>Linear Fluoro</td>
<td>14</td>
<td>50</td>
<td>700</td>
<td>T5 Fluorescent Kit</td>
<td>14</td>
<td>28</td>
<td>392</td>
</tr>
<tr>
<td>Service</td>
<td>Linear Fluoro</td>
<td>2</td>
<td>50</td>
<td>100</td>
<td>T5 Fluorescent Kit</td>
<td>2</td>
<td>28</td>
<td>56</td>
</tr>
<tr>
<td>Kitchen</td>
<td>Halogen 50W</td>
<td>8</td>
<td>55</td>
<td>440</td>
<td>IRC Lamps 35w</td>
<td>8</td>
<td>35</td>
<td>280</td>
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<td>Total</td>
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<td></td>
<td>8965</td>
<td></td>
<td>170</td>
<td></td>
<td>5547</td>
</tr>
</tbody>
</table>

The Building Display Centre is now very well lit with substantially less impact on the environment saving over **13 Tonnes of CO₂ emissions per annum**. The Building Display Centre will save **$1,657 each year** in electricity plus **$1,007** per annum in traditional lighting maintenance for many years to come.

**About the Eco Lighting for Victorian Businesses Project**

The Eco Lighting for Victorian Businesses Project aims to demonstrate the latest energy saving lighting technologies to business and organisations. The Project is funded by the Victorian Government’s Sustainability Fund.

We have $20,000 in subsidies to pay half the cost of lighting upgrades for selected businesses. This is your chance to make your business more energy efficient, reduce your running costs and lower your environmental impact.

Contact us at lighting@environmentshop@com.au for a free information kit or to request a free basic lighting assessment.

**Who is Behind the project?**

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The project is funded by the Sustainability Fund with the management being conducted from the Environment Shop. Other partners including the Alternative Technology Association, the Cities of Darebin, Banyule and Hume, the Moreland Energy Foundation (MEFL), the Northern Area Greenhouse Alliance (NAGA), VECCI Grow Me the Money, Megaman Australia, CLA and Low Energy developments.
Peter J Ramsay & Associates
Eco Lighting Case Study

Consultants focused on sustainable outcomes for their clients... and the planet

Case Study Key Findings
- A 70% reduction in electricity for lighting.
- A saving of over $1,812 each year on electricity.
- A reduction of 14.7 tonnes of CO₂ emissions per year.
- On top of that, there are savings of $471 each year in maintenance costs.
- A return on investment in just under two years.
- Cost of retrofit: $4,634

About Peter J Ramsay & Associates
Peter J Ramsay & Associates is a boutique environmental consulting firm offering a range of services in contaminated land, industrial facilities management and climate change including carbon asset management and strategy. Peter J Ramsay & Associates is focused on achieving sustainable outcomes for their clients.

Before the Eco Lighting Retrofit
Prior to the eco lighting retrofit, Peter J Ramsay & Associates’ annual electricity bill for lighting was $2,569.
After the Eco Lighting Retrofit

After conducting a systematic lighting audit, the energy consumption for lighting at Peter J Ramsay & Associates was reduced by 70%. Table One below shows the lights that were replaced during the retrofit, including the details about the globes replaced and the wattage per globe.

<table>
<thead>
<tr>
<th>Location</th>
<th>Original Item</th>
<th>No.</th>
<th>Consumption (W)</th>
<th>Total</th>
<th>Efficient Lighting</th>
<th>No.</th>
<th>Consumption (W)</th>
<th>Total</th>
<th>Power (W)</th>
<th>Replacement Item</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Board Room</td>
<td>T8 Fluoro 36W</td>
<td>12</td>
<td>40</td>
<td>480</td>
<td>T5 Fluoro 28W</td>
<td>10</td>
<td>30</td>
<td>300</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T8 Fluoro 36W</td>
<td>2</td>
<td>40</td>
<td>80</td>
<td>T5 Fluoro 28W</td>
<td>2</td>
<td>30</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T8 Fluoro 18W</td>
<td>2</td>
<td>20</td>
<td>40</td>
<td>T5 Fluoro 14W</td>
<td>2</td>
<td>15</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MR 16 50W</td>
<td>6</td>
<td>55</td>
<td>330</td>
<td>6w MR LED</td>
<td>6</td>
<td>6</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MR 16 50W</td>
<td>1</td>
<td>55</td>
<td>55</td>
<td>6w MR LED</td>
<td>1</td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FR GLS 100W</td>
<td>2</td>
<td>100</td>
<td>200</td>
<td>CLA CFL 20W</td>
<td>2</td>
<td>20</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FR GLS 100W</td>
<td>2</td>
<td>100</td>
<td>200</td>
<td>CLA CFL 20W</td>
<td>2</td>
<td>20</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R80 GLS 50W</td>
<td>2</td>
<td>80</td>
<td>160</td>
<td>MEGA R63 T1W</td>
<td>2</td>
<td>13</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Admin Office</td>
<td>T8 Fluoro 36W</td>
<td>4</td>
<td>40</td>
<td>160</td>
<td>T5 Fluoro 28W</td>
<td>2</td>
<td>30</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reception</td>
<td>FR GLS 100W</td>
<td>2</td>
<td>100</td>
<td>200</td>
<td>CLA CFL 20W</td>
<td>2</td>
<td>20</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MR 16 50W</td>
<td>9</td>
<td>55</td>
<td>495</td>
<td>6w MR LED</td>
<td>9</td>
<td>6</td>
<td>54</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accounts</td>
<td>T8 Fluoro 36W</td>
<td>4</td>
<td>40</td>
<td>160</td>
<td>T5 Fluoro 28W</td>
<td>2</td>
<td>30</td>
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Table One: Original and efficient lighting replacements during the retrofit

