Appendix 1: Standards

Relevant Australia / New Zealand Lighting Design Standards

Standards important 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. The important lighting design standards are listed below.

AS/NZS 1680 Series	**Interior and Workplace Lighting**
AS/NZS 1680.0:2009	Safe movement
AS/NZS 1680.1:2006	General principles and recommendations
AS/NZS 1680.2.1:2008	Specific applications - Circulation spaces and other general areas
AS/NZS 1680.2.2:2008	Specific applications - Office and screen-based tasks
AS/NZS 1680.2.3:2008	Specific applications - Educational and training facilities
AS/NZS 1680.2.4:1997	Industrial tasks and processes
AS/NZS 1680.2.5:1997	Hospital and medical tasks
AS 1680.3:1991	Measurement, calculation and presentation of photometric data
AS/NZS 1680.4:2001	Maintenance of electric lighting systems
AS/NZS 1680.5:2012	Outdoor workplace lighting

AS/NZS 2293 Series	**Emergency Evacuation Lighting For Buildings**
AS/NZS 2293.1:2005	System Design, Installation and Operation
AS/NZS 2293.2:1995	Inspection and Maintenance
AS/NZS 2293.3: 2005	Emergency Luminaires and Exit Signs

AS/NZS 1158 Series	**Lighting for Roads and Public Spaces**
AS/NZS 1158.0:2005	Introduction
AS/NZS 1158.1.1:2005	Vehicular traffic (Category V) lighting - Performance and design requirements
AS/NZS 1158.1.2:2010	Vehicular traffic (Category V) lighting - Guide to design, installation, operation and maintenance
AS/NZS 1158.2:2005	Computer procedures for the calculation of light technical parameters for Category V and Category P lighting
AS/NZS 1158.3.1:2005	Pedestrian area (Category P) lighting - Performance and design requirements
AS/NZS 1158.4:2015	Lighting of pedestrian crossings
AS/NZS 1158.5:2014	Tunnels and underpasses
AS/NZS 1158.6:2015	Luminaires - Performance

AS/NZS 4282 – 1997	**Control Of The Obtrusive Effects Of Outdoor Lighting**

AS/NZS 2560 Series	**Sports Lighting**
AS 2560.1-2002	General principles
AS 2560.2.1-2003	Specific applications - Lighting for outdoor tennis
AS 2560.2.2-1986	Specific recommendations - Lighting of multipurpose indoor sports centres
AS 2560.2.3-2007	Specific applications - Lighting for football (all codes)
AS 2560.2.4-1986	Specific recommendations - Lighting for outdoor netball and basketball
AS 2560.2.5-2007	Specific applications - Swimming pools
AS 2560.2.6-1994	Specific recommendations - Baseball and softball
AS 2560.2.7-1994	Specific recommendations - Outdoor hockey
AS 2560.2.8-2007	Outdoor bowling greens

Relevant LED Test Methods

At the time of writing of this manual, the LED test methods developed in the USA (by the IESNA), and also by the CIE, were the most commonly used to assess LED performance. The relevant test methods are listed below. Note that many new LED test methods are being developed all the time.

CIE International Standard S 025/E:2015 - Test Method for LED Lamps, LED Luminaires and LED Modules

This standard provides requirements to perform reproducible photometric and colorimetric measurements on LED lamps, LED modules, and LED luminaires (LED devices). It also provides advice for the reporting of the data. The availability of reliable and accurate photometric data for LED devices is a basic requirement for designing good lighting systems and evaluating performance of products. By obtaining these data through measurements in specific normalized measuring conditions, the consistency of the data should be ensured between different laboratories (within the limits of the declared measurement uncertainty) and comparison of different products on the same basis is possible.

The standard specifies the requirements for measurement of electrical, photometric, and colorimetric quantities of LED lamps, LED modules and LED luminaires, for operation with AC or DC supply voltages, possibly with associated LED control gear. LED light engines are assimilated to LED modules and handled accordingly. Photometric and colorimetric quantities covered in this standard include total luminous flux, luminous efficacy, partial luminous flux, luminous intensity distribution, centre-beam intensity, luminance and luminance distribution, chromaticity coordinates, correlated colour temperature (CCT), colour rendering index (CRI), and angular colour uniformity. This standard does not cover LED packages and products based on OLEDs (organic LEDs).

The standard aims in particular to cover measurement methods for testing the compliance of LED devices with the photometric and colorimetric requirements of LED performance standards issued by IEC/TC 34 “Lamps and related equipment”.

As LED devices offer a large variety of configurations in respect to geometry and/or colour, the photometric and colorimetric performances are considered individually for each configuration.

CIE TC 2-71: CIE Standard on Test Methods for LED Lamps, Luminaires and Modules (in drafting stage)

Objective is to prepare a CIE standard on test methods for photometric and colorimetric performance of LED lamps, LED luminaires, and LED modules in cooperation with CEN TC169 WG7 and IEC TC34.

CIE 177 - Colour Rendering of White LED Light Sources (in drafting stage)

The Committee recommends the development of a new colour rendering index (or a set of new colour rendering indices) by a Division 1 Technical Committee. This index (or these indices) shall not replace the current CIE colour rendering index immediately. The usage of the new index or indices should provide information supplementary to the current CIE CRI, and replacement of CRI will be considered after successful integration of the new index. The new supplementary colour rendering index (or set of supplementary colour rendering indices) should be applicable to all types of light sources and not only to white LED light sources. Possibilities for an improved description of colour rendering are summarized in the Appendix of this Technical Report.

IES LM-79 - Electrical and Photometric Measurements of Solid-State Lighting Products

This approved method describes the procedures to be followed and precautions to be observed in performing reproducible measurements of total luminous flux, electrical power, luminous intensity distribution, and chromaticity, of solid-state lighting (SSL) products for illumination purposes, under standard conditions. This approved method covers LED-based SSL products with control electronics and heat sinks incorporated, that is, those devices that require only AC mains power or a DC voltage power supply to operate. This document does not cover SSL products that require external operating circuits or external heat sinks (e.g., LED chips, LED packages, and LED modules). This document covers SSL products in a form of luminaires (fixtures incorporating light sources) as well as integrated LED lamps (see section 1.3 f). This document does not cover fixtures designed for SSL products sold without a light source. This document describes test methods for individual SSL products, and does not cover the determination of the performance rating of products, in which individual variations among the products should be considered.

SSL products as defined in this document utilize LEDs (including inorganic and organic LEDs) as the optical radiation sources to generate light for illumination purposes. An LED is a p-n junction semiconductor device that emits incoherent optical radiation when biased in the forward direction. White light is produced by LEDs using two methods: visible spectra of two or more colours produced by LEDs are mixed, or the emission (in the blue or ultraviolet region) from LEDs is used to excite one or more phosphors to produce broadband emission in the visible region (Stokes emission). A general description of LEDs and lighting is available in Ref. 1. Although constant current control is typical for stand alone LEDs, this document deals with integrated SSL products incorporating the semiconductor device level current control, thus the electrical parameters of interest are the SSL product's input electrical parameters.

For special purposes, it may be useful to determine the characteristics of SSL products when they are operated at other than the standard conditions described in this approved method. Where this is done, such results are meaningful only for the particular conditions under which they were obtained and these conditions shall be stated in the test report.

The photometric information typically required for SSL products is total luminous flux (lumens), luminous efficacy (lm/W), luminous intensity (candelas) in one or more directions, chromaticity coordinates, correlated colour temperature, and colour rendering index. For the purpose of this approved method, the determination of these data will be considered photometric measurements.

The electrical characteristics measured for AC-powered SSL products are input RMS AC voltage, input RMS AC current, input AC power, input voltage frequency and power factor. For DC-powered SSL products, measured electrical characteristics are input DC voltage, input DC current, and input power. For the purpose of this approved method, the determination of these data will be considered electrical measurements.

IES LM-80 - Measuring Luminous Flux and Colour Maintenance of LED Packages, Arrays and Modules

LEDs typically exhibit very long operational life characteristics and, depending on drive current and use conditions, can be in use for 50000 hours or longer. The light output from LEDs slowly decreases over time. This characteristic of declining output without catastrophic failure creates a risk that an LED-based lighting product near end-of-life may be operating, but performing outside the product's specification, or outside required codes, standard practices or regulations. LEDs may also undergo gradual shifts in the emitted spectra over time that may result in unacceptable appearance, colour rendering or degraded efficacy.

This document describes the procedures by which LEDs are tested for the luminous (or radiant, or photon) flux maintenance and chromaticity maintenance or wavelength changes over time when operated under controlled environmental and operational conditions. The resulting measurements may be used for comparison of LEDs, and they may be utilized in models that project long-term changes in light output during the life of the LEDs.

ANSI/IES LM-80-15 does not provide guidance or make any recommendation regarding predictive estimations or extrapolation for the maintenance characteristics beyond the time duration of the actual measurements.

IES LM-82 - Characterizations of LED Light Engines and LED Lamps for Electrical and Photometric Properties as a Function of Temperature

The intent of this document is to establish consistent methods of testing and data presentation for ease of interpretation and comparison, which will assist luminaire manufacturers in selecting suitable LED light engines and integrated LED lamps for each luminaire product. This approved laboratory method defines the procedures to quantify the performance of LED light engines and integrated LED lamps as a function of temperature.

IES LM-84 - Measuring Luminous Flux and Colour Maintenance of LED Lamps, Light Engines, and Luminaires

The method for measuring luminous flux and colour maintenance of LED light sources has been documented in IES LM-80-08. At the solid-state lighting (SSL) system level such as LED lamps, light engines, and luminaires, other system components, in addition to the LED light sources, also contribute to luminous flux decay and colour change over time. The system performance changes over time can be directly tested at the SSL product level. This document addresses the evaluation of the changes in performance of SSL systems over time and can be a useful tool for engineering evaluations and luminous flux maintenance for entire assemblies when environmental considerations and variability for the base LED deprecation is incorporated into the analysis.

Furthermore, performances of SSL systems, LED integrated lamps, non-integrated lamps, LED light engines, and LED luminaires, are typically but not without exception affected by operational and environmental variables such as operating cycle, conditions imposed by auxiliary equipment and fixtures, ambient temperature, airflow and orientation. This test method has been developed to establish consistent and environmental conditions across laboratories to achieve reproducible results and to permit reliable comparison of results.

IES LM-85 - Electrical and Photometric Measurements of High-Powered LEDs

This document is a guide developed for the measurement of high-power light emitting diodes (LEDs), normally in a form of LED packages, used for lighting products. High-power LEDs are those that require a heat sink for their normal operation. The light output of an LED depends strongly on its thermal conditions, in particular, the junction temperatures Tj. Junction temperature, however, is difficult to measure. Various different methods have been used to operate LEDs for photometric measurements and the results could not be compared. This document provides uniform test methods for operation of high power LEDs and test methods for photometric and colorimetric measurement of high-power LEDs.

