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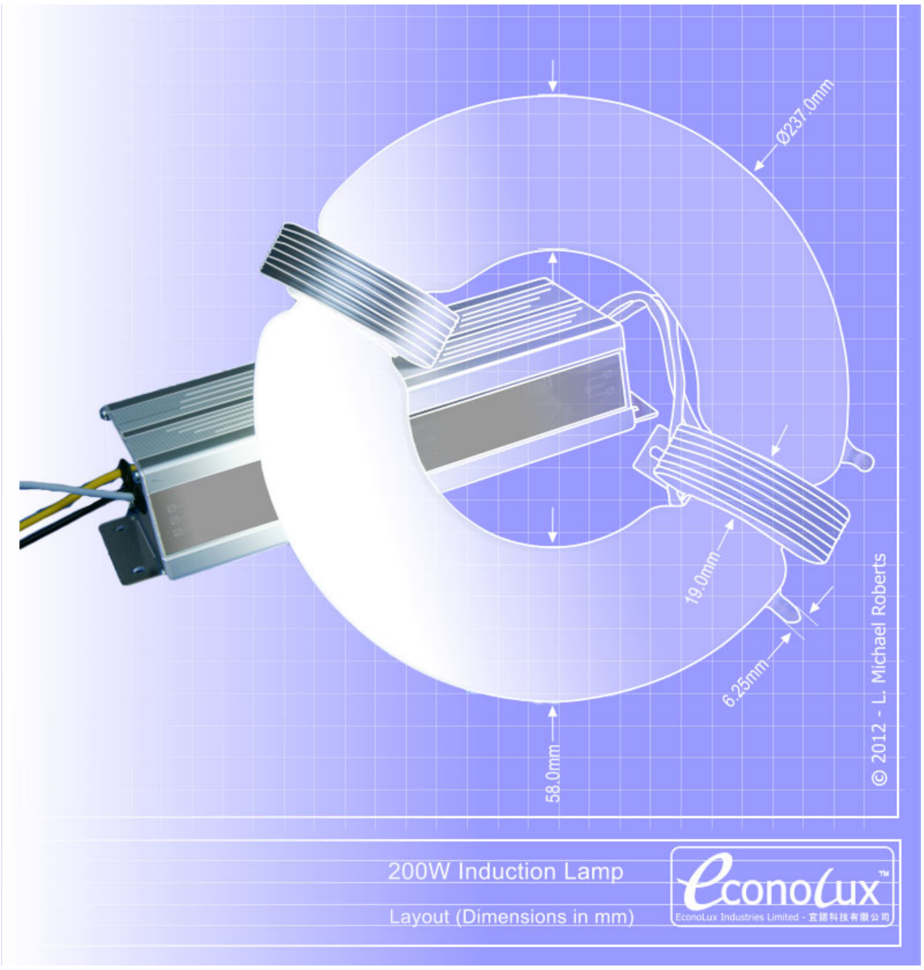
The Science Behind EconoLux Induction Lighting



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The Science Behind EconoLux Induction Lighting

Contents

Introduction

Magnetic Induction Lamps are a long lasting, energy efficient, light source which has the potential to save users between 35% and 75% in energy and maintenance costs over their lifetime, compared to the typical Metal halide, Mercury Vapour and Sodium lamps usually used in commercial and industrial lighting applications.

Many people who see the EconoLux lamps remark at how bright they appear and the high quality of the light emitted from the lamps. However, when people have compared light meter readings of the new lights, with reading of conventional lighting, the new lights are measured as producing less output than conventional lights. This has led to people questioning the installation of the Induction Lamps - even though they use far less energy - as they expect that areas lit by them, will not be bright enough compared to conventional lighting, even though their eyes are telling them they the light level is the same or brighter.

The problem is not the lights, which are visually brighter, but the way in which the light meters are calibrated using the 1951 CIE standard. This standard, used to set the sensitivity curve of light meters, does not take into account the contribution of scotopic vision ["night vision"] to the sensitivity of the eye. Scientific studies have shown that the eye is more sensitive to blue wavelengths than the measurement curve of the light meters and, in fact, blue light acting on human scotopic vision is largely responsible for "visual acuity" or sharpness of vision.

The result of using light measurements, based on old standards that have not kept pace with scientific research, is that the light meters are wrong! People are paying for energy and equipment which is not contributing to improved lighting levels, while innovative products which are energy efficient and which produce a better "quality of light" are ignored. Sometimes additional fixtures/lamps must be installed to make the light meters happy thus mitigating some of the energy savings.

It is important to understand the science behind the induction lighting and why they are better and brighter even though conventional lighting meters show otherwise. This paper will briefly explain the science behind magnetic induction lighting, in a simplified manner. This paper also includes footnotes listing the scientific studies and papers on which the science is based for those who would like to follow up on the details.

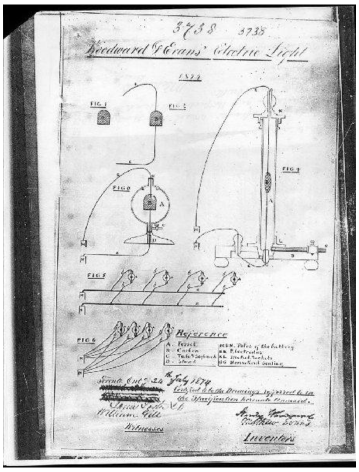
A Very Brief History of Magnetic Induction Lamps

Introduction:

Since the days when humans first inhabited caves, they have sought and used artificial lighting to improve their lives. While the flickering fires of Cro-Magnon man generated more heat than light, they put the limited light to good use in creating some of the earliest forms of art by recording their surroundings and experiences on the walls of their caves. These primitive painting demonstrate one of the most important properties of artificial lighting - it increases literacy and culture by extending the time available to us for self improvement.

