CARBON TRUST

Lighting

Bright ideas for efficient illumination

enter

Contents

Introduction

Lighting is something that most of us take for granted. How often do we question the amount or quality of that light? Or how much it costs to run and maintain?

This guide sets out to explain the basics of artificial lighting; the equipment, design principles and the effect it has on our work and leisure.

It is intended to inform a wide range of readers about the importance of light; both natural and artificial. In particular, it will help you to understand how to choose artificial lighting equipment that will deliver the most energy efficient solutions without compromising on quality.

A better understanding of good lighting practices helps when considering its direct and indirect costs.

A bad lighting scheme is a complete waste of energy and is not sustainable. This guide will explain why and help you to improve the lighting where you work, saving money and carbon.

Lighting uses some 20% of the electricity generated in the UK. With the majority of current lighting systems still reliant on inefficient light sources there remains significant potential to move to low energy lighting such as LED.

The need to reduce carbon emissions presents an opportunity to make lighting more efficient and more effective; so long as the right decisions are made when selecting new lighting.

Did you know?

Replacing legacy light sources with LED technology can reduce lighting energy costs by 70%

Supplied courtesy of Zumtobel

Importance of light

The quality of artificial lighting is one of the most important influences on performance in the work place. Some 80% of our sensory input at work comes through our eyes; compromising our vision is therefore not an option when considering energy efficiency measures.

Health & well-being

Low lighting levels can cause discomfort for employees if they are insufficient to easily complete the tasks required.

Glare and flicker can have an even more disruptive effect, including triggering headaches and eyestrain, especially for desk-based tasks.

Lighting levels also have an impact on health and safety at work. This is especially pertinent for sectors where risk of accidents is high, such as the manufacturing, construction and catering industries.

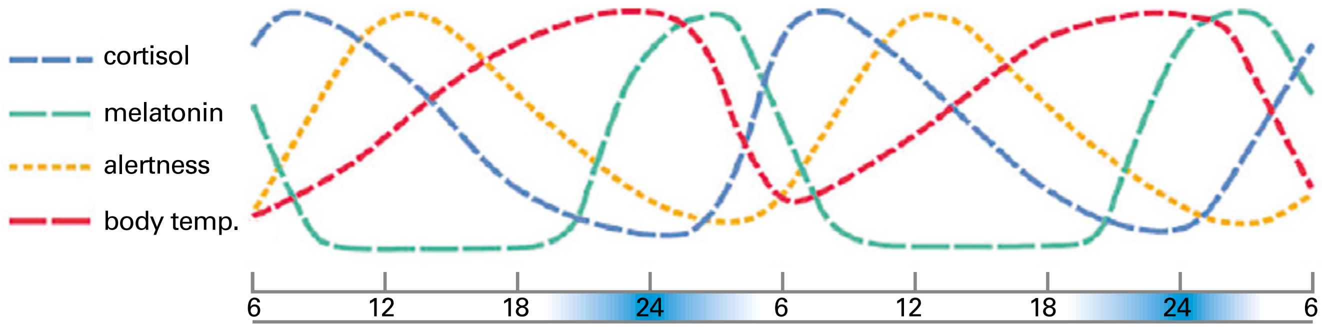
It is vital to provide good quality lighting that is designed to match the tasks being undertaken and to respect the needs of the occupants in a space.

Circadian rhythm

The non-visual receptor in our eyes responds to light and controls our levels of the key hormones: cortisol, melatonin and serotonin. Cortisol triggers our levels of alertness and energy; high levels of melatonin encourage us to sleep; and serotonin is our 'happiness' hormone, so a deficiency of serotonin will adversely affect our mood. Serotonin is produced by the brain when melatonin levels are low.

Daylight regulates these hormones, to ensure a good balance throughout the day. For office workers, good lighting design is required to have the same effect.

Figure 1: Human circadian rhythm

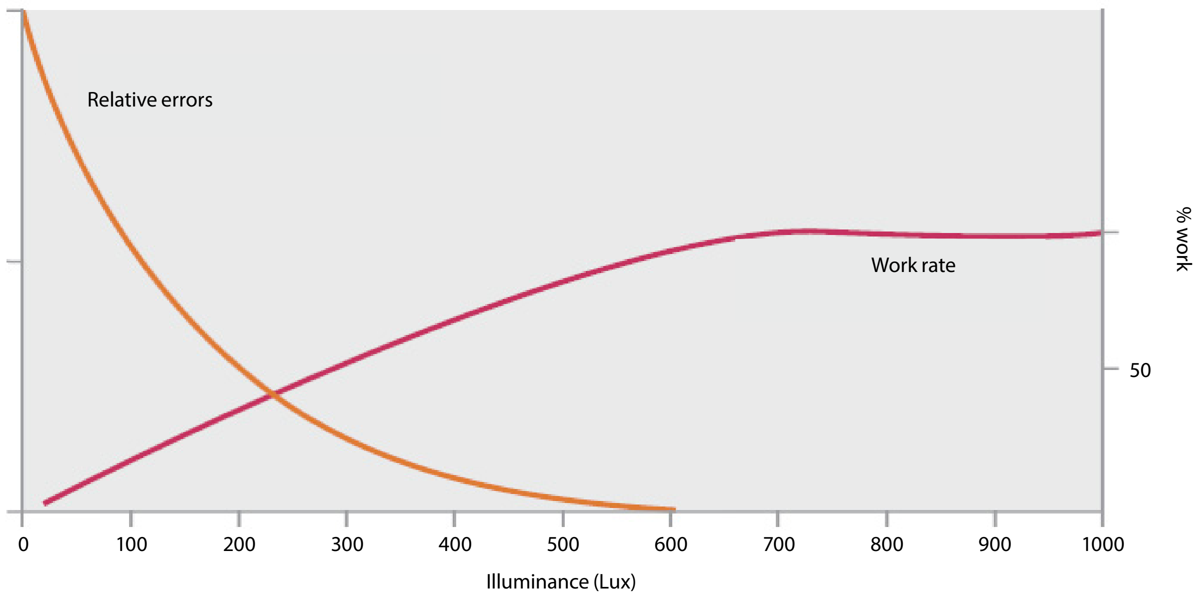


Productivity

By getting the lighting right, staff will be more comfortable in their working environment and they can become more productive.

Research has shown that the amount of errors that employees make is reduced when lighting levels are increased.

Figure 2: How illuminance affects work rate and relative errors



A well-designed energy efficient lighting scheme can reduce the amount of electricity you consume, whilst increasing the quality of light to retain or even improve the health, well-being and productivity of your employees.

Understanding light

Light travels at approximately 700 million miles per hour and from leaving the sun, it takes around eight minutes to reach the surface of the earth.

Light is electromagnetic radiation. Light visible to humans though is only a tiny proportion of the whole electromagnetic spectrum as shown in Figure 3. In fact the visible part of the spectrum ranges from just 350nm-780nm – just 400nm out of over 5 million!

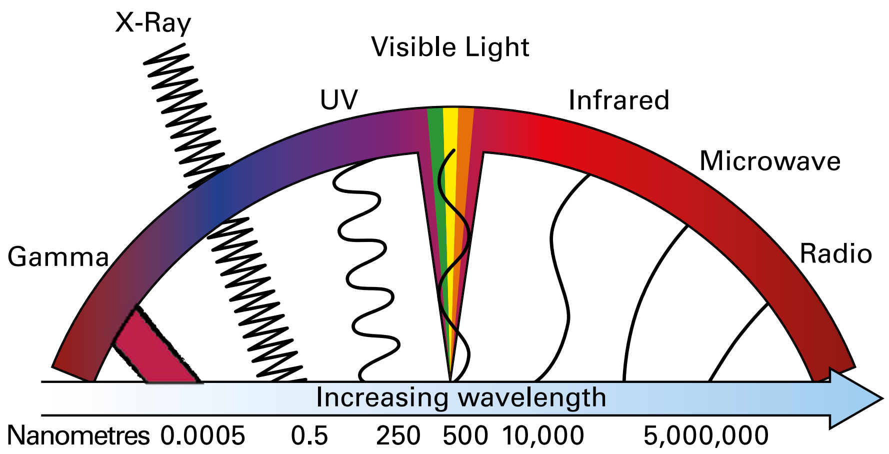
Just outside of the visible part of the spectrum lie infrared and ultra-violet light. These terms are probably familiar and with special equipment, we are able to 'see' these areas of the spectrum too.

Our eye-brain system is a highly sophisticated system of data transfer. When light enters the eye, we have a number of receptors which absorb the information they are receiving and pass information to our brain.

We have three receptors in our eye: rods, cones and ganglion cells. Rods detect shape and form but are monochromatic. Cones enable us to see and distinguish colour so someone who is referred to as 'colour-blind' has a deficiency of cones. They can usually see colour but have difficulty in distinguishing between some colours, especially red and green.

The third receptor, the ganglion cell, doesn't aid our vision but controls our circadian rhythm, our daily cycle of awake and asleep.

Figure 3: Electromagnetic spectrum



Understanding light

Lighting levels

The demand for light varies according to the people who are in the space and what tasks they are completing.

Who is using the space? The reason it is important to know this is because our eyesight deteriorates with age. Irrespective of other eye conditions, the visual ability of a 10-year old child is hugely heightened when compared to that of a 50-year old. Because of this, younger people need less light to perform the same task.