IES TM-21 - Projecting Long Term Lumen Maintenance of LED Light Sources

This document provides recommendations for projecting long term lumen maintenance of LED light sources using data obtained when testing them per IES LM-80 - IES Approved Method for Measuring Lumen Maintenance of LED Light Sources.

IES TM-28 - Projecting Long-Term Luminous Flux Maintenance of LED Lamps and Luminaries

The objective of this Technical Memorandum is to provide guidance and recommended procedures for sampling, test intervals and duration, and a method for long-term luminous flux maintenance projection for LED lamps and luminaires. The intent is to help product manufacturers and users, standard developing bodies, and other organizations to avoid any unnecessary burdens related excessive product testing.

Typically, LED sources test data are available for at least 6000 hours prior to the design of lamps or luminaires with them. This provides the starting information for the luminous flux maintenance projection according to the combined method. That method also takes into account any detectable further contribution from the remaining lamp or luminaire components, rather than using only LED sources test data as a proxy. As a result, the luminous flux maintenance projection for the lamp or luminaire can begin as early as 3000 hours into their testing, when the protocol proposed by this document is followed.

Appendix 2 - Control Gear

LED Drivers

LEDs require a constant current, rather than a constant voltage which most other lamps require. An LED driver is an electronic circuit which regulates current to an LED (or LEDs). Typically, LEDs are supplied with the driver either integral to the LED lamp/luminaire, or connected to it via cables (refer images below)

The voltage drop across an LED junction is approximately constant over a wide range of operating current, thus a small increase in the voltage applied to the LED will significantly increase the LED current. Only simple circuits are used for low-power indicator LEDs - more complex, current source drivers are required when driving high-power LEDs such as those used for illumination.

An LED driver should be carefully matched to the electrical characteristics of the LED(s) to be driven. This also helps to avoid “thermal runaway” as the constant current LED driver compensates for changes in the LED forward voltage, while delivering a constant current to the LED.

There are two main types of LED drivers, those that use low voltage DC input power (generally 5-36VDC) and those that use high voltage AC input power (generally 90-277VAC). LED drivers that use high-voltage AC power are called Off-Line drivers, or AC LED drivers. LED drivers will also have differing abilities and means of dimming the LED. Drivers with DALI (and other control regimes) are also available.

Conventional magnetic / wire-wound control gear (for discharge lamps)

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.

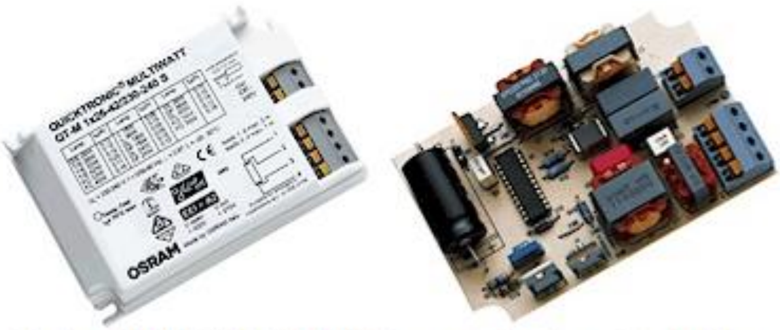
The less expensive metal halide lamp fittings will use CCG to keep the cost down, but the ‘top end’ of the market will use the more efficient ECGs. In fact most of the development of ECGs for HID lamps has been directed to metal halide lamps, as this is where the HID market is seen to be expanding most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

Electronic Control Gear (for discharge lamps)

HEADS UP: Electronic Control Gear and Energy Efficiency

Electronic control gear allows the lamp to run more efficiently and has lower losses than conventional (wire-wound) control gear.

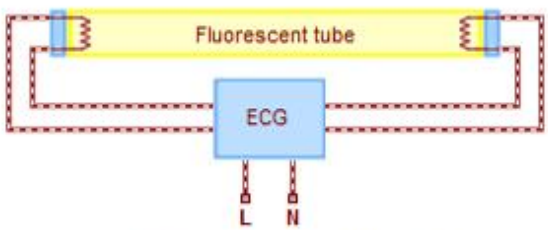
Electronic Control Gear (ECG) is a one-piece unit that combines starting (or igniting), operating the lamp at the correct voltage and current, has virtually unit power factor and safely shuts down the lamp as it approaches the end of its useful life.



The tiny QUICKTRONIC MULTIWATT can control a wide variety of tubular, circular and compact fluorescent lamps. It replaces the conventional ballast, capacitor and starter.

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.

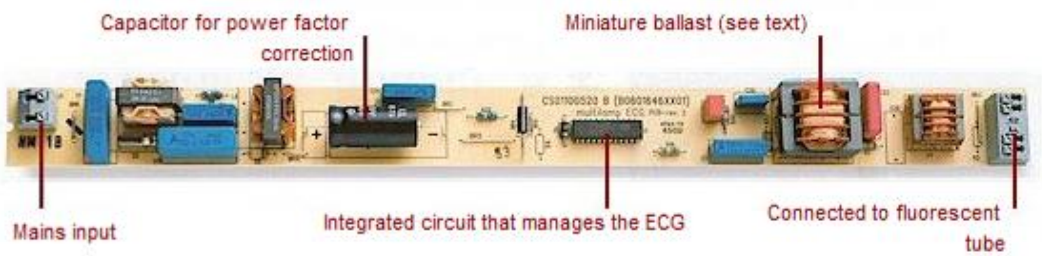
Physical wiring connections of typical fluorescent ECG



Circuit layout of typical fluorescent ECG

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.

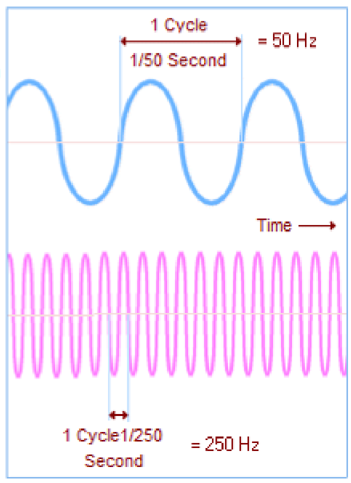
ECG operation – metal halides

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.

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).

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.

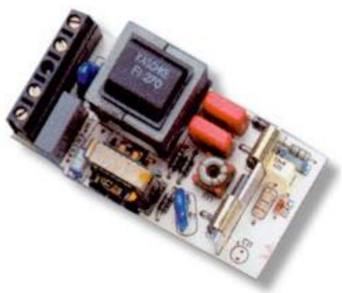
For example, a 58W T8 fluorescent tube operated on CCG and ECG:

	Conventional control gear	Electronic control gear
Lamp power	58W	50W?
Light output	5,200 lm	5,100 lm
Luminous efficacy	89.9 lm/W	102 lm/W
Control gear losses	13W	5W
Total circuit power	58W + 13W = 71W	50W + 5W = 55 W
Power saving	71W – 55W = 16W (23%)	

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.



HALOTRONIC electronic transformer for low voltage tungsten halogen lamps

HALOTRONIC electronic transformer produces low voltage DC for low voltage halogen lamps

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.

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.

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').

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.

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.

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.

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.

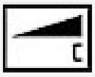
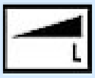
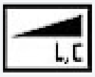
To be able to have different types and wattages of fluorescent lamps operating in the same light fitting from a single ECG gives the designer much greater scope for more aesthetic light fittings. Just as important is that the fittings manufacturer and the electrical wholesaler will need to stock far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

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.

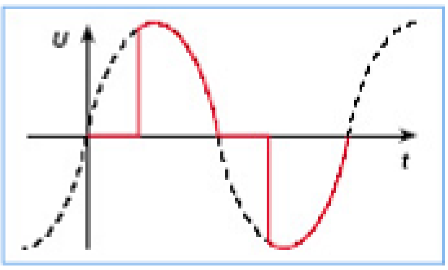
All the major electronic transformer manufacturers have agreed on a convention to mark transformers with a symbol to indicate the type of dimmer that should be used:

Symbol	Type
	Trailing edge phase control dimmer suitable for capacitive loads.
	Leading edge phase control dimmer suitable for inductive loads.
	Leading-edge and trailing-edge phase control dimmer suitable for either inductive and capacitive loads.

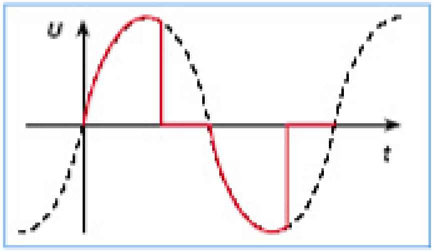
Phase control dimmer types

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.



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



The symbols marked on the transformer indicate the type of phase control that is compatible with that transformer.

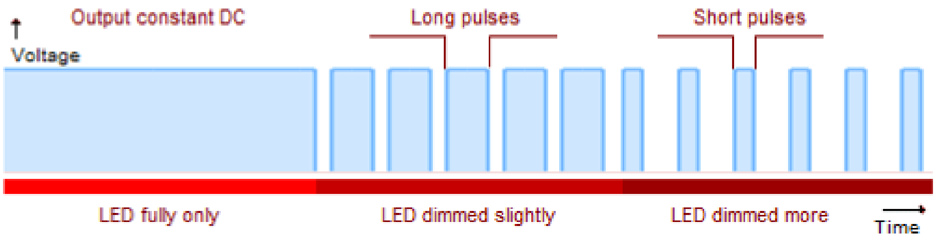
Use with fluorescent lighting schemes

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.

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

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.

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.

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.

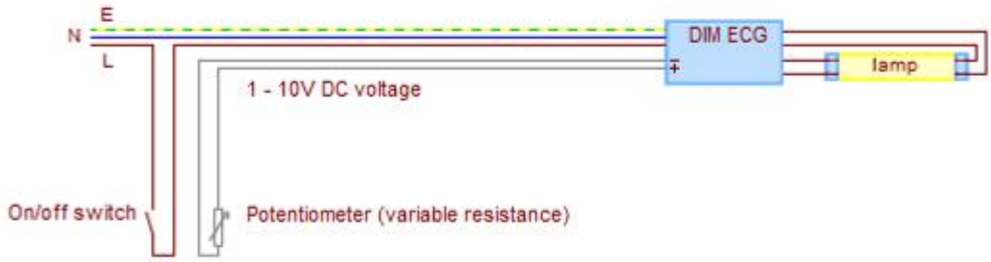
To dim fluorescent lamps requires special dimmable ECGs as normal ECGs are not capable of being dimmed. These dimmable ECGs operate on the principle of controlling the lamp current to regulate the power and hence the light output. The dimming control circuits are built into the dimmable ECGs, so it is 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**.