The first electric light was demonstrated at the Royal Institution in London by Sir Humphry Davy in the early 19th century (1809 by most accounts but the exact year is unclear). He used two charcoal sticks and a 2000 cell battery to create an arc across a 10 centimetre [4 inch] gap. He had mounted his electrodes horizontally and noticed that the arc formed the shape of an arch, due to convection currents from local heating of the air. He coined the term "arch lamp", which was later contracted to "arc lamp" when these lights came into common usage.

Thomas Edison is generally credited with the invention of the commercially viable electrical lamp we are familiar with. He was building on work done by early pioneers where the conversion of electricity to light was demonstrated in laboratories.



Canadian Patent CA 3738

Interestingly, Canadians Henry Woodward and Matthew Evans filed a patent in 1874 for a light bulb which used a carbon filament in a nitrogen atmosphere. They were unsuccessful in commercialising the lamp but caught the interest of Edison, who considered this Canadian technology so intriguing, he bought their Canadian and US patents [Canadian Patent CA 3738 and U.S. Patent 181,613] in 1875 for the then princely sum of $5,000 US. Edison continued this line of development and improved upon the Woodward and Evans patent by using a metal filament in a vacuum eventually producing the first practical and commercially successful incandescent light bulb in 1880.

Nikola Tesla demonstrated the transfer of power to electrodeless incandescent and fluorescent lamps in his lectures and articles in the 1890's.[1] On 23 June 1891, Tesla was granted US patent 454,622 to cover a very early form of Induction lamp. When looking at the diagrams from Tesla's lectures and patents, the close similarity to currently available electrodeless lamps is striking.

John M. Anderson, an engineer at General Electric Company, applied for patents in 1967 and 1968, for electrodeless lamps.[2] [3] In 1990, Philips introduced their QL induction lighting systems, in Europe and then in 1992 in the USA. These lamps were an internal inductor type operating at 2.65 MHz and were touted for their longevity. Matsushita had an induction lighting system available in Japan and Asia in 1992.

Genura lamp

In April 1994, General Electric Lighting, then one of the world's largest fluorescent tube manufacturers, announced that the "world's first practical compact high-tech induction lamp" would be available in Europe within weeks. GE displayed the lamp at the Hanover Fair in April and at the Light Fair in New York in May, 1994. At first GE called it an E-lamp, but then switched to using the "Genura" trade name. The Genura lamp is an internal inductor lamp with an integrated electronic ballast operating at 2.65 MHz.

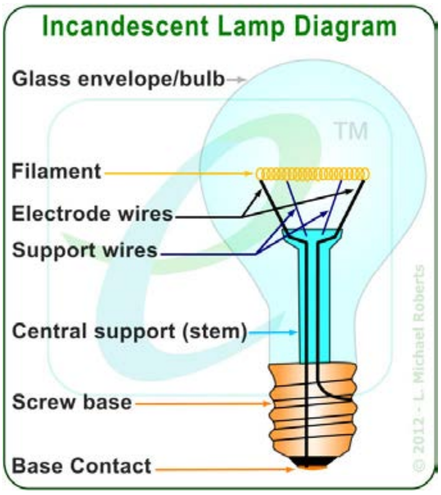
There are now many manufacturers who offer various types of induction lamps and matching ballasts. EconoLux Industries distinguishes itself from other products on the market by offering more advanced, high quality, lamps which incorporate our proprietary and patent-pending technology. EconoLux magnetic induction lamps are amongst the most energy efficient induction lamps available today.

"Surely, my system is more important than the incandescent lamp, which is but one of the known electric illuminating devices and admittedly not the best. Although greatly improved through chemical and metallurgical advances and skill of artisans it is still inefficient, and the glaring filament emits hurtful rays responsible for millions of bald heads and spoiled eyes. In my opinion, it will soon be superseded by the electrodeless vacuum tube which I brought out thirty-eight years ago, a lamp much more economical and yielding a light of indescribable beauty and softness."

From a statement by Nicholas Tesla published in "The World" in 1929.

How Magnetic Induction Lamps Work

Incandescent Lamps:



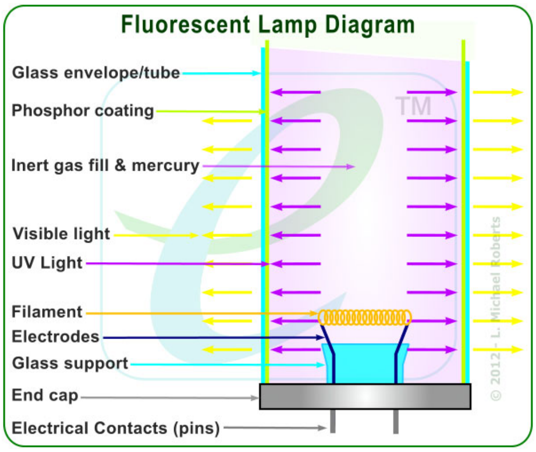
We will begin our review with the most common form of electrical light we are all familiar which is the incandescent lamp.[4] This consists of an evacuated glass envelope, which generally has two electrodes protruding through the wall of the