What are they doing? Our demand for light varies with what we are doing. Walking down a corridor is a much simpler visual task than reading a book. In an office, we might need less light to look at a computer than to read a printed report.

Table 1 below can be used as a guideline to determine required lighting levels. Detailed guidance for the lighting level required for different tasks can be found in the Society of Light and Lighting's Code for Lighting.

Table 1: Required lighting levels for various activities

Illuminance (lux)	Activity	Area
100	Casual seeing	Corridors, changing rooms, stores
150	Some perception of detail	Loading bays, switch rooms, plant rooms
200	Continuously occupied	Foyers, entrance halls, dining rooms
300	Visual tasks easy/moderate	Libraries, sports halls, lecture theatres
500	Visual tasks moderate/difficult	General offices, kitchens, laboratories, retail
750	Visual tasks difficult	Drawing offices, meat inspection, chain stores
1,000	Visual tasks very difficult	General inspection, electronic assembly, paintwork, supermarkets
1,500	Visual tasks extremely difficult	Fine work and inspection, precision assembly
2,000	Visual tasks exceptionally difficult	Assembly of minute items, finished fabric inpsection

Deciphering lighting terminology

Luminous flux (lumens; lm):
The amount of light produced by a lamp.

Efficacy (lumens per watt; lm/W):
The ratio of light emitted by a lamp to the power consumed by it, that is, lumens per Watt.

Illuminance (lux; lx):
The amount of light falling on an area, measured in lux. One lux is equal to one lumen per square metre.

A full list can be found in the glossary.

Understanding light

Colour temperature and colour rendering

There are two very important aspects of light relating to colour which are often referred to but not always understood: colour temperature and colour rendering. They are both properties of lamps but have very different meanings and implications.

Colour temperature

Also known as colour appearance, the colour temperature is the colour of 'white' the light appears. It is measured in Kelvin, and ranges from 1,800K (very warm, amber) to 8,000K (cool). 6,500K is daylight.

There are many colours of 'white' available. For general use these are: a warm white (2,600 to 2,700 degrees Kelvin), a medium white (3,000 to 3,500 degrees Kelvin) and a cool white (4,000 degrees Kelvin). The colour temperature of a light can have a significant effect on the space: higher colour temperatures feel more clinical, whereas lower colour temperatures create a more ambient environment.

Initial models of LED lighting were criticised for producing cool, bright lights, but technological developments and a better understanding of lighting design mean that LED products can now be produced with much warmer colour temperatures, equivalent to temperature levels of conventional lighting sources.

Colour rendering

The colour rendering index has been defined by the CIE (Commission Internationale de l'Eclairage or International Commission on Illumination) and determines how accurately colours are represented by a light source.

Good colour rendering equates to a high CRI (CRI 100 = daylight), poor colour rendering equates to a low CRI. A practical example of CRI is the low colour rendering of streetlighting. Conventional low pressure sodium streetlighting has a low CRI, meaning that even bright red objects appear a dull brown or yellow colour.

The majority of indoor lighting schemes would be expected to meet a CRI of 80 or higher for most working activities. CRI is specified in Ra in product specifications, as shown in the figure below.

Figure 4: Colour temperature

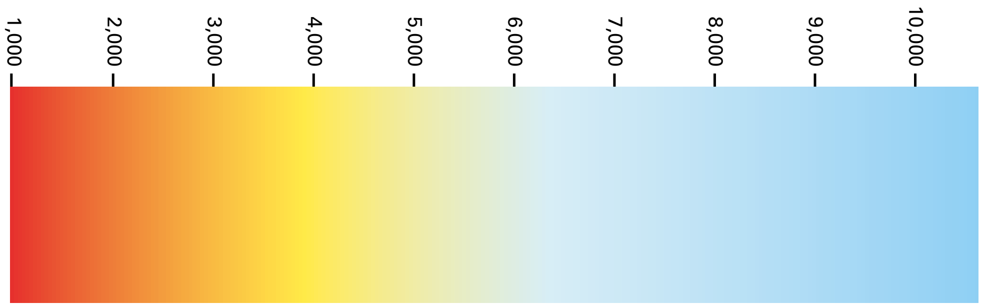
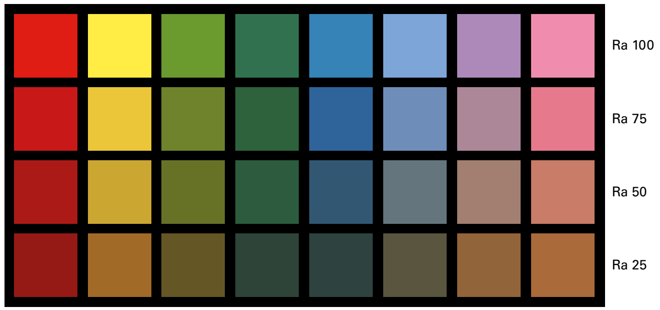


Figure 5: Example of the effect of different Ra levels on the appearance of various colours



Understanding light

Glare

Glare is typically caused by 'excessive and uncontrolled brightness', whether that is from sunlight or artificial lighting. Discomfort from glare can be due to the source itself being in the direct line of vision, or from the source reflecting from buildings, windows or computer screens. All of these forms of glare can be distracting for employees and can make it difficult for them to easily see and complete the task in hand.

A well designed lighting system will minimise glare and ensure visual comfort. European Standard EN 12464-1 regulates the lighting of indoor workplaces, so should be taken into account at design stage to avoid having to retrofit glare reduction after installation.

Unified Glare Rating (UGR) is used to evaluate glare and guidance is provided in Table 2 below.

Table 2: UGR Limits Specified in EN 12464-1 "The Lighting of Workplaces"

≤ 16	Technical drawing or fine detail
≤ 19	Typical office environment, reading, writing, computer work
≤ 22	Light industry and craft work
≤ 25	Heavy industry
≤ 28	Large public spaces, foyers etc.

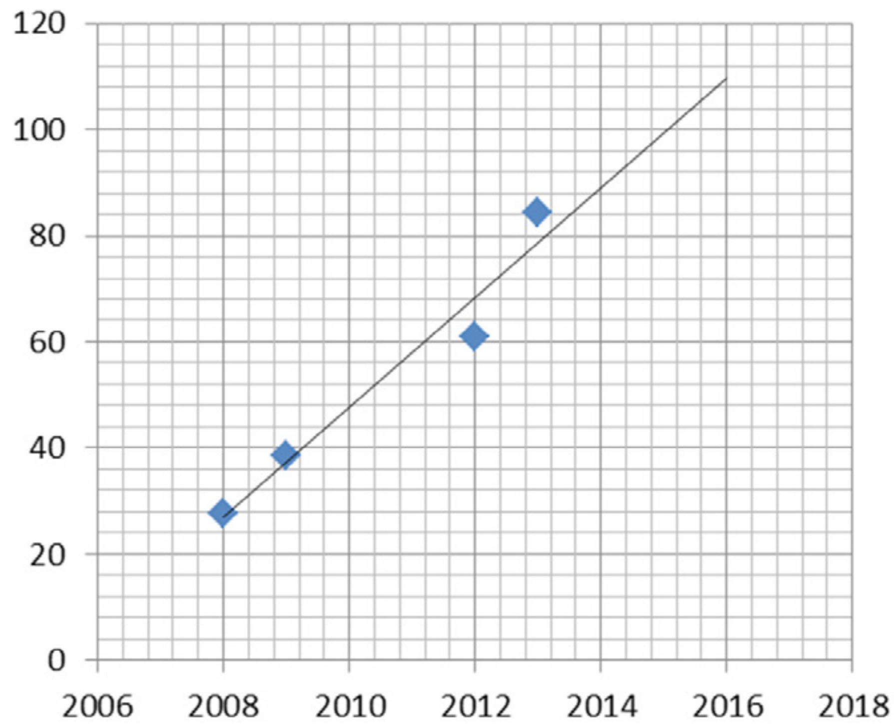
Understanding lighting technology

Electric lighting has been in use since the early 1800s and within the past 10 years a step change in the technology has occurred. The advent, development and widespread adoption of LED lighting technology has created significant opportunities to reduce lighting energy use, minimise energy costs and decrease associated carbon emissions.

The need for lighting is ubiquitous across all businesses and industries. In this section we shall review how LED technology and the variety of legacy light sources operate, examine how light sources are packaged into luminaires and how they are supplied with power.

Choosing the most effective and efficient lighting solution for your business will provide long term savings.

Figure 6: Extrapolation of mean test data, in luminaire lumens per Watt, for white LEDs tested for the Carbon Trust



Understanding lighting technology

Lamps

Light sources are called lamps, rather than light bulbs, and each lamp type has different characteristics which affect where and when they should be used.

The most important three characteristics of lamps are the efficacy (how efficient the lamp is), its expected lifetime and its colour rendering ability.