Analogue dimming control

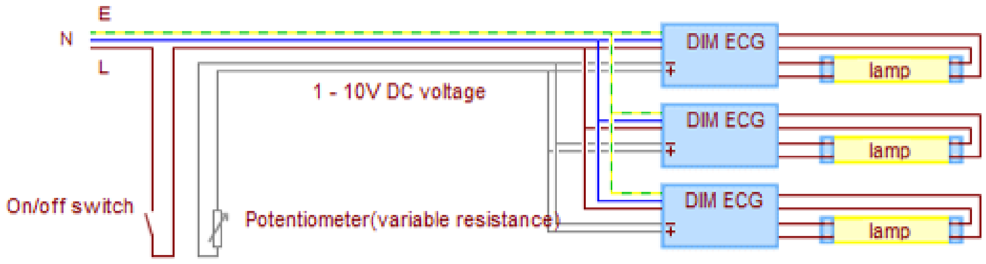
The current and voltage of the dimming control into the dimmable ECG is a low voltage DC signal (referred to as an analogue signal).

- '***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.



Circuit for Dimmable ECG with 1-10V dimming control

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.



Circuit for Dimmable ECG with 1-10V dimming control - multiple lamps

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.

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.

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 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.

Typical domestic consumer unit (used to be called a fuse-box!) showing the MCBs.

Appendix 3 - Legacy Lamps

Incandescent lamps

Incandescent lamps used to be the most commonly used type of lighting. They were inexpensive to buy, but their running costs were high. Standard incandescent lamps were most suitable for areas where lighting was 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. Although they are being phased out, it is useful, from a legacy perspective, to describe the construction and operation of incandescent lamps.

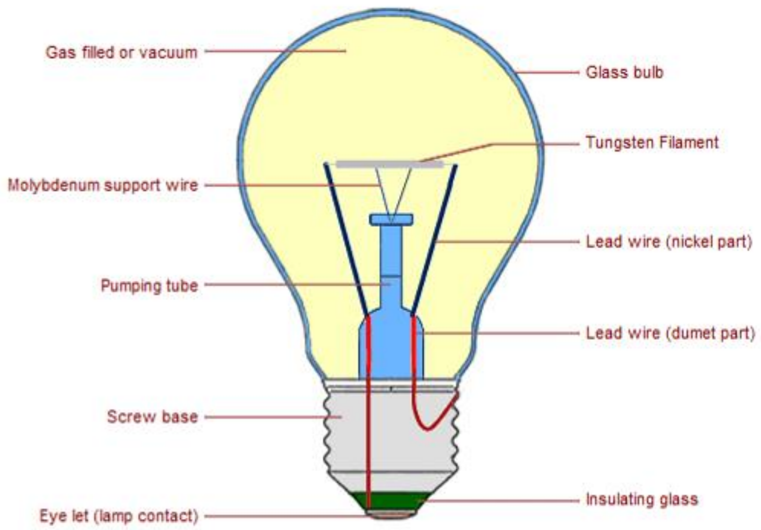
Incandescence is technically 'thermo-luminescence', which means to create light by means of heat. When an electric current flows in a tungsten filament or other conducting material, heat will be generated. Should the temperature of the filament be raised sufficiently, not only will heat be emitted but 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.

Performance summary	
Range	25 – 300 watt
Colour temperature	2,700 Kelvin
Life	1000 hours
CRI	100
Efficacy	12 lm/watt

Pros	**Cons**
Immediate on	Very expensive to operate
Immediate full light output	Low colour temperature
No extra equipment	Shorter lamp life
Cheap initial cost	300W maximum power

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.



The component parts of a GLS lamp

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.

Tungsten filament

A typical tungsten filament operates at about 2,400^{o}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.

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.

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.

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.

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.

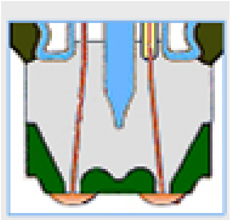
Most lamp cap shells are made of aluminium, although brass or nickel plated brass can be used.

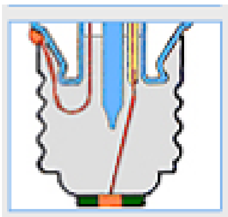
Insulating glass

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.

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.

Tungsten Filaments

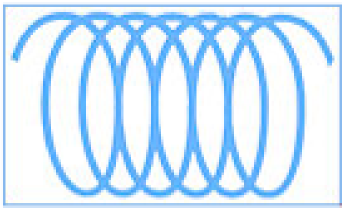
As has already been discussed, tungsten is specifically chosen as the material to manufacture filaments, because it can be drawn into very fine wires and maintain a high temperature without melting whilst giving off considerable light.

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.

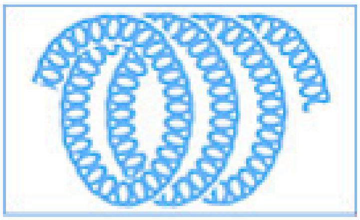
Single coil filaments

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.



Single coil



Coiled coil

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.

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.

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 is 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.

Coloured and Lacquered Lamps

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.

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.

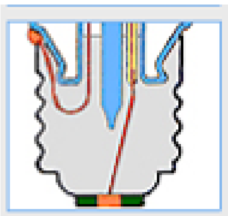
Lamp Caps

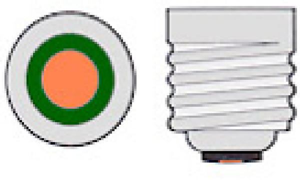
As mentioned earlier, the lamp cap (or lamp base) provides the live and neutral connections for the appropriate voltage electricity supply. It also provides safe and easy to use mechanical and electrical connections to the lamp holder.

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.

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).





Edison Screw

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.

Edison screw lamp sizes

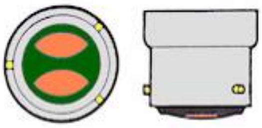
IEC	Description	Approximate diameter
E14	Small Edison screw	14mm
E27	Edison screw	27mm
E40	Goliath Edison screw	40mm

Bayonet caps

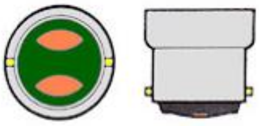
The bayonet cap (BC) fixing method gets its name from the 'push and twist' action required to fix a bayonet to early rifles.

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.



3 pin 22mm Bayonet Cap



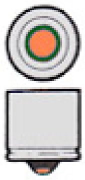
Standard two pin 22mm Bayonet Cap

Bayonet cap sizes

IEC	Description	Approximate diameter
B15d	Small bayonet cap	15mm
B22d	Bayonet cap	22mm
B22d-3	Bayonet cap 3 pin	22mm

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.



Single Contact cap

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.

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.

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.

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' (**p**ressed glass **a**luminised **r**eflector).

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.

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:

Energy type	Percentage output
Ultraviolet	0.03%
Visible light	9.0%
Infrared	84.0%
Conducted and convected heat	7.0%
Conducted heat is that lost through the lamp holder. Convected heat is that lost to the air surrounding the lamp.	

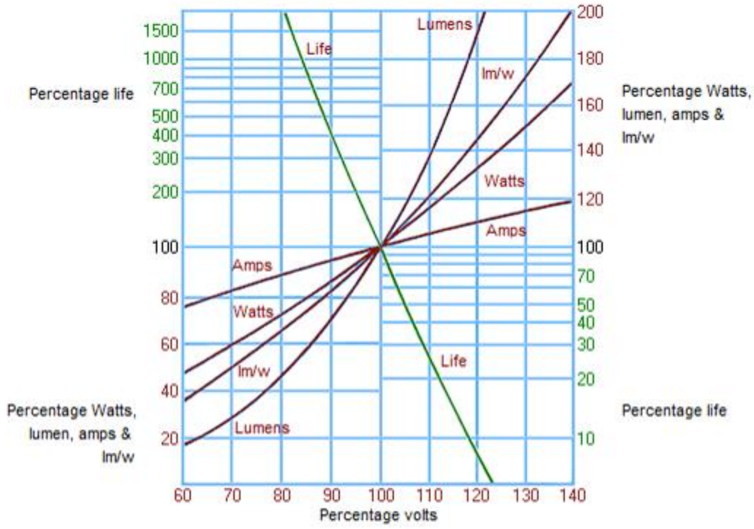
Applied voltage

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.



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.

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

Tungsten Halogen Lamps

Halogen lamps are also a type of incandescent lamp, which are now much less popular due to their poor efficiency in comparison to LED and fluorescent lamps. Halogen lamps are relatively inexpensive and can 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.

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.

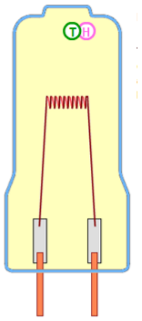
In the 1950's it was found that the addition of a small amount of a halogen (a group of chemical elements with certain properties, one of which has a marked tendency to chemically combine with metals) could prevent the blackening. The five halogen elements are iodine, bromine, chlorine, fluorine and 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	
Range	Low voltage: 20 – 50 watt Mains voltage: 40 – 600 watt
Colour temperature	2,800 – 3,200 Kelvin
Life	2,000 – 5,000 hours
CRI	100
Efficacy	10-30 lm/watt

Pros	**Cons**
Immediate on	Expensive to operate
Immediate full light output	May require a transformer
Whiter light than incandescent	Limited range
Long life	High cost lamps
Compact size, designer luminaires	Reflector lamps not appropriate for general lighting design
More economical than incandescent	

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.

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.

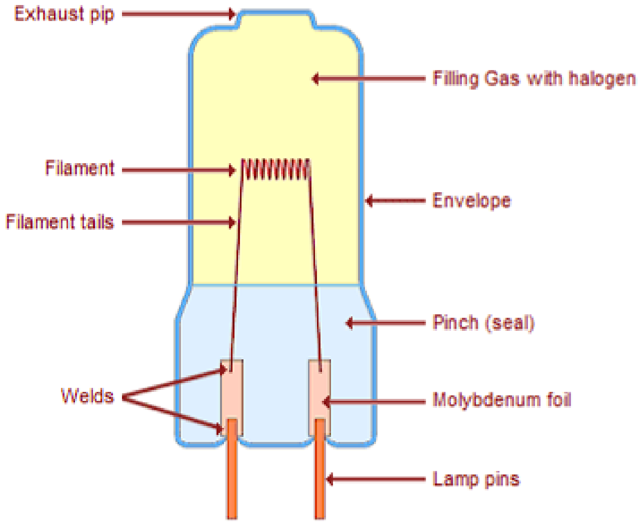
3. During lamp operation the high temperature ensures the halogen is in vapour form.