"We are extremely happy with our new energy efficient lighting system. Not only has it improved the lighting quality and aesthetic of the office, but it has also helped us to reduce our own carbon footprint!" Peter Clark, Consultant at Peter J Ramsay & Associates

Peter J Ramsay & Associates has reduced its lighting costs by $2,283 a year (electricity and maintenance costs), with substantially less impact on the environment with a saving of 14.7 tonnes of CO₂ emissions per annum.

Peter J Ramsay & Associates Board Room – daytime meeting scenario (left), nighttime meeting scenario (right).
Bibliography

- Queensland University of Technology in-house training modules
- www.arpansa.gov.au/radiationprotection/factsheets/is_CFL.cfm
- www.lightsearch.com/resources/lightguides/index.html
- www.aprapps.lighting.philips.com/ala - Philips Lighting Academy
Appendix 1: Standards

Why are standards important? They provide boundaries for designers; continuity for repetitive tasks; provide a baseline recommendation for HS&E and the legal system; improve product quality and indirectly productivity and probably most importantly, it educates “the great unwashed”. This has to be balanced with achieving an acceptably lit environment.

The issue is that prior to the computer calculation era, the lumen method of calculation was used and uniformity was generously dealt with. Calculations are now being done with computers, to an apparent degree of precision that is not supported by an appropriate level of accuracy in post installation measurements.

AS1680.1-2006, ‘Interior and workplace lighting - general principles and recommendations’

Abstract
Provides general principles and recommendations for lighting building interiors to enhance the performance and comfort of those performing visual tasks. Deals with illuminating essential task details, using both artificial light and daylight, while controlling or excluding factors that might cause visual discomfort.

Scope
This standard sets out general principles and recommendations for the lighting of interiors of buildings for performance and comfort. It applies primarily to interiors in which specific visual tasks are undertaken and takes into account both electric lighting and daylight. The recommendations have the object of producing a visual environment in which essential task details are made easy to see and adverse factors which may cause visual discomfort are either excluded or appropriately controlled.

Recommendations for the lighting of particular interiors or activities are provided in the standards which comprise AS(/NZS)1680.2. Refer also to AS/NZS1680.0 for basic requirements for safe movement. The standard does not deal with lighting for the purposes of decoration, display, entertainment or sport.

NOTE: Attention is drawn to the AS(/NZS)2293 series of standards which set out requirements for the lighting necessary to alleviate panic and to permit safe evacuation of the building occupants should this be required in the event of loss of the normal lighting.

Australian Standards

<table>
<thead>
<tr>
<th>AS 1680 Series</th>
<th>Interior Lighting</th>
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<tr>
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### AS/NZS 2293 Series

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### AS/NZS 1158 Series

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<td>The Lighting of Urban Roads and Other Public Thoroughfares – Computer Procedures for the Calculation of Light Technical Parameters for Category A Lighting</td>
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<td>3.1 – 1999</td>
<td>Road Lighting – Pedestrian Area (Category P) Lighting – Performance and Installation Design Requirements</td>
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<td>The Lighting of Urban Roads and Other Public Thoroughfares – Supplementary Lighting at Pedestrian Crossings</td>
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<td>Lighting for Roads and Public Spaces – Tunnels and Underpasses</td>
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### AS/NZS 4282 – 1997

Control Of The Obtrusive Effects Of Outdoor Lighting

### AS/NZS 2560 Series

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<th>Guide to Sports Lighting</th>
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Over 74 Australian and New Zealand Standards exist related to lighting in some way.