Artificial light can be created in different ways:

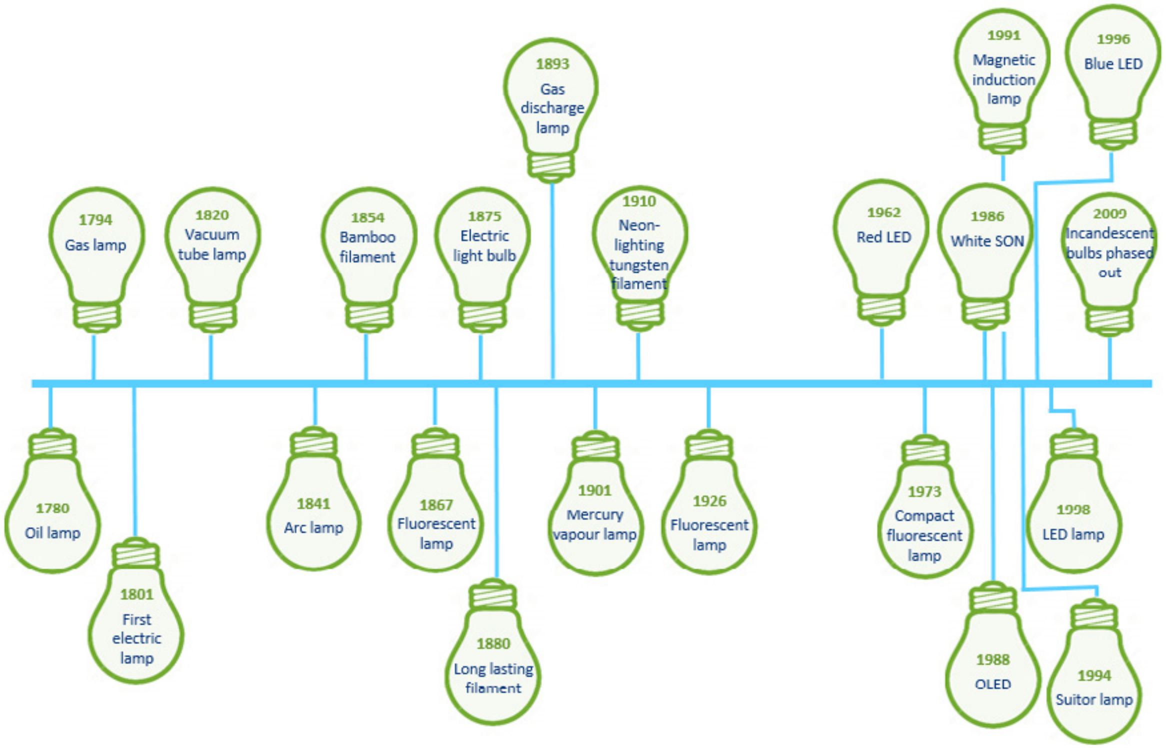
Semiconductor: light being generated at the junction of a semi-conductor (e.g. LED).

Discharge: the generation of light occurs within a gas filled envelope that is driven by an electric circuit (e.g. Fluorescent).

Incandescent: where light is created by passing an electrical current through a wire so that it glows white hot (e.g. Tungsten).

Although there are some other methods, these cover over 99% of currently used lamp technologies.

Figure 7: Illuminating the past



Lamp lifetime, efficacy and colour rendering have all increased significantly alongside the invention of new lamp technologies. The following pages give an overview of the typical characteristics of each lamp type, clearly showing a steady improvement from incandescent to LED.

Understanding lighting technology

Light Emitting Diodes (LEDs)

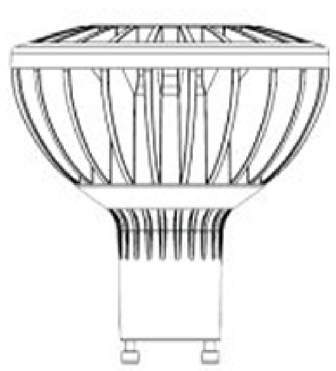
LEDs were developed for use in electronics over 60 years ago, and in the last ten years have become the light source of choice, providing illumination at a fraction of the cost of legacy sources.

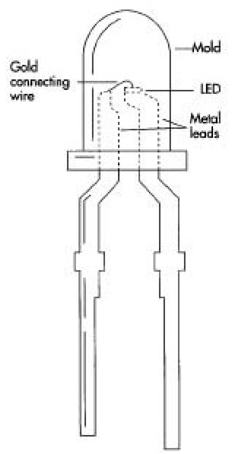
LEDs have the highest efficacy and lamp life of all widely used lighting types, are easy to control and have no warm up period.

The cost of LEDs has come down significantly in recent years and technological developments have improved light output, efficacy and reliability. These factors have made LED technology the mainstream solution for the vast majority of lighting applications in the UK. LED lighting sales have now overtaken legacy lighting sales in the commercial market and this progress is expected to continue, with manufacturers turning their product development focus away from legacy light sources towards LED innovation.

Did you know?

A new generation of LED lighting exists which will soon be viable for commercial use as a lamp technology: organic light emitting diodes (OLEDs). OLED lighting is composed of thin organic layers sandwiched between two electrodes and will be able to provide incredibly thin and flexible lighting solutions.





Application

LED lighting is now considered the light source of choice for the vast majority of sectors and applications

CCT (K)	CRI (Ra)
2,700-8,000	65 - 97
Efficacy (lm/W)	**Lamp life (hours)**
70-150+	25,000-75,000+

Understanding lighting technology

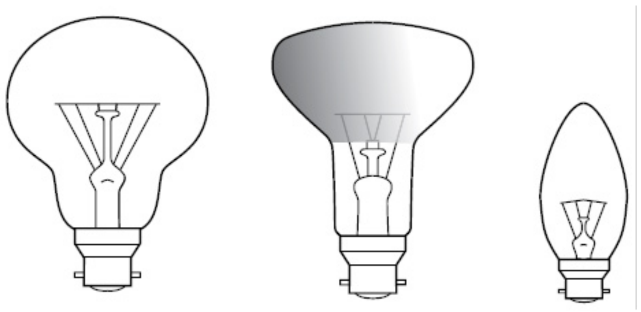
Legacy lamps: incandescent

Due to inefficiency, incandescent tungsten lamps began to be phased out by the UK Government in 2009, followed by the phase out of halogen lamps in 2016 as stipulated by an EU Directive. The aim of the legislation being to minimise the use of the inefficient sources.

Incandescent tungsten filament

Invented well over 100 years ago, incandescent tungsten filament lamps are currently being phased out of the market because they are inefficient, generate unwanted heat and are expensive to run.

These lamps have a short lifetime but do offer good colour rendering. They are also – in the most part – easily dimmed.

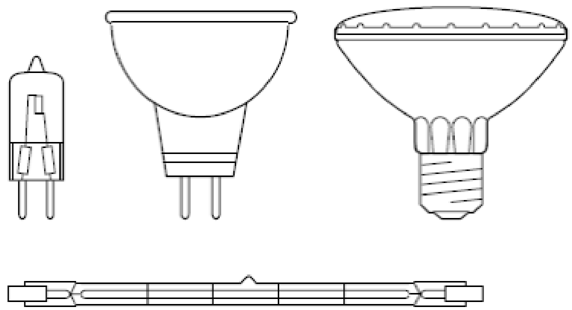


Application	CCT (K)	CRI (Ra)
Used extensively throughout homes and businesses. Currently being ‘phased-out’.	2,500 - 3,000	100
	Efficacy (lm/W)	**Lamp life (hours)**
	5-20	1,000

Tungsten halogen / quartz lamps

Tungsten halogen or quartz lamps are incandescent lamps with the addition of a small amount of a halogen, such as iodine or bromine.

The halogen gas and the tungsten filament produces a halogen cycle chemical reaction which re-deposits evaporated tungsten back onto the filament, increasing its life and maintaining the clarity of the envelope. The efficacy is increased slightly through this process, though all other key characteristics remain the same.



Application	CCT (K)	CRI (Ra)
Widely used in hospitality, retail, display areas.	3,200	100
	Efficacy (lm/W)	**Lamp life (hours)**
	15 - 24	2,000

Understanding lighting technology

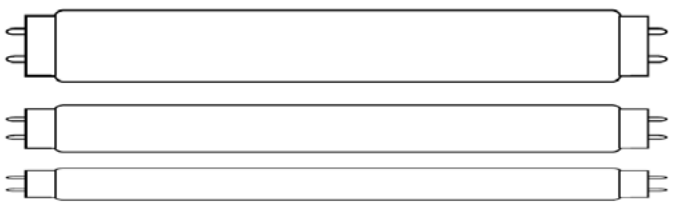
Legacy lamps: discharge

Commonly used in commercial applications, discharge lighting includes a range of lamps that use glowing gas discharges and phosphors to create light. Discharge lighting is characterised by its long strike time, varying from a few seconds to several minutes to 'warm up' to full brightness. In some settings non-LED lamps are still appropriate, but effective LED lighting has now been developed for most applications.

Tubular fluorescent lamps

A low pressure mercury-vapour gas-discharge lamp that uses fluorescence to produce visible light. An electric current in the gas excites mercury vapour and produces short-wave ultraviolet light that causes a phosphor coating on the inside of the bulb to emit photons.

The spectral power distribution is improved through use of multiple phosphors. Fluorescent lighting is also the most easily controlled of this type of lamp, as it can be switched on and off quite readily, and with the right control gear can be successfully dimmed. Three types exist: T12, T8 and T5, increasing in efficacy as they decrease in diameter.