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.

Lamp Construction

The components of a typical halogen lamp are shown below.



The component parts of a typical halogen lamp

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.

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.

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.

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.

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.

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.

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.

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.

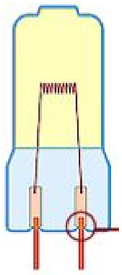
The long edges of the molybdenum foil are tapered to a razor edge. This is necessary so that the semi-molten quartz will seal perfectly around the foil during the pinching process and make an airtight seal.

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 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.

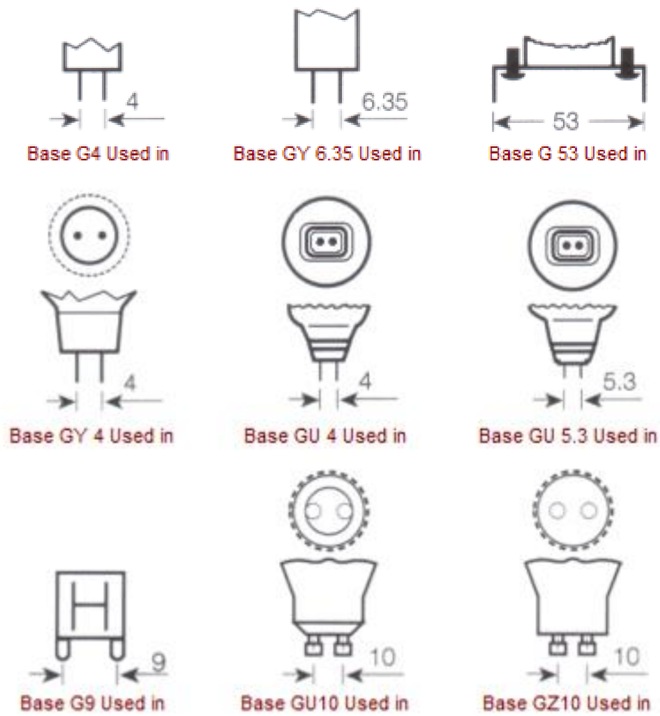
Welds

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.

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:



Popular domestic bayonet and Edison screw fittings:

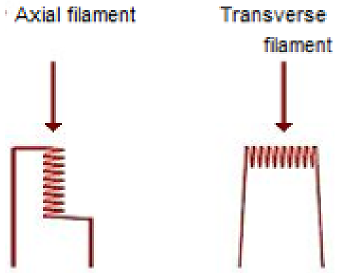
Tungsten Filaments

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.

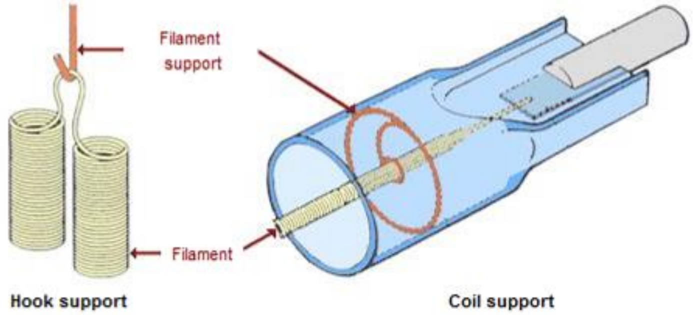
Filament orientation

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.



Filament supports

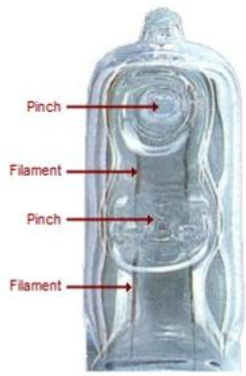
Low voltage halogen lamps have filaments that are rigid enough not to require additional support. Mains voltage lamps have filaments similar to those of GLS lamps, in that they are floppy and have to be supported to prevent them sagging when hot. There are two types of filament support used in mains 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-pinch 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.



Bulb-pinch support

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.

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.

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.

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%. However LEDs now represent a much more efficient solution.

These lamps 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.).

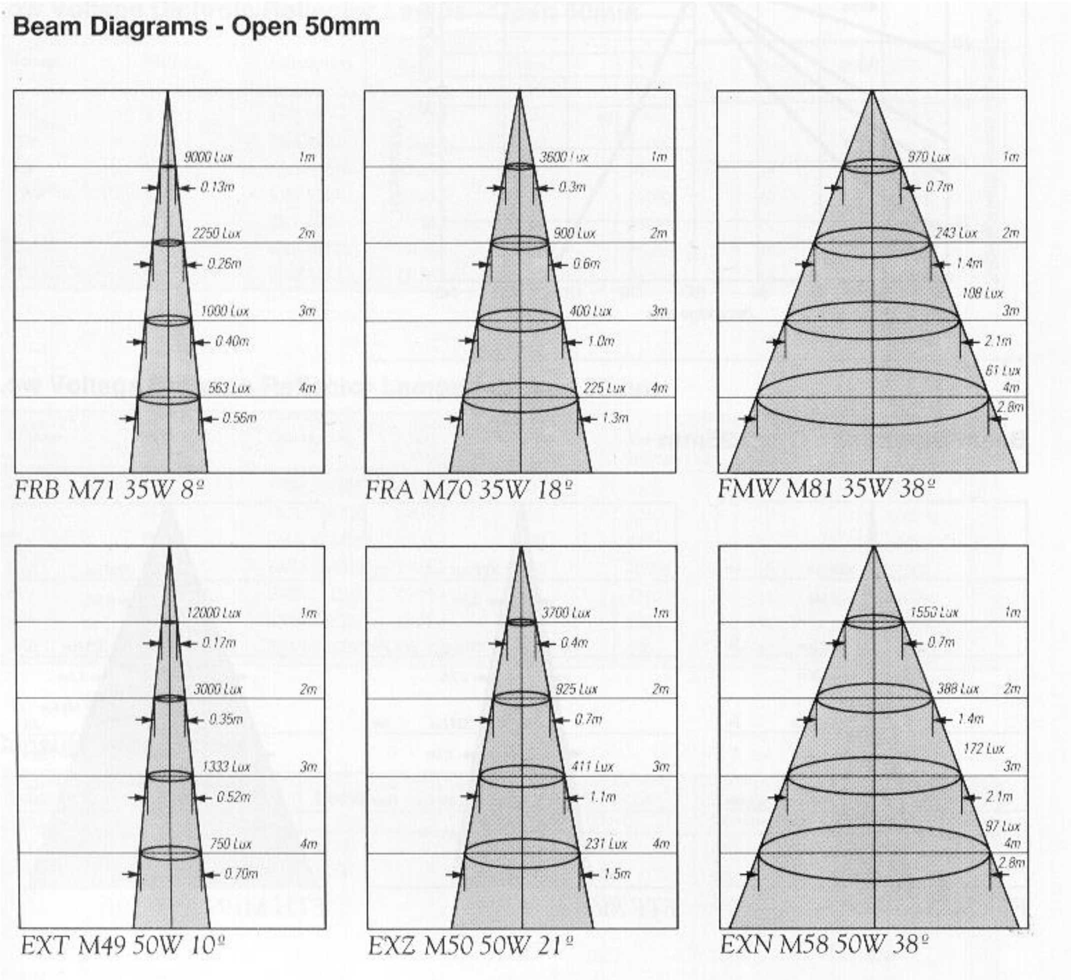
Dichroic – where a dual purpose reflective coating has been deposited onto the inside surface of the reflector lamp. The coating consists of alternate layers of two materials with special optical qualities - silica and zinc sulphide. These materials are deposited on the inside of the glass reflector 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.

<u>SAFETY NOTE:</u>

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.



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.

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.

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.

Conventional transformers - rectangular and toroidal. Both are based on an iron core.

A conventional 12 V transformer for supplying a single low voltage tungsten-halogen lamp.

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.

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 in to 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 convertors for ELV lamps; Part 2: Minimum Energy Performance Standards (MEPS) requirements.

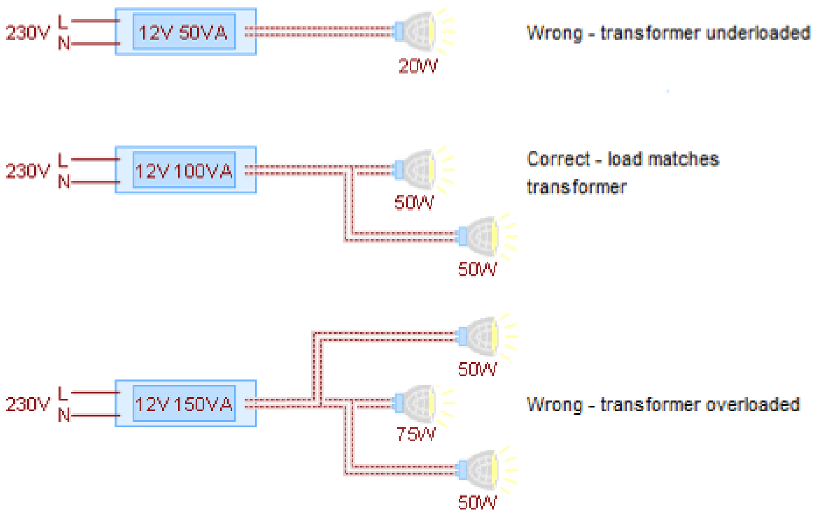
Transformer loading

- **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: 50VA/230V = 0.217 Amp

  and the output (secondary) side is taking: 50VA/12V = 4.17 Amp

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



Transformer loading

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.

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.