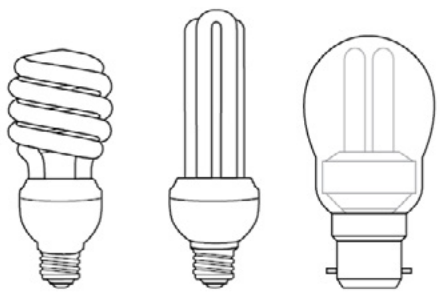


Application	CCT (K)	CRI (Ra)
Offices, commercial buildings & low bay industrial.	2,700 - 6,500	>80
	Efficacy (lm/W)	**Lamp life (hours)**
	60 - 105	10,000 - 20,000

Compact fluorescent lamps (CFLs)

Designed to replace an incandescent lamps; some types of CFLs fit into light fixtures formerly used for incandescent lamps. Most require a few minutes of warm-up time to reach full output.

Integrated lamps combine the tube and ballast in a single unit and non-integrated CFLs have the ballast permanently installed in the luminaire. Other key characteristics remain the same as tubular fluorescent lamps.

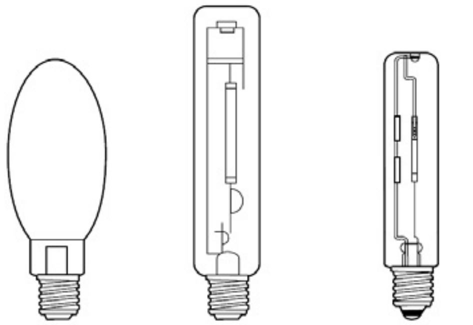


Application	CCT (K)	CRI (Ra)
Used extensively throughout homes and businesses.	2,700 - 4,000	>85
	Efficacy (lm/W)	**Lamp life (hours)**
	45 - 80	6,000 - 15,000

High pressure sodium lamps (HPS/SON)

A gas-discharge lamp that uses sodium in an excited state to produce light, these lamps are easily identified as the bright golden street lights on many of our motorways.

Due to a long warm-up and restrike time this lamp type is not suitable for frequent switching, although with the right control gear they can be dimmed to a limited degree.



SON/E (Elliptical) SON/T (Tubular) White sodium

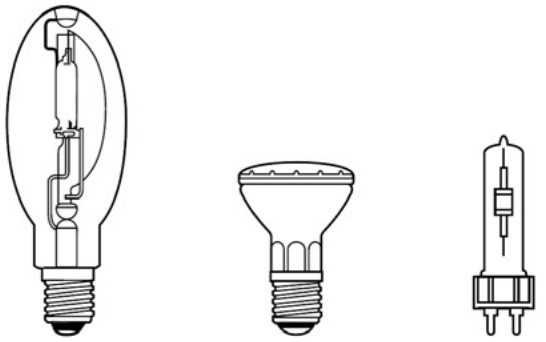
Application	CCT (K)	CRI (Ra)
Industrial lighting including high bay applications, flood lighting and street lighting.	2,000 - 2,700	25 - 85
	Efficacy (lm/W)	**Lamp life (hours)**
	85 - 150	12,000 - 30,000

Metal halide lamps

This group of lamps offers a highly efficient source, typically 80 lumens per watt, in a very large range of power ratings, making it a versatile light source.

Metal halide lamps are a type of high-intensity discharge (HID) gas discharge lamp that produces light by an electric arc through a gaseous mixture of vaporised mercury and metal halides.

Many types have long warm-up and re-strike times of up to ten minutes. 'Hot re-strike' models reduce this time, though are less efficient.



Elliptical CDM/R CDMT

Application	CCT (K)	CRI (Ra)
Industrial lighting including high bay applications, flood lighting and street lighting.	3,000 -6,000 +	65 - 93
	Efficacy (lm/W)	**Lamp life (hours)**
	50 - 113	6,000 - 20,000

Understanding lighting technology

Relative performance of LED sources

Table 3: Relative performance of LED sources

	Lamp Life	Colour Temperature	Colour Rendering	Efficacy
Standard Incandescent	2,000 - 3,000 Hours	2,500 - 3,000K	100 Ra	5 - 20 lm/W
Tungsten Halogen	2,000 Hours	3,200K	100 Ra	15 - 24 lm/W
Tubular Fluorescent	10,000 - 12,000 Hours	2,700 - 6,500K	>85 Ra	60 - 105 lm/W
Compact Fluorescent	6,000 - 15,000 Hours	2,700 - 4000K	> 85 Ra	45 - 80 lm /W
High pressure sodium	12,000 - 30,000 Hours	2,000 - 2,700K	25 - 85 Ra	25 - 85 lm/W
Metal Halide	6,000 - 20,000 Hours	3,000 - 6,000K	65 - 93 Ra	50 - 113 lm/W
LED	25,000 - 75,000+ Hours	2,700 - 8,000K	65 - 97 Ra	70 - 150+ lm/W

LED lighting can match the colour temperature range and colour rendering standards of legacy lighting whilst providing far superior lamp life and efficacy.

Understanding lighting technology

LED light fittings

The LED light source needs to be packaged into a luminaire to provide useful light output for the wide range of available applications. As with legacy lighting, LED luminaires vary in style, shape, size and importantly light output. As can be seen below there are a number of key features which are common to all LED luminaires.

LED chip

The fundamental semiconductor technology that operates as the light source.

Heat sink

Although LED technology does not emit heat in the form of infrared radiation (the reason for the inefficiency of incandescent lighting), heat is still produced internally by semiconductors. It is essential for this heat to be managed effectively, as when the operating temperature rises above the maximum level, the lifespan of the LED is reduced. To keep temperatures low, LEDs are designed with an in-built 'heat sink' through which excess heat is conducted and dissipated into the air.

Lens

A small primary optic is placed directly over the LED, however the light output lacks focus. The lens focuses the light from the primary optic to control beam angle, management glare and provide better light distribution.

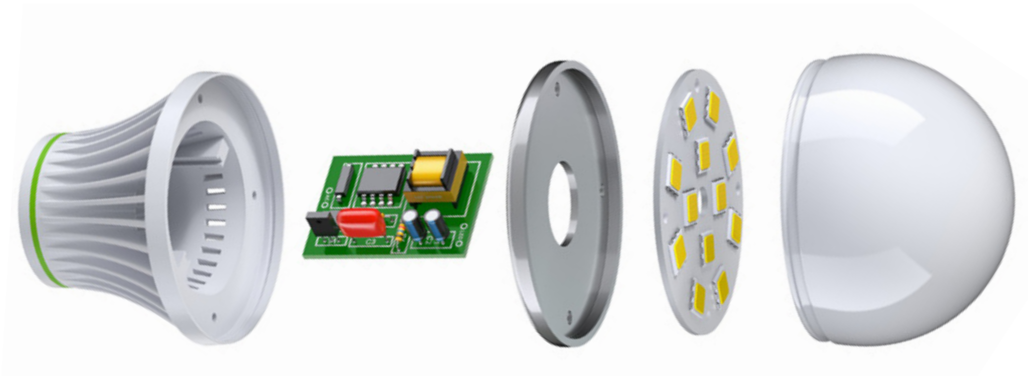
Housing

The body of the luminaire is designed to meet the needs of the specific application. It may include reflectors or simply rely on the lens to provide the required light output.

LED driver

As detailed in the 'Control gear' section on page 21, the driver ensures that the correct voltage and current are provided to the LED chip, with much lower voltages than UK mains used by the chip.

Figure 8: Components of LED lighting



Components of LED lighting technology

For LED lighting solutions all components are commonly integrated and sealed into a single luminaire.

As can be seen in Figure 8, the chip board is often mounted directly on the heat sink, with the LED driver providing the power supply to the chip. The lens and housing then focuses the light output for the required application.

Understanding lighting technology

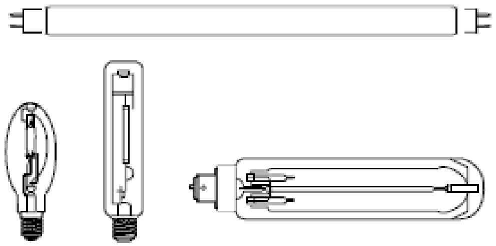
Legacy light fittings

The three main components of a legacy light fitting are lamps, control gear and luminaires. All three components have an effect on the efficacy and lifetime of the fitting, as well as the amount of light that the fitting provides as a whole.

Components of legacy lighting technology:

Lamps

Light sources are called lamps, rather than light bulbs, and each lamp type has different characteristics which affect where and when they should be used.

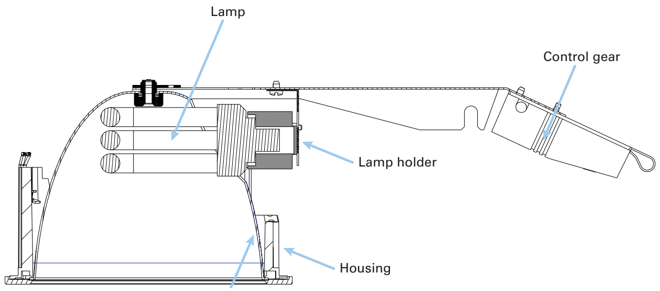


Control gear

Most lamps require an additional piece of equipment to help them run; sometimes called a ballast or driver, but widely described as control gear.