Mains Voltage Halogen Lamps

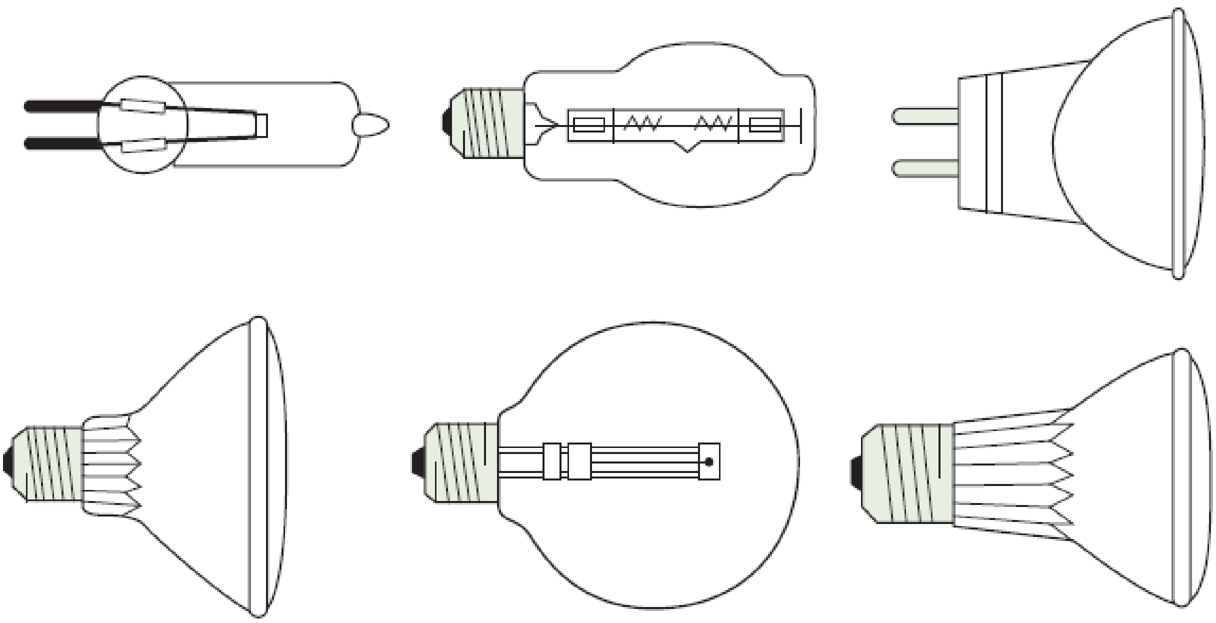
There are two types of mains voltage tungsten halogen lamp:

- Single ended
- Double ended

Single ended halogen lamps

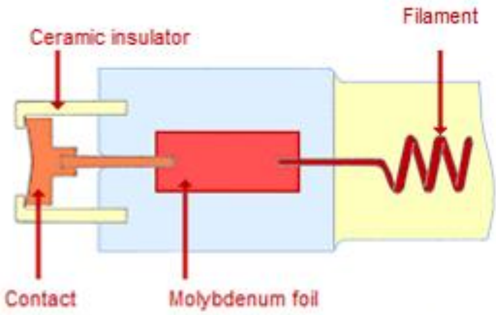
Single ended halogen lamps have a compact filament inside a quartz envelope, which can be clear or 'frosted' (achieved by sandblasting the outer surface of the envelope). They have caps to fit domestic lamp holders, e.g. E27, B15d and B22d.

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



Double ended halogen lamps

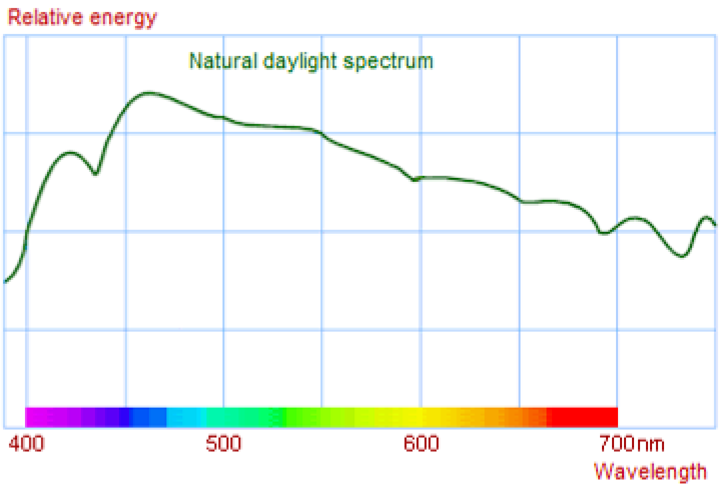
Double ended halogen lamps are tubular lamps with a contact at each end. These contacts are attached to a short pin emerging from the pinch seal, and recessed into a ceramic insulator.



One end of a linear quartz halogen lamp base

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.



Spectral power distribution for tungsten halogen lamps

The output of a typical quartz tungsten halogen lamp across the spectrum is as follows:

Energy type	Wavelength	Percentage output
Ultraviolet	below 380 nm	0.03%
Visible light	380 – 780nm	11.3%
Infrared	above 780 nm	88.4%

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

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.

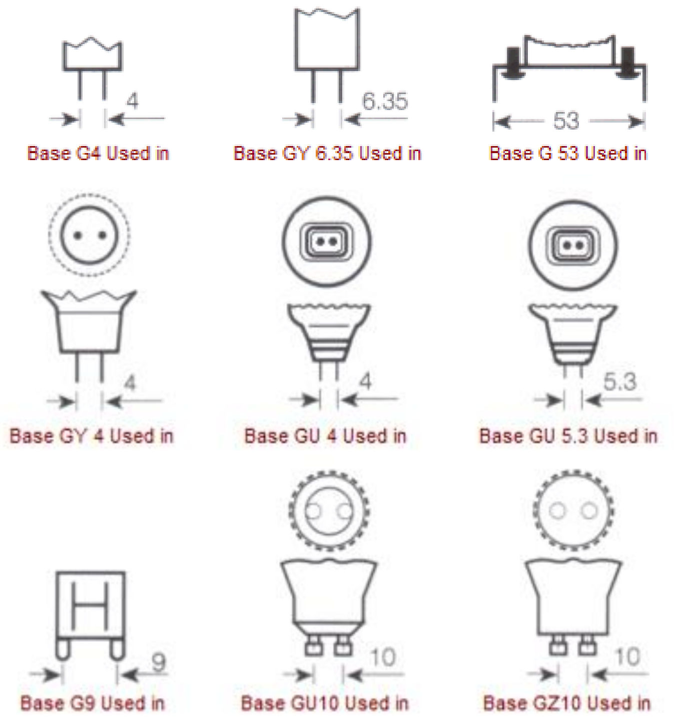
Lamp Standards

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*'.

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:



User Protection

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.

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 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.

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.

Appendix 4 - 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.

Case Study 1 - Residential LED Design

The main focus of this case study was reducing energy costs for lighting through upgrading to LED lighting from halogen, however the end result does so much more. Controlled lighting that allows generous flexibility in the main living space by using a combination of cove lighting and wall washing, along with carefully selected low glare downlights has given this apartment a new lease on life.

Overview

Home Owners Andrew and Brigid were looking to update their LED Downlights to make the most of the energy savings this new technology offers, but after much research discovered that although there are many options in the market for LED downlights, they could not determine which of those options met their expectations of quality light. By engaging a professional designer, the upgrade not only saved them energy on downlights, it also vastly improved the light in their home.
Following the renovation of their lighting, a comprehensive review of energy consumption has demonstrated a dramatic drop in daily cost, and an overall saving of $800 per year in energy bills for the lighting alone.

Key Issues/Goals/Problems

Saving energy without losing the quality of light was a key issue for this home. We also had to take into consideration the ground floor location, and the gloomy atmosphere of the apartment with the existing downlights. In the end, we significantly reduced energy costs and dramatically improved the lighting conditions through selecting the right lighting effects for each room, and controlling the switching and dimming for maximum flexibility.
The couple have an extensive art collection, beautiful furniture and a vast book collection. With the pre-existing lighting, none of these elements were highlighted, and the corridors felt small and gloomy. By replacing downlights with wall washing lights, we illuminated the walls, books and art creating a feeling of space and drawing attention to the objects of beauty. Selecting the right, low glare downlights to replace the functional lighting in circulation and kitchen areas improved the overall light quality with minimal impost during installation.
By using darklighter downlights over the dining table, we reduced the visual impact of the lights in the ceiling, and created the flexibility to change the feel of the space into one of a luxury restaurant.
The couple each have vastly different requirements for their home office. By adding an extra switch line, and selecting different lights for each side of the small room, 3 completely different lighting states are possible, allowing each person to change the room to suit their own needs.
The most transformative change was installing lighting in the pre-existing ceiling cove in the main living area. This lighting effect not only brightens the room, it also creates a sense of daylight coming in to a ground floor apartment that has limited access to natural light. The light source is barely noticeable, yet the effect, used during daylight hours as well as at night creates an expansive, bright sensation completely transforming the room.

The result is a ground floor apartment that feels like a free standing house. Ceilings feel higher, and rooms feel larger. Artworks are highlighted, bringing colours to life, and the book collection is now the feature it always deserved to be.

Key Design Criteria:

- Energy savings through LED lighting upgrade
- Include fans to reduce air conditioning energy consumption
- Highlighting art collection
- Removing gloomy corners in circulation areas
- Adding light to the kitchen
- Changing the feel of the living room to increase the perception of space
- Joint office with two different lighting states to meet different working needs
- Enhance bathroom lighting for more brightness and visibility in mirrors
- Use existing lighting locations for all new fittings

Data

The graph below demonstrates the impact this lighting upgrade had on energy savings in the home.

The blue line is the important one for lighting purposes. It represents general light and power at a peak rate of 22.65c/kwh and an off-peak rate of 13.86c/kwh, less a discount of 28 percent for on-time payment. This meter runs all light and power in the apartment except for the hot water service (red line) and the controlled-load concrete slab heating (green line). Prior to switching to LED lighting, the average cost per day of the electricity supply through this meter was around $5.60. The daily cost is quite high for an apartment because we run a full-time office (including two computers, two printers and ancillary equipment), three refrigerator/freezers and two 24-hour water-feature pumps.