Luminaires

Lamps and control gear are housed in fixtures called luminaires, alongside the housing, lamp holder and reflector.



In most luminaires for legacy lamp technology, not all of the light emitted by the lamp is emitted by the luminaire. This is due to losses caused by inter-reflection and absorption.

The luminaire performance can be measured by comparing the total light emitted by the luminaire with that of the bare lamp. This is referred to as the Light Output Ratio (LOR). The higher the LOR, the better the luminaire performance. Each luminaire will have different performance characteristics depending upon the optical design and quality of materials used by different manufacturers.

Some types of luminaires using legacy lamps make use of reflective materials to increase the light output of the lamp, whilst others use diffusers to cover the bare lamp to reduce glare.

Material within luminaires which directs the light beams can vary in its reflecting ability from 0.5 for a satin chrome material to 0.9 for an aluminium material with a silver coating so the LOR in luminaires using these materials will vary enormously.

Figure 9: Reflective material used in a luminaire to increase light output

Understanding lighting technology

Common luminaire types

The most typical luminaires used in commercial properties are:

- Modular
- Downlights
- Pendants
- Spotlights
- Wall lights

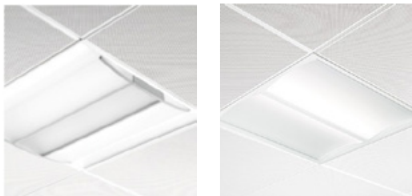
The following pages provide a summary of both common legacy and LED luminaires types, their typical performance and common application areas.

LED technology can now be applied in every application and bespoke solutions are available to meet specific requirements with regard to glare, colour temperature, colour rendering and more general aspects such as ingress protection.

Figure 10: Modular luminaires with reflector

Mounting:	Surface, Recessed
Lamp types:	Fluorescent
LOR:	0.6 – 0.9
Applications:	Office, IT areas

Figure 11: Modular luminaires with diffuser



Mounting:	Surface, Recessed
Lamp types:	Fluorescent, LED
LOR:	0.5 – 0.9
Applications:	Office, Retail

Figure 12: Downlights

Mounting:	Recessed
Lamp types:	CFL, Tungsten halogen, Metal halide, LED
LOR:	0.6 – 0.9
Applications:	Circulation, Retail

Images courtesy of Zumtobel and Thorn Lighting

Figure 13: Pendants

Mounting:	Suspended
Lamp types:	Fluorescent, Metal Halide, HPS, LED
LOR:	0.5 – 0.9
Applications:	Office, Industrial, Retail

Figure 14: Spotlights

Mounting:	Surface, Track
Lamp types:	Metal Halide, LED Tungsten Halogen
LOR:	0.8 – 1.0
Applications:	Retail

Figure 15: Wall lights

Mounting:	Recessed, Surface
Lamp types:	CFL, Metal halide, LED
LOR:	0.4 – 0.6
Applications:	Office, Circulation

Images courtesy of Zumtobel and Thorn Lighting

Understanding lighting technology

Drivers and control gear

In a similar way to laptop power supplies, the control gear or driver transforms the 230V mains electrical supply into one which the luminaire requires. This protects the luminaire, can extend lamp life and can facilitate dimming. In legacy light sources in particular the control gear can account for significant energy losses, beyond the rated wattage of the luminaire, often of 15% or more.

LED

For LED lighting, LED drivers integrated into the light fitting deliver the correct voltage and current to the LED devices and enable further controllability through dimming. The quality of an LED driver can have a significant effect on the LED performance.

Unless you are involved in the detailed design of the lighting system you can rely on your supplier to select the appropriate drivers to meet the needs of you lighting installation.

Legacy Light Sources

For legacy lamp sources, early control gear used wound components and was referred to as 'magnetic'. This was very inefficient and although the technology improved with time, losses are significant at around 15%. In practical terms this means that a 400W metal halide lamp operating with a magnetic ballast may require up to 460W to run. A further drawback to magnetic gear is that it causes lamp flickering (100Hz) which induces headaches for some people.

The majority of legacy lamps now use electronic control gear. The electronic controls improved the quality of artificial light, by driving the lamp at a higher frequency with no perceptible lamp flicker. High frequency electronic control gear is also more efficient producing more light with less power than previous magnetic designs.

Did you know?

The voltage characteristics of an LED change with temperature. As the temperature increases the voltage across the diode decreases – leading to current increases. The LED driver modulates its output to ensure that current levels are regulated across the temperature profile of the LED.

Figure 16: LED driver

Image courtesy of Zumtobel

Figure 17: Magnetic and electronic control gear

Image courtesy of Philips lighting

Opportunity for reduction

Lighting uses around 20% of the electricity generated in the UK. With the majority of current lighting systems still reliant on inefficient light sources there remains significant potential to move to low energy lighting such as LED.

The need to reduce carbon emissions presents an opportunity to make lighting more efficient and more effective; so long as the right decisions are made. Reducing lighting electricity consumption is possible on any budget:

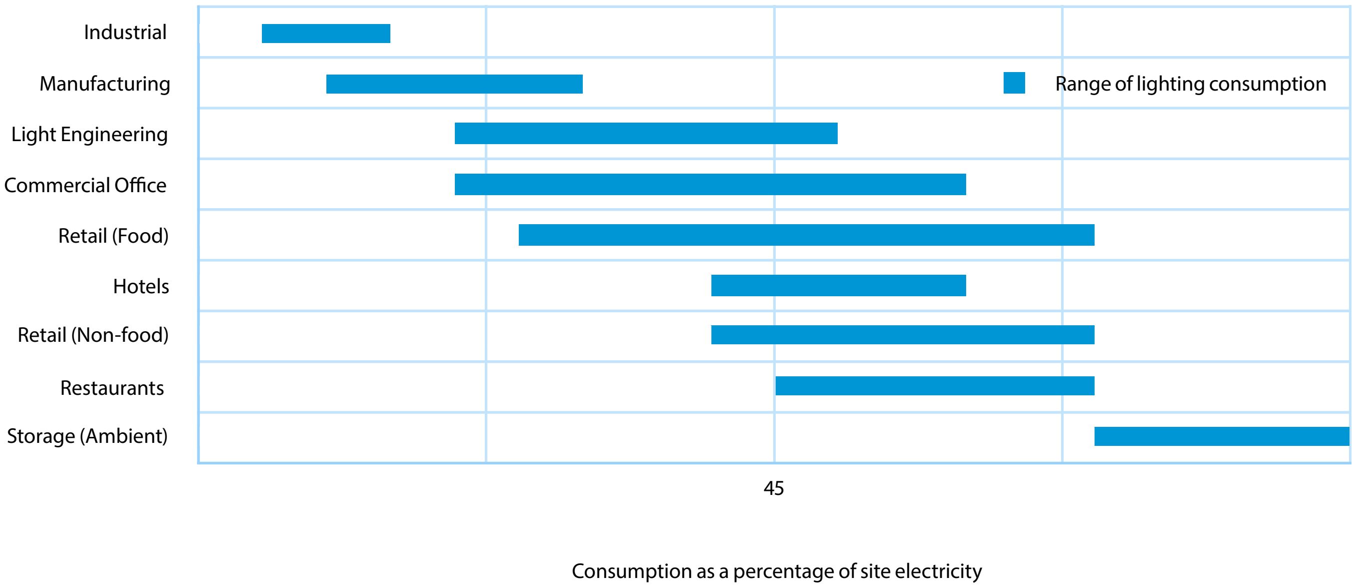
- No and low cost measures: staff awareness and maintenance can provide savings of up to 10%
- Medium cost: lighting controls can provide savings of 30-50%
- Higher cost: lighting upgrades from conventional lighting to LED technology can provide savings of up to 80% (depending on the efficiency of the existing technology)

A combination of measures can be implemented to maximise savings.

Opportunity by sector

Lighting energy consumption in commercial applications can vary from as little as 5% (or less) of total energy consumption in heavy industry to a much as 50% or more in a retail store with leagacy lighting .

Figure 18: Chart showing the typical range of lighting consumption, as a percentage of site electricity, by sector



Opportunity for reduction

Low and no cost measures

Many companies can introduce 'quick win' measures that require no or very little capital cost and achieve immediate savings. Implement the following measures to see savings of up to 10%.

Conduct a walk round

Walk round the office in the morning, at midday and in the evening to record which lights are left on unnecessarily.

Label light switches that can be turned off by all staff

Especially in infrequently occupied areas such as meeting rooms, storerooms and bathrooms. Download the Carbon Trust stickers from our website.

Implement a switch-off schedule

Who is the last person to leave the building every evening? Ensure that cleaners and late workers know which switches they need to turn off on their way out.

Ensure furniture is not blocking light sources

Move tall cupboards and filing cabinets away from windows, and don't place them directly under lights.

Remove excess lighting

When furniture cannot be moved, or lighting levels are too high, consider removing bulbs from unnecessary light fittings for immediate energy savings.

Use natural daylight as much as possible

Consider fitting slatted daylight blinds, which allow sunlight to enter the room without decreasing employee comfort, by directing sunlight up to the ceiling where it is reflected throughout the room.