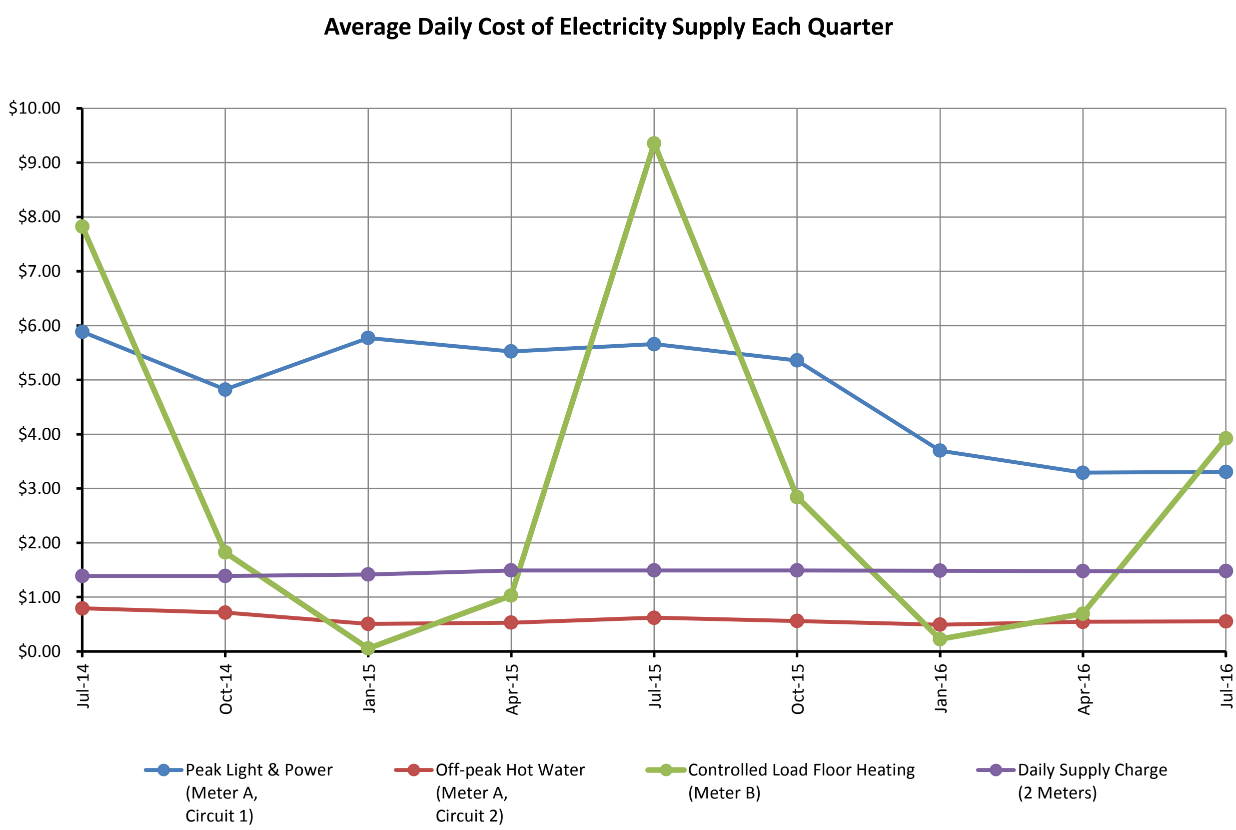
Our initiatives to reduce costs were as follows:

- Installation of efficient Big Ass Haiku fans in every room in November 2015. These virtually eliminated our need for air-conditioning during the 2015/16 Summer.
- Replacement of about forty halogen downlights throughout the apartment with a similar number of LED downlights, wall washers and feature lights in December 2015. The effect of this replacement was immediate, both in dramatically improved light quality and in significantly reduced electricity costs.
- Installation of the LED cove lighting in March 2016. The cove lighting is used as an alternative to the living area down-lights, rather than as an addition, and is probably marginally more expensive to run, but it seems to have had little or no effect on electricity costs.

Collectively, these initiatives have reduced our daily costs through this meter to about $3.30/day, a reduction of about 40%, i.e. more than $800/year.

The green line on the graph represents the daily cost of running our controlled-load concrete slab heating. The controlled load means that it runs only at off-peak rates for a few hours mid-afternoon and from midnight to 7:00 a.m. It is intended to maintain an even ambient temperature, but I felt that the $8 to $10 per day we were paying in winter, just to heat the slab, was excessive, so I replaced the original atmospheric thermostats mounted on the walls with sensors embedded in the slab. This allowed me to control the temperature of the slab directly rather than relying on air temperature. I also installed a reverse-cycle heater/air-conditioner which allowed me to boost the air temperature at any time as required. Heating costs during the coldest winter we have had for several years fell from more than $9/day to less than $4/day. I expect this seasonal cost reduction to translate to about $800/year.

In total, electricity costs for the winter quarter have been cut from about $17/day in 2015 to about $9/day in 2016. Further cost-reduction measures are also being introduced such as programming the dishwasher, washing machine and clothes dryer to run only at night at off-peak rates. Overall, I am expecting my annual electricity costs to fall by about $2,000/year.


Average Daily Cost of Electricity Supply Each Quarter
$10.00
$9.00
$8.00
$7.00
$6.00
$5.00
$4.00
$3.00
$2.00
$1.00
$0.00
Jul-14
Oct-14
Jan-15
Apr-15
Jul-15
Oct-15
Jan-16
Apr-16
Jul-16
Peak Light & Power (Meter A, Circuit 1)
Off-peak Hot Water (Meter A, Circuit 2)
Controlled Load Floor Heating (Meter B)
Daily Supply Charge (2 Meters)

Case Study 2 - Office Upgrade of Linear Fluorescent

The table below shows the energy savings and financial case for upgrading linear fluorescent fittings in an office environment.

Case Study Summary

Office space: upgrade linear fluorescent fittings to LED integrated fittings

Project Details

Area of space (m^2)	2,000
Operating hours p.a.	3,000
Av lifetime electricity cost (per kWh)	$0.200
Air conditioned (Y/N)	Yes
Project time horizon (years)	10

Existing Light Fittings

Type	Fluorescent T8
Ballast / transformer type	Magnetic - class B2
Lamp power (W)	36
Lamps per fitting	2
Total power per fitting (W)	88
No. fittings in the space	400
Lighting power density (W/m^2)	17.6

New Light Fittings

Type	LED
Total power per fitting (W)	30
No. fittings in the space	400
Total installed cost per fitting	$150
Lighting power density (W/m^2)	6.0

Results

Total capital cost	$60,000
Energy cost saving p.a. (incl air conditioning savings*)	$18,096
Simple payback (years)	3.3
Internal rate of return	28%

*Air conditioning energy savings can represent and additional 30% of lighting energy savings

Case Study 3 - Retail Upgrade of Halogen Downlights

The table below shows the energy savings and financial case for upgrading halogen downlights in a retail environment.

Case Study Summary

Retail space: upgrade halogen downlights to LED

Project Details

Area of space (m^2)	100
Operating hours p.a.	4,400
Av lifetime electricity cost (per kWh)	$0.250
Air conditioned (Y/N)	Yes
Project time horizon (years)	10

Existing Light Fittings

Type	Halogen 12V
Ballast / transformer type	Magnetic
Lamp power (W)	50
Lamps per fitting	1
Total power per fitting (W)	63
No. fittings in the space	48
Lighting power density (W/m^2)	30.0

New Light Fittings

Type	LED
Total power per fitting (W)	8
No. fittings in the space	48
Total installed cost per fitting	$60
Lighting power density (W/m^2)	3.8

Results

Total capital cost	$2,880
Energy cost saving p.a. (incl air conditioning savings*)	$3,741
Simple payback (years)	0.8
Internal rate of return	130%

*Air conditioning energy savings can represent and additional 30% of lighting energy savings

Case Study 4 - Retail Upgrade of Metal Halide Shop Lights

The table below shows the energy savings and financial case for upgrading metal halide "shop lights" in a retail environment.

Case Study Summary

Retail space: upgrade metal halide "shop lights" to LED

Project Details	
Area of space (m^2)	100
Operating hours p.a.	4,400
Av lifetime electricity cost (per kWh)	$0.250
Air conditioned (Y/N)	Yes
Project time horizon (years)	10

Existing Light Fittings	
Type	Metal halide
Ballast / transformer type	Magnetic (const. W)
Lamp power (W)	150
Lamps per fitting	1
Total power per fitting (W)	183
No. fittings in the space	20
Lighting power density (W/m^2)	36.5

New Light Fittings	
Type	LED
Total power per fitting (W)	24
No. fittings in the space	20
Total installed cost per fitting	$200
Lighting power density (W/m^2)	4.8

Results	
Total capital cost	$4,000
Energy cost saving p.a. (incl air conditioning savings*)	$4,537
Simple payback (years)	0.9
Internal rate of return	114%

*Air conditioning energy savings can represent and additional 30% of lighting energy savings

Case Study 5 - Industrial Upgrade of HID

The table below shows the energy savings and financial case for upgrading HID metal halide fittings in an industrial space.

Case Study Summary

Industrial space: upgrade HID highbay fittings to LED

Project Details	
Area of space (m^2)	10,000
Operating hours p.a.	8,500
Av lifetime electricity cost (per kWh)	$0.160
Air conditioned (Y/N)	No
Project time horizon (years)	10

Existing Light Fittings	
Type	Metal halide
Ballast / transformer type	Magnetic (reactor)
Lamp power (W)	400
Lamps per fitting	1
Total power per fitting (W)	432
No. fittings in the space	225
Lighting power density (W/m^2)	9.7

New Light Fittings	
Type	LED
Total power per fitting (W)	180
No. fittings in the space	225
Total installed cost per fitting	$450
Lighting power density (W/m^2)	4.1

Results	
Total capital cost	$101,250
Energy cost saving p.a.	$77,185
Simple payback (years)	1.3
Internal rate of return	76%

Case Study 6 - Industrial Upgrade of Linear Fluorescent

The table below shows the energy savings and financial case for upgrading linear fluorescent fittings in an industrial space.

Case Study Summary

Industrial space: upgrade linear fluorescent fittings to LED

Project Details	
Area of space (m^2)	10,000
Operating hours p.a.	8,500
Av lifetime electricity cost (per kWh)	$0.160
Air conditioned (Y/N)	No
Project time horizon (years)	10

Existing Light Fittings	
Type	Fluorescent T8
Ballast / transformer type	Magnetic - class B2
Lamp power (W)	36
Lamps per fitting	2
Total power per fitting (W)	88
No. fittings in the space	1250
Lighting power density (W/m^2)	11.0

New Light Fittings	
Type	LED
Total power per fitting (W)	30
No. fittings in the space	1250
Total installed cost per fitting	$150
Lighting power density (W/m^2)	3.8

Results	
Total capital cost	$187,500
Energy cost saving p.a.	$98,600
Simple payback (years)	1.9
Internal rate of return	52%

Case Study 7 - Residential Upgrade of Halogen Downlights

The table below shows the energy savings and financial case for upgrading halogen downlights in a residential setting.

Case Study Summary

Residential space: upgrade halogen downlights to LED

Project Details	
Area of space (m^2)	50
Operating hours p.a.	2,000
Av lifetime electricity cost (per kWh)	$0.290
Air conditioned (Y/N)	No
Project time horizon (years)	15

Existing Light Fittings	
Type	Halogen 12V
Ballast / transformer type	Electronic
Lamp power (W)	35
Lamps per fitting	1
Total power per fitting (W)	38
No. fittings in the space	24
Lighting power density (W/m^2)	18.1

New Light Fittings	
Type	LED
Total power per fitting (W)	6
No. fittings in the space	24
Total installed cost per fitting	$45
Lighting power density (W/m^2)	2.9

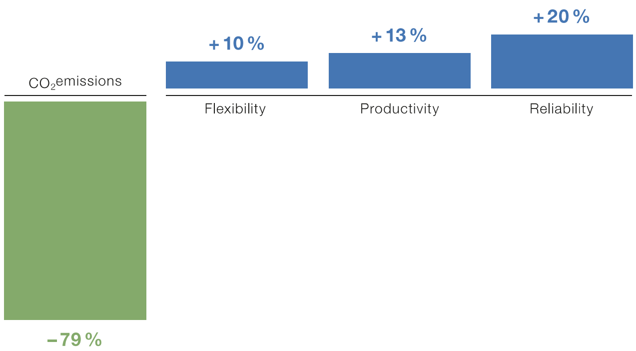
Results	
Total capital cost	$1,080
Energy cost saving p.a.	$440
Simple payback (years)	2.5
Internal rate of return	41%

Case Study 8 - Upgrade of Ferrari Factory

Live-cell therapy for historic sports cars

Almost all the Ferrari models that have left the works in Maranello since the company was formed in 1947 are still roadworthy. “Ferrari Classiche” – a mixture of car workshop, laboratory and museum – is committed to ensuring that they stay roadworthy in the future. Inspecting, examining and repairing these sports cars demands impeccable precision and hence large amounts of light.

The building, a former foundry covering an area of 950 m², has undergone extensive refurbishment. The first step was to glaze part of the roof in order to let more daylight into the white factory floor areas. A LUXMATE daylight-based lighting control system and a TECTON LED IP50 continuous-row lighting system are responsible for delivering the required amounts of artificial light.



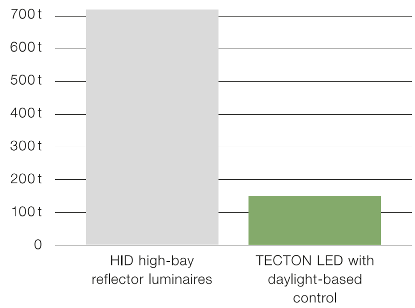
Ferrari s.p.a., Maranello | IT
Architects: Prospazio, Modena | IT
Lighting design: Arch. Francesca Nasi, Carpi | IT
Lighting solution: TECTON LED IP 50 continuous-row system, LUXMATE daylight lighting control system

1. CO_2 efficiency and cost efficiency

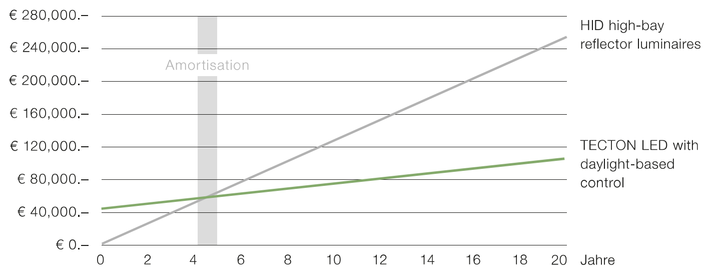
–79 % CO_2

LEDs and daylight slash energy consumption
Ten TECTON light lines up to 30 m long span the room. The 1.5 m long TECTON LED modules butt up against each other with no visible gap between luminaires. The continuous-row luminaires, each with power consumption of 53 W, embody the very latest LED technology: They consume roughly 55% less electricity than conventional metal halide lamps, even though their light output is twice as high. The lighting solution developed for Maranello is controlled by a LUXMATE PROFESSIONAL lighting management system. Daylight streaming in through the glazed roof and the daylight-based lighting control system ultimately slash power consumption by 79 percent. This will save 560 tonnes of CO_2 over the next 20 years.

CO_2 emissions over service life (20 years)



Amortisation 4,5 Jahre (total cost)



All potential savings and improvements were calculated using the online lighting analysis tool.
zumtobel.com/industriallighting

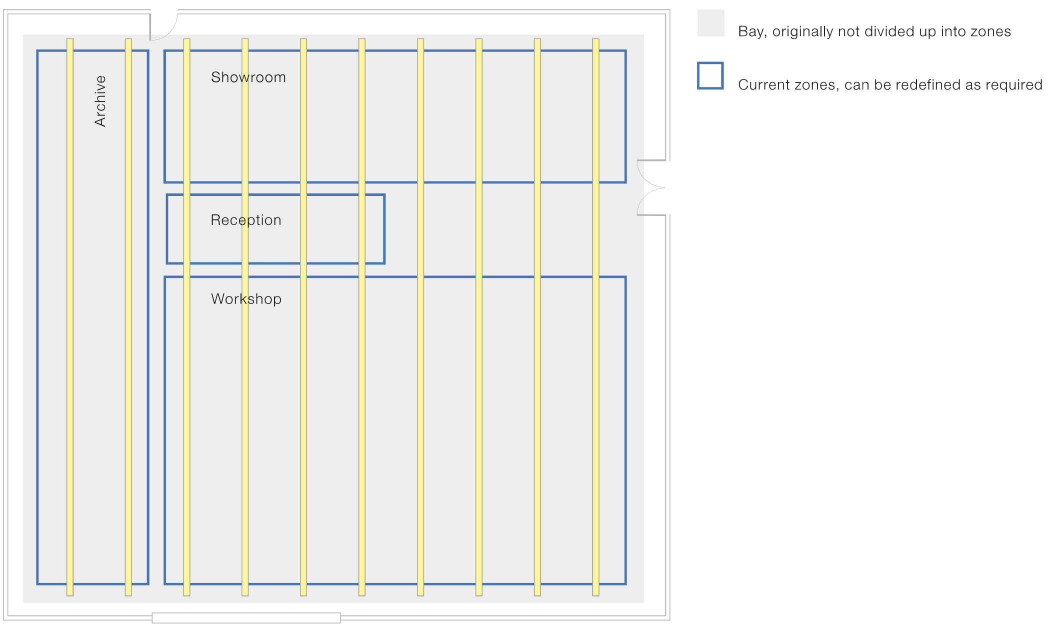
Detailed energy efficiency data was acquired using ecoCALC.
zumtobel.com/ecocalc

2. Flexibility

+10 %

Flexible use of space thanks to dimmable luminaires
A huge variety of tasks are performed at Ferrari: several restored sports cars are on show and visiting customers are welcomed in the 4 m high bays. Cars are inspected, examined and repaired in the workshop area. The original construction plans of every vehicle Ferrari has ever built are kept in the archives. If previous owners have made modifications or done conversions, vehicles will be restored to their original condition. Precise replicas can be produced in the foundry if necessary. Faced with performing such a wide variety of tasks, the general dimmability of LED luminaires makes it easy to adjust the lighting to cope with various activities and usage periods.

Usable area of car workshop 34.4 × 32 × 4 m (Length × Width × Height)



3. Productivity

+13 %

Peak performance with daylight and higher illuminance levels
Daylight streaming in through the new glazed roof, high lighting levels and excellent colour rendering all boost productivity and meet the exacting requirements associated with very demanding visual tasks involving precision work and fine details. The intensity of the artifi – cial lighting is continuously kept in balance with daylight brightness by the LUXMATE PROFESSIONAL lighting control system to ensure that workbenches are illuminated at a constant 1,000 lx at all times. The colour temperature (4,000 K) is ideal for precision craftsmanship and shows off the familiar red Ferrari livery to splendid effect.

Better performance thanks to more light

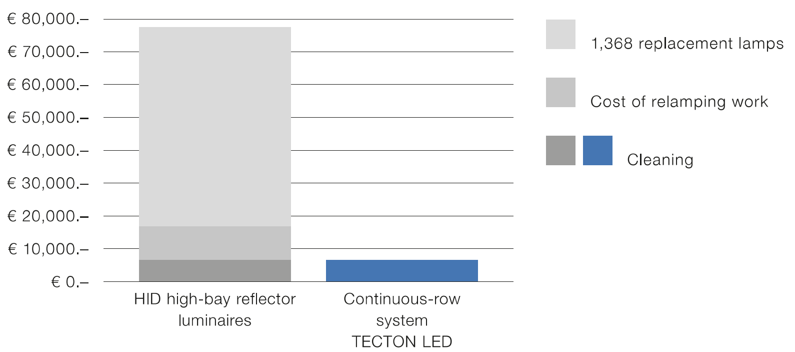
Reception 500 lx | Workshop 1,000 lx | Archives 500 lx | Showroom 1,000 lx

4. Reliability

+20 %

Maintenance-free lighting for general and emergency lighting
By switching over to a TECTON LED continuous-row system, the customer is saving a considerable portion of its operating costs. Lamp failures and the associated maintenance work and lamp costs are now a thing of the past. The lighting is also protected against dust by its IP 50 protection rating, which meets the recommended specifi cations in the industry standard. This extra reliability is achieved thanks to the LEDs long service life and a high IP 50 rating. When it came to the emergency lighting, ensuring that luminaires appeared as unbroken lines and avoiding the conventional interruptions associated with emergency lighting were decisive criteria. Every third TECTON LED luminaire is operated by a separate emergency power supply in order to prevent the lights going out in the event of a power failure.

Maintenance costs over service life (20 years)



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IP 50

Case Study 9 - Upgrade of Print Shop

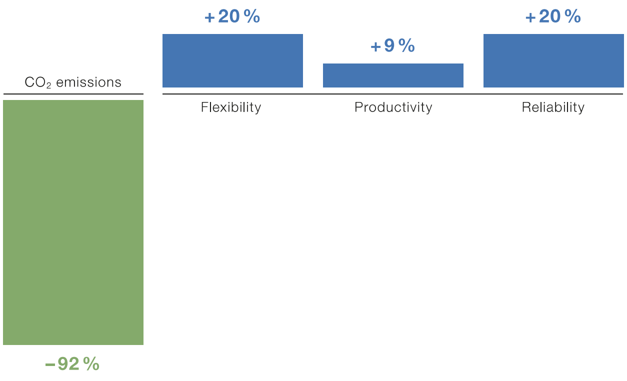
FERAG AG

Daylight-based lighting solution for a pleasant, bright lighting atmosphere in an industrial bay.

BEFORE 72.76 kWh/m²a

Sustainable renovation of lighting systems
Conveyor and processing systems for the print media industry are manufactured, cabled and tested in Ferag AG's machine shop. The lighting in the machine shop was ancient until just a few months ago. Unsatisfactory illuminance levels and frequent failures of lamps and ballasts disrupted workflows and entailed considerable costs. The lighting in the machine shop has been extensively renovated with a TECTON continuous-row lighting system and a LUXMATE DIMLITE lighting control system – and the resulting difference is quite striking: even demanding visual tasks are easier to accomplish at 500 lx, and the power consumed by lighting has been cut by more than 90 percent.