Lighting maintenance

Look at the windows and light fittings in your office – are they clean? Without regular maintenance light levels can fall by up to 30% in 2-3 years, leading to more lights being turned on to compensate.

Simply cleaning windows, skylights and the glass or plastic coverings in front of light fittings can make your office a much nicer place to work, and save energy at the same time.

Opportunity for reduction

Lighting controls

No matter how efficient a luminaire is, if its use is uncontrolled there will still be waste, avoidable costs and unnecessary CO_2 emissions.

Lighting controls are the key to managing the use of light and to ensure that the right light is provided in the right place and at the right time.

Artificial lighting is often manually switched off or dimmed according to the needs of a task or activity, when there is sufficient daylight or when an area is unoccupied. Properly applied lighting controls facilitate this and ensure that there is no unnecessary use of electricity, eliminating the risk of human error (e.g. forgetting to switch off the lights).

Automatic lighting controls generally react to three main stimuli:

- Movement sensor – occupancy control
- Time clock – timed schedule
- Light sensor – daylight linking.

There are additional functions in some lighting control systems but these are the principle techniques for reducing electricity use.

Automated controls should always be combined with manual override options, as we all like to be able to make decisions for ourselves.

These user controls or manual override options must be easily understood and conveniently located. Wherever there might be doubt then clear labelling should be employed. The principle of combining user controls with automatic management is to have an environment where users switch lighting on but it is switched off automatically when it is no longer required.

There is clear evidence that giving people more control of their lighting conditions also contributes to their perception of comfort. And in those buildings where there is a high ratio of local switches to lights less electricity is used. Comfort and lighting energy efficiency have been shown to go hand-in-hand.

The following pages describe the different types of automated lighting controls in more detail.

Lighting controls can make huge reductions in energy use, usually between 30% and 50% in a typical office environment

Opportunity for reduction

Lighting controls

Motion sensors

Motion sensors monitor occupancy. They rely on three technologies to detect presence:

- Passive infra red – PIR
- Ultrasonic detection
- Microwave detection.

PIR sensors are the most common type used in office spaces because they offer a good compromise between value and sensitivity. They can generally monitor smaller areas than the other two methods, which can be beneficial.

The location of a motion sensor is important; it must be able to 'see' the activity that requires the light but not beyond that area. Many sensors do not work effectively because people passing close by trigger the lighting to come on when it is not actually needed.

The table on page 26 was originally developed some years ago by the Building Research Establishment (BRE Digest 498 – Selecting Lighting Controls) in order to help people understand how lighting controls in any given space might be applied. A similar table appears in the Building Regulations.

If a room is 'owned' by a single occupant then it is reasonable to pass responsibility for lighting control to that individual. Once a space is 'shared' it then becomes more complicated because the occupants may have different lighting needs. The 'type' helps inform the application with regard to the best choice of local controls.

Motion sensors can be used in two, different, modes – 'presence' and 'absence' detection. Presence detection automatically brings on the light as soon as it senses movement; and switches the light off when the space is vacant. Absence detection lighting must be switched on manually and the sensor then switches the lighting off when the space is empty.

Figure 19: Some typical motion sensors

Opportunity for reduction

Lighting controls

Time control

Whilst timed operation used to be an effective method to control lighting based on predicted occupancy levels in buildings, this doesn't fit so well with modern, flexible working practices. To have any chance of success there needs to be a very large number of local overrides that are easily found and used. The need for these can mean that systems that rely only on scheduled switching actually use more energy than a manually operated installation.

In modern, networked control systems time scheduling is now used to change the overall operating mode. The behaviour of other controls may need to be different at certain times of day. They do, however, remain vital in exterior lighting so lights are only on when it is dark outside.

Table 4: Defining spaces and appropriate controls

Type of space	Examples	Controls
Owned	Cell office, small workshop, consulting room.	Wall switch, movement sensor; preferably in combination (absence mode).
Shared	Open plan office, production area, ward.	Wall switches, movement sensors, photocell; local and remote operation; combined.
Temporarily owned	Meeting room, 'hot' office, classroom.	Wall switch, scene plate, movement sensors; preferably in absence mode.
Occasionally visited	Store room, book-stack, toilet.	Wall switch (with time delay), movement sensor; auto operation OK.
Un-owned	Corridor (open or closed), stairs.	Remote manual or automatic operation, movement sensors; linked to work area lights.
Managed	Hotel lounge, museum, foyer, terminal.	Remote manual and automatic operation; time scheduling.

Figure 20: Illustrating the effect of time controls

Opportunity for reduction

Lighting controls

Light sensors

The technologies used to detect light are, in the main, less important than the way they are used.

Light sensors are commonly used in two ways. They can be used to observe the external (natural) lighting conditions and hence be a reference level for the control system to act upon. Or they can be mounted in the ceiling to observe the lighting conditions immediately below.

The use of an outward looking sensor is usually made in applications where a lot of daylight is coming into the building and the control function is limited to switching only.

It works on the principle that the amount of daylight penetrating the building will always be directly proportional to the current ambient light. The system then makes decisions about calculated levels of light in various parts of the building.

Downward facing, ceiling mounted light sensors are usually used in office spaces where the intention is to use dimming control to integrate the artificial and natural lighting. As daylight increases the sensor automatically reduces the amount of artificial light.

It is generally better practice to use dimming controls when adjusting the lighting in response to daylight. The light level in any space will be the sum of the natural and artificial light. If the light level was 1000lux, with 500lux provided by the artificial lighting, then a switch off will halve the lighting level and occupants may think the light level is too low. The reaction will be to restore the artificial lighting even if it is not required.

Figure 22: Interior making good use of daylighting

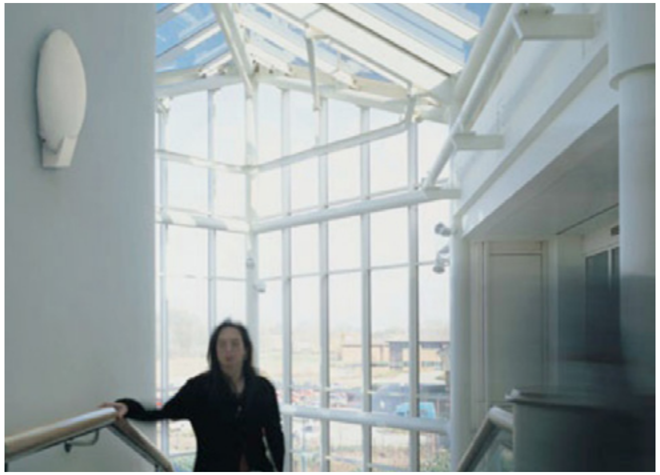


Image courtesy of Thorn Lighting

Figure 21: Light sensors

Image courtesy of Zumtobel

Image courtesy of Philips lighting

Opportunity for reduction

Benefits of upgrading to LED

Upgrading your lighting to more efficient lamp sources requires more upfront investment than the opportunities mentioned so far in this guide, but it can also achieve the highest energy savings.

Upgrading to LED technology is an effective way of decreasing lighting electricity consumption by up to 80% when replacing conventional lamp technology, such as halogen, metal halide and old T12 fluorescent tubes. The savings for upgrading more efficient fluorescent lighting such as T8 or CFL lamps to LED are smaller, but will still give you a good return on investment – a lighting supplier or specialist can calculate this for you.

It is possible to retrofit most luminaires with LED technology without altering the fitting. For example fluorescent tubes can be replaced by LED replacement battens and halogen GU10 spotlights by LED replacement spotlights. Whilst retrofitting luminaires in this manner allows individual fittings to be upgraded as they fail, and offers a significant energy saving, it is a less effective solution than full luminaire replacement. Existing legacy luminaires and control gear are not necessarily suited to an LED light source, and therefore the performance of the unit as a whole cannot be verified.

As a result we would always recommend that the entire luminaire is replaced. This will ensure that the new fitting uses the correct wiring and control gear for the lamp technology, and also that the correct amount of lighting is provided for the space.

The next two pages provide practical examples of reduced running costs for typical LED upgrade applications, as well as recent case studies to give you an indication of the scope of the opportunity.

As well as providing direct energy savings, LEDs can provide further cost savings due to:

- **Longer lamp life: this equates to lower and less frequent maintenance costs.**
- **Reduced heat gain: LEDs produce very little waste heat compared to conventional sources, reducing the need for additional cooling on warm days.**
- **Better controllability: through dimming and instantaneous switch on and off.**

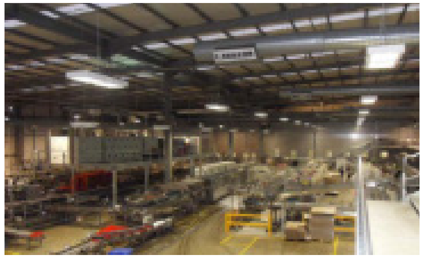
Opportunity for reduction

Benefits of upgrading to LED: Practical examples

Figure 23: Warehouse & production saving potental (Operating cost per fitting per year)

400W Metal Halide

£385



220W T5 Fluorescent

£212

150W LED

£131

Figure 24: Office saving potential: 5 Foot Strip Lights (Operating cost per fitting per year)

2x58W SS T8

£50

2x49W HF T5

£39

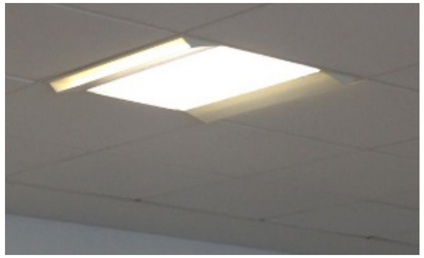
48W LED

£20

Figure 25: Office saving potential: 2 Foot Square Grids (Operating cost per fitting per year)

4x18W T8

£32



3x14W T5

£17

30W LED

£11

Based on a single luminaire of the wattage stated; electricity costs of 10p per unit; ballast losses of 10% for discharge and fluorescent and continuous operation 365 days per year.

Based on a single luminaire of the wattage stated; electricity costs of 12p per unit; ballast losses of 20% for T8 lighting and 10% for T5 lighting, operation 5 days per week 12 hours per day.

Opportunity for reduction

Benefits of upgrading to LED: Case studies

‘Some example projects identified by the Carbon Trust’s Green Business Fund programme:

Pentagon Plastics

Pentagon Plastics are an injection moulding company based in West Sussex. A Carbon Trust site survey made recommendations for annual energy savings totalling £8,100, including the lighting measure outlined.

Key figures:

- Estimated Cost: £14,100
- Annual Saving: £4,700
- Project Payback: 2.1 Years
- Lighting Savings of 62%

APS Metal Pressings

By implementing three simple Carbon Trust recommendations, including upgrading to LED lighting with controls, APS Metal Pressings will reduce their energy bills by £12k annually with a payback period of 2.7 years.

Key figures:

- Estimated Cost: £24,000
- Annual Saving: £6,000
- Project Payback: 4
- Lighting Savings: 63%

“Thanks to the Carbon Trust’s Green Business Fund we received a comprehensive report with recommendations for improvements which will benefit the environment and our bottom line.”

- Liz Ratcliffe, Pentagon Plastics

“The report provided was full of useful information that has allowed us to home in on specific areas where savings can be easily made.”

- Amish Chapaneri, APS Metal Pressings

Implementation considerations

Lighting design

To minimise energy consumption and provide the correct lighting levels for the area, it is important to specify the right light, in the right place, at the right time. These are the three fundamental considerations for good lighting design.

Ask any lighting designer what lies behind good lighting design and you'll get the same response.

Each of these components is explained in greater detail elsewhere in this guide, but whilst each component has its own level of efficiency, when they are brought together in a designed solution, they will combine to provide even greater efficiencies.

The essential premise is that it is important to use the most efficient and suitable type of lamp, 'the right light', but that considerations need to go beyond this to optimise energy reduction potential.

Less light is required in a corridor than in an office, so getting the right amount of light is important. The design of the layout of the luminaires will ensure that the light is delivered in the right place.

It is important to only deliver light to where it is required; if a cellular office has one desk, then the light needs to be delivered to the desk and not the surrounding carpet!

Finally, it doesn't matter how efficient your lamp or luminaire is if it is on at 2am in an empty office. 'At the right time' means it is switched off when there is no need for it to be on.

In order to decide how much light you need and where you need it, ask the following questions:

- Who is using the space?
- What are they doing?
- When will they be there?
- How long will they be there?

Figure 26: Effective and efficient lighting design needs to take into account a wide range of factors

Implementation considerations

The importance of daylight for lighting design

Daylight is the only freely available light source and yet all too often it is overlooked. Well controlled daylight can provide a space with the best possible lighting effect, superb colour rendering, great user comfort and with zero cost or CO_2 emissions. Research has demonstrated that daylight has tremendous physiological and psychological benefits; bringing daylight into hospitals can speed recovery and in schools it can help with concentration and improve learning. So why don't we make more of it?

The argument is that using daylight successfully is not always simple or straightforward, but commonly highlighted problems such as heat gain and glare from direct sunlight can be avoided at the initial design stage, or even subsequently with shading devices. Daylight can be brought into spaces through roof lights, atria and light guidance systems as well as windows.

Lightly coloured walls and ceilings will aid the distribution of daylight in rooms while architectural light wells can aid daylight penetration further into the building.

Artificial lighting is still needed of course, but by ensuring it is linked to the daylight availability, it will be used most efficiently.

Successfully managing the balance of natural and artificial light is key; whilst it is possible for artificial lighting to be completely off when there is sufficient daylight in a space, consideration must be given to what happens when that changes; a sudden change of lighting level through the artificial lighting all coming on (or turning off) at once, creates distraction and discomfort. So artificial lighting should be dimmed to balance the daylight and deliver a constant light level for the users.

Did you know?

Light-dark adaptation is found in many situations – walking from bright sunlight into a dark room, driving through a tunnel.

These extremes of brightness cause a huge loading on our eye-brain system to adapt quickly and the same is true, even if in less extreme circumstances, in most workplaces.

Creating a good balance of light on the task – whatever that task is – the surrounding area and our overall visual field is crucial to user comfort.

Implementation considerations

Lighting design: in pictures

Figure 27: Inappropriate luminaires for application modular lay-in in retail

Image courtesy of JWSA

Figure 28: Poor maintenance illustrated by mixture of lamps in luminaire

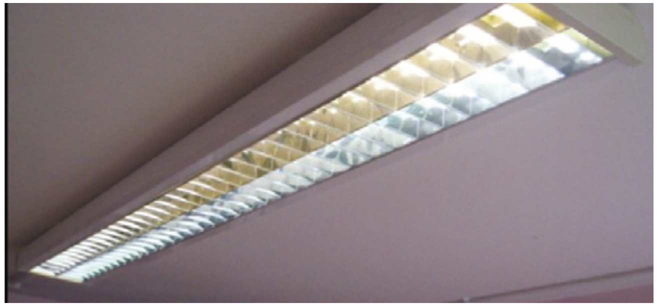


Image courtesy of JWSA

Figure 29: Poor UGR19 application

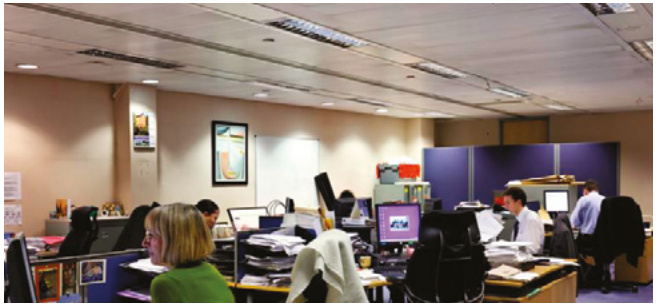


Image courtesy of Zumtobel

Figure 30: Balance of light on walls and tasks

Image courtesy of Zumtobel

Figure 31: Good examples of daylighting in the work place

Images courtesy of Thorn Lighting

Figure 32: A well controlled office building with lights turned off at night

Image courtesy of Zumtobel

Implementation considerations

Applications

How might lighting be effectively used in three categories of project: new construction, refurbishment and retrofit?

New construction

A lighting scheme will be required as part of the original design.

As the name suggests, this is a completely new lighting installation. Normally there will be a lighting expert on the design team.

For new construction projects we recommend that LED solutions are always considered as the first choice, due to the broad range of benefits provided by LED technology (high efficacy, long lifetime, good controllability and the broad range of options available). Legacy lighting should only be considered only where LED solutions are not advisable in very specific circumstances, for example in high temperature working environments.

When developing the brief for the lighting in a new building it is important to bear in mind the impact the design choices might have on the future operational costs, particularly maintenance. Detailed guidance on design considerations can be found in on page 31.

Refurbishment

Lighting is often a significant element of the project. An opportunity to consider a new, more effective, lighting scheme.

There are arguably two levels of refurbishment: treating the lighting project as a blank canvas or utilising some or all of the existing services. In the case of the former, the design objectives and considerations will be the same as for a new construction project.

In a lot of cases, however, the refurbishment programme will look to use some or all of the existing services. Whilst the principles of lighting design can still be followed, there may be some constraints such as ceiling types or layout.

It will be worth exploring all avenues before reaching decisions on the best way forward as it may prove more beneficial to go the extra mile with the refurbishment to achieve the optimum solution long term. See How to implement lighting refurbishment (CTL163).

Retrofit

A stand-alone project when the lighting in a building is out-dated and/or inefficient.

A retrofit is a project where only the lighting is being reviewed and no other works are being actively pursued.

When considering an upgrade of out-dated or inefficient lighting, it is often tempting to go for a 'quick win'. Whilst this is possible, consideration should be given to the potential increased benefits of a deeper renovation. Quick wins are only a short-term fix. If the lighting is very inefficient then the benefits of a larger capital investment to an enhanced upgrade will be heightened and the savings on energy will quickly repay the investment.