AFTER 5.96 kWh/m²a



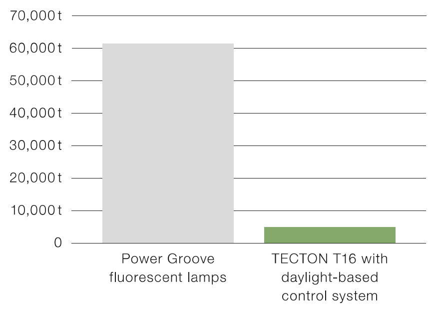
Ferag AG, Hinwil | CH
Lighting solution: TECTON 2/49 W T16 LDBX, DIMLITE multifunctional lighting management system

1. CO_2 efficiency and cost efficiency

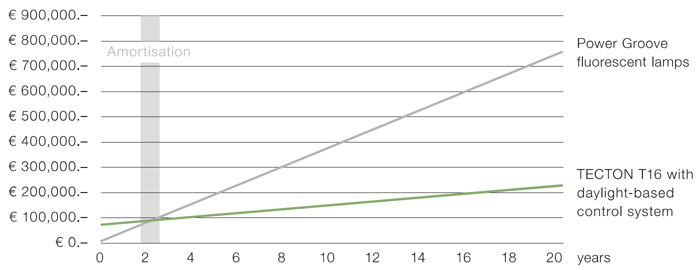
–92 % CO_2

Responsible use of energy
Investing in this new lighting solution with a dimmable TECTON T16 continuous-row system – combined and used with 2-channel lighting control units that are part of the DIMLITE multifunction lighting management system – will pay for itself in a very short time-scale: compared with the previous lighting that used Power Groove fluorescent lamps, this new lighting system will have paid for itself in 2.3 years. This refurbishment is set to save 56 out of 61 tonnes of CO_2 over the next 20 years. The new solution is therefore fully consistent with the fundamental principles of using resources carefully and making a commitment to sustainability that Ferag lives by.

CO_2 emissions over service life (20 years)



Payback period: 2.3 years (total cost)



All potential savings and improvements were calculated using the on-line lighting analysis tool.
zumtobel.com/Industriallighting

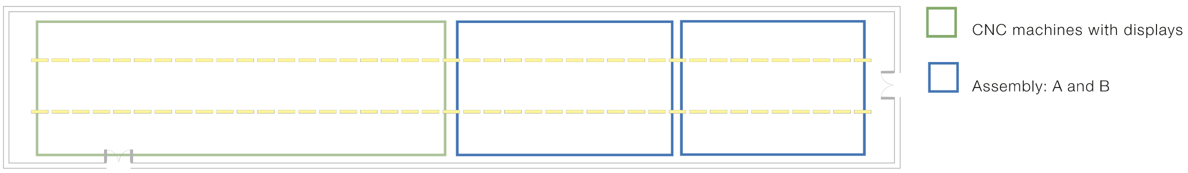
Detailed energy efficiency data was acquired using ecoCALC.
zumtobel.com/ecocalc

2. Flexibility

+20 %

Flexibility thanks to plug&play system and control system
Trunking which accommodates the 11-pole current conducting section is the key component of the TECTON continuous-row system. One click is therefore enough to make both the mechanical and electrical connections of the modules. Twin-lamp T16 luminaires with efficient RW reflectors were chosen for Ferag's 8.8 m high machine shop, bearing in mind the visual tasks in question. If any changes are made to the layout of the installed machinery, the illuminance level can be adjusted at any time by the DIMLITE lighting control system, or luminaires can be repositioned and supplemented with other luminaires quickly and easily as required. The best thing about it is that this daylight-based lighting solution consists of just three components: dimmable luminaires, a light sensor and DIMLITE multifunction lighting control units – one in each of the three areas.

Illuminance level adjusted according to visual task



3. Productivity

+9%

Working and feeling at ease
The various task areas in the machine shop and a desire to integrate daylight provided the starting point for lighting design work. There are CNC machines with displays in the front part of the shop and mechanical plant components and control devices are assembled elsewhere. The flexible TECTON continuous-row lighting system now provides precisely the right light for each of these activities: it delivers 500 lx for demanding visual tasks, the illuminance level is dimmed to 300 lx for assembly work – always depending on the amount of available daylight.

Better performance thanks to more light

CNC machines with displays 500 lx

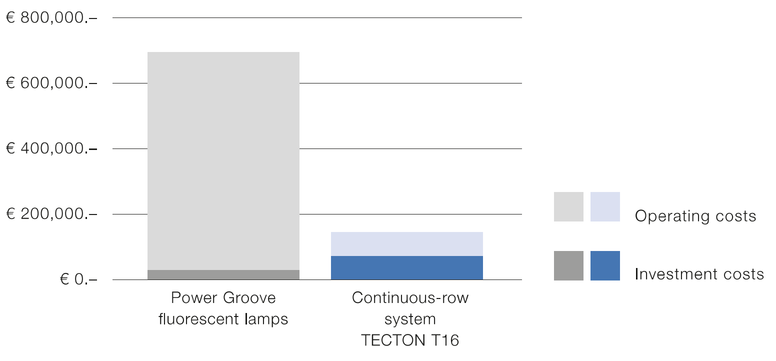
Assembly 300 lx

4. Reliability

+20 %

Advanced lamp and control technology
This extra reliability is reflected above all in lower luminaire failure rates. The service life of the Power Groove lamps that were previously used was relatively short and the associated maintenance work involved was correspondingly onerous. The TECTON continuous-row system installed for Ferag uses T16 fluorescent lamps to produce light. Thanks to this, downtimes are significantly less frequent and expenditure on relamping is also lower. The reliability of luminaires and lighting control systems, including all LUXMATE modules, is backed up by Zumtobel's five-year guarantee.

Comparison of investment and operating costs



Case Study 10 - Office Upgrade (CitySwitch)

EXERGY AUSTRALIA
6 STAR NABERS TENANCY – IT'S EASIER THAN YOU THINK

CITYSWITCH GREEN OFFICE

Exergy, a national energy efficiency consultancy, joined CitySwitch in November 2009. As the first CitySwitch Signatory to achieve a 6 Star NABERS Energy rating without GreenPower, Exergy's Canberra office is proof that outstanding energy efficiency is often not about the latest and greatest technologies, rather, it's about getting the simple things right.

Highly experienced in the improvement of energy efficiency for the built environment sector, Exergy is committed to reducing emissions in a replicable and cost-effective manner.

Lighting energy consumption is minimised through simple but effective zone-level manual controls for most areas, and occupancy sensors for the tea room and meeting room. Equipment power consumption is minimised through company-wide adoption of laptops and active utilisation of equipment standby/off modes. A sub-circuit monitoring system sends an alarm when usage is displaying a higher than usual pattern. Having the commitment from all staff members to contribute to a reduced energy footprint was the last step in achieving a 6 Star NABERS tenancy.

GOALS

- Maintain the 6 star NABERS Energy rating without GreenPower
- Further reduce emissions towards a net-zero target
- Manage rating risks through ongoing measurement and verification via online monitoring system

Signatory status

Date joined CitySwitch	November 2009
Tenancy size	294 sqm
NABERS commitment rating	★★★★★★
NABERS rating	★★★★★★
Website	www.xgl.com.au

Key outcomes

Annual energy and CO_2 saving	34,300 kWh* or 34 tonnes of CO_2-e**
Annual financial savings	$7,700*
Technology	Occupancy-based lighting controls, laptops, utilising equipment standby, cloud IT services, multifunction device for printing, photocopying, faxing and scanning.

** compared to an average NABERS 2.5 star tenancy*
***July 2013 NGA Factors were used to estimate emissions*

EXERGY

> "As an energy efficiency nerd and as a Scotsman, the Exergy Canberra office fulfils all my criteria: it uses very little energy and it cost me very little to achieve. What can be better than that?"

Dr. Paul Bannister, Managing Director
Exergy Australia Pty Ltd

CITYSWITCH GREEN OFFICE

Energy efficiency made simple... and cheap

There is often a misconception that great energy efficiency can only be achieved through capital investment or significant behavioural changes. However, in considering more complex ideas, often the more obvious savings opportunities are overlooked. Exergy has always prioritised solutions that make business sense—measures that are cheapest and easiest to implement.

Lighting control – turn it off

Exergy discovered that lighting made up around 40 per cent of their overall energy consumption. The best way to reduce lighting consumption is to minimise its use. While upgrading to LED lighting is a good idea, it can be capital intensive. Adopting simpler solutions such as occupancy-based lighting in the general office and manual on/auto-off lighting in more occasional areas (e.g. tea/meeting rooms) provided Exergy almost immediate payback. Finer zoning of lighting controls and reductions to the lighting power density (W/m^2) through luminaire reconfiguration and de-lamping further enhanced savings. Exergy also ensure lights are clean and dust free which allows more light to be emitted.

Computers – efficient technology and cloud services

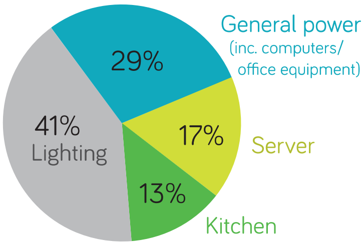
A significant portion of the tenancy energy consumption was attributable to IT equipment. By ensuring that all staff members use laptops and LED monitors with active standby, the IT footprint of PCs now accounts for approximately 20 per cent of the total tenancy footprint. By migrating parts of the IT services to the cloud, Exergy also reduced its server room footprint by 50 per cent going from around 5.5 kWh per day to 2.7 kWh per day.

Other equipment – scheduling and user awareness

Using the principle of keeping only essential equipment, the Canberra office peripheral now consists of a single multi-function printer with intelligent power management features and default double-sided/two-up printing that helps to keep consumption to a bare minimum. This printer accounts for approximately 30 per cent of overall office equipment energy use.

In the kitchen (which represents 13 per cent of total energy demand), the chilled/hot drinking water system is scheduled to operate on weekdays only and the coffee machine is always switched off at the end of every day.

Total (kWh)
Canberra office energy use breakdown



Get involved

Exergy is part of a national network of businesses that, with the help of CitySwitch, are playing an important part in reducing the carbon emissions of our cities and demonstrating a high level of environmental leadership and action.

Australian Government
Department of Industry

This Activity received funding from the Department of Industry as part of the Energy Efficiency Information Grants Program.

CitySwitch Green Office is Australia's flagship tenant energy efficiency program. Run in partnership between local and state governments, CitySwitch is a growing network of business leaders committed to addressing their environmental impact. **cityswitch.net.au**

Appendix 5 - LED Buyers Guide