Implementation considerations

Regulations

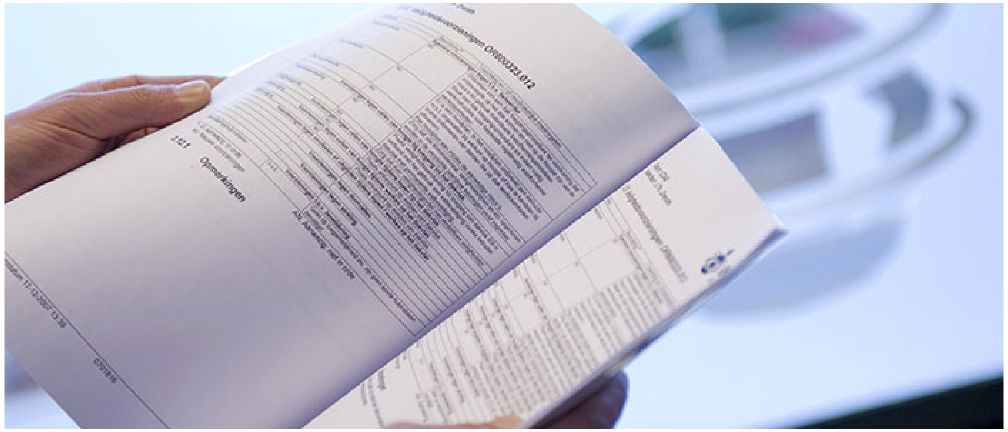
There are over 30 European Standards which affect lighting in the UK. These cover a wide range of subject areas but the most relevant one is EN12464 which covers the lighting of workplaces. EN12464 provides guidance on ensuring light quality, by setting recommendations related to illuminance, colour rendering, glare and maintenance to retain quality over time. No European Standards are mandatory and there is no legal requirement for lighting other than that it must be "suitable and sufficient."

The Health & Safety Executive publishes guidance on minimum lighting levels titled HSG 38: Lighting at Work, which can be downloaded from their website.

More detailed guidance on standards relating to lighting and sector-specific application can be found from the Society of Light & Lighting.

For new construction and significant refurbishment projects, the lighting must comply with the Building Regulations. It should be noted that the requirements for England & Wales differ from both Northern Ireland and Scotland.

For England & Wales, the section covering lighting is Part L. In Northern Ireland, it is Section F and in Scotland, it is Section 6 of the Building Standards. These all cover the conservation of fuel and power.



The Energy Technology List

The Energy Technology List (ETL) is a government list of energy saving products used by businesses. With nearly 17,000 listed products the ETL is one of the world's largest databases of top performing energy saving products. Businesses that purchase products listed on the ETL can claim a 100% Enhanced Capital Allowance (tax relief) and will also benefit from reduced ongoing running costs given that the products are the most efficient on the market.

Lighting products are not listed individually on the ETL as there are too many product variations for the listing process to be practical. Instead, manufacturers or suppliers should be able to provide a statement that products meet the criteria.

For further information please visit https://www.gov.uk/guidance/energy-technology-list or call the Carbon Trust on 0300 3300657.

Next steps

There are many easy low and no-cost options to help save money and improve the operation of your lighting system.

Step 1. Understand your energy use

Find out what lighting you have, where it is installed and how it is used. Ask staff to report any lighting issues and act on any feedback. Check the condition and operation of lamps and luminaires and monitor how the lighting is used over, say, one week to obtain a base case against which energy efficiency improvements can be measured.

Step 2. Identify your opportunities

Compile an energy checklist of your lighting. Walk round your building and complete the checklist at different times of day (including after hours) to identify where energy savings can be made.

Step 3. Prioritise your actions

Draw up an action plan detailing a schedule of improvements that need to be made and when, along with who will be responsible for them. Short-term actions could include launching an awareness campaign and writing a usage policy; long-term plans could include planning a major refit of lighting controls and zoning the lights.

Step 4. Seek specialist help

It may be possible to implement some energy saving measures in-house but others may require specialist assistance. Discuss the more complex or expensive options with an expert.

Step 5. Make the changes and measure the savings

Implement your energy saving actions and measure against original consumption figures. This will assist future management decisions regarding your energy priorities.

Step 6. Continue to manage your business for energy efficiency

Enforce policies, systems and procedures to ensure that your business operates efficiently and that savings are maintained in the future.

Related publications

- Display lighting guide (CTG010)
- How to implement lighting controls (CTL161)
- How to implement external lighting (CTL162)
- How to implement lighting refurbishments (CTL163)
- How to implement LED lighting (CTL164)
- How to implement T5 retrofits (CTL165)

Glossary

Ballast

A component of conventional control gear. It controls the current through the lamp, and is used with discharge lighting, including fluorescent, sodium, mercury and metal halide lamps. The term is sometimes used loosely to mean control gear. Also called a choke.

Choke

Alternative name for ballast.

Colour rendering (Ra)

An indicator of how accurately colours can be distinguished under different light sources. The colour rendering index compares the ability of different lights to render colours accurately with the Ra measurement of 100 being 'ideal'. Colour rendering properties of a light source are specified by the colour rendering index (CRI).

Colour temperature (K)

Also known as colour appearance, the colour temperature is the colour of 'white' the light appears. It is measured in Kelvin, and ranges from 1,800K (very warm, amber) to 8,000K (cool). 6,500K is daylight. There are many colours of 'white' available. For general use these are: a warm white (2,600 to 2,700 degrees Kelvin), a medium white (3,000 to 3,500 degrees Kelvin) and a cool white (4,000 degrees Kelvin).

Control gear

A 'package' of electrical or electronic components including ballast, power factor correction capacitor and starter. High-frequency electronic control gear may include other components to allow dimming etc.

CRI

Colour rendering index has been defined by the CIE (Commission Internationale de l'Eclairage).
The CRI is specified in Ra. Good colour rendering equates to a high CRI (CRI 100 = daylight), poor colour rendering equates to a low CRI.

Diffuser

A translucent screen used to shield a light source and at the same time soften the light output and distribute it evenly.

Discharge lamp

A lamp which produces illumination via electric discharge through a gas, a metal vapour or a mixture of gases and vapours.

Efficacy (luminous efficacy) (lm/W)

The ratio of light emitted by a lamp to the power consumed by it, that is, lumens per Watt. When the control gear losses are included, it is expressed as lumens per circuit Watt.

Illuminance (lux)

The amount of light falling on an area, measured in lux. 1 lux is equal to one lumen per square metre.

Kelvin (K)

A measure of colour temperature for lamps.

Light output ratio (LOR)

The ratio of the total amount of light output of a lamp and luminaire to that of just the bare lamp.

Luminaire

A light fitting and lamp including all components for fixing and protecting the lamps, as well as connecting them to the supply.

L70, L80 and L90

Stated alongside the lifetime hours to rate the lifespan of LED light sources. L70 40,000 hours reveals that the particular lamp source can last for 40,000 hours before the output will be reduced to 70% of the original output.

Lumen

Unit of luminous flux, used to describe the amount of light produced by a lamp.

Lux

An international unit of measurement of illuminance intensity of light.

Maintained illuminance (lm)

The illuminance averaged over the reference surface at the time maintenance has to be carried out (by replacing lamps and/or cleaning luminaires and room surfaces).

Ra

The colour rendering performance of a lamp is described by its general colour rendering index (Ra) which defines its ability to show surface colours accurately. It is described by a number – 100 is considered to be excellent, a value of 80 and above is good and appropriate for most situations where people are present. Where colour identification is important, a value of 90 or above should be used.

Rated average lamp life

The number of hours after which half the number of lamps in a batch fail under test conditions.

Re-strike

The time taken for a lamp to illuminate after being switched off and then on again.

Start-up

The time taken for a lamp to illuminate after being switched on from cold.

Lighting for task

The lighting provided for specific tasks within a lighting design. For example, task lighting design will depend on the particular tasks undertaken and the building lighting design.

Universal operating position

Refers to a lamp that can be oriented in any way without affecting light quality.

Go online for more information

The Carbon Trust provides a range of tools, services and information to help you implement energy and carbon saving measures, no matter what your level of experience.

Website – Visit us at www.carbontrust.com for our full range of advice and services.

www.carbontrust.com

Tools, guides and reports – We have a library of publications detailing energy saving techniques for a range of sectors and technologies.

www.carbontrust.com/resources

Events and workshops – We offer a variety of events, workshops and webinars ranging from a high level introductions to our services through, to technical energy efficiency training.

www.carbontrust.com/events

Small Business Support – We have collated all of our small business support in one place on our website.

www.carbontrust.com/small-to-medium-enterprises

Our client case studies – Our case studies show that it's often easier and less expensive than you might think to bring about real change.

www.carbontrust.com/our-clients

The Carbon Trust Green Business Fund – is an energy efficiency support service for small and medium-sized companies in England, Wales and Scotland. It provides direct funded support through energy assessments, training workshops, equipment procurement support and up to £5,000 capital contribution per company towards your energy saving equipment purchase.

www.carbontrust.com/greenbusinessfund

SME Network - Join a community of over 2000 small and medium-sized businesses to discuss your strategy and challenges to reducing carbon emissions and improving resource efficiency. Sign up for free to share knowledge, exchange useful resources and find out about the support and funding available in your area, including the details of your local energy efficiency workshops.

www.carbontrust.com/resources/tools/sme-carbon-network

The Carbon Trust is an independent company with a mission to accelerate the move to a sustainable, low-carbon economy. The Carbon Trust:

- advises businesses, governments and the public sector on opportunities in a sustainable, low-carbon world;
- measures and certifies the environmental footprint of organisations, products and services;
- helps develop and deploy low-carbon technologies and solutions, from energy efficiency to renewable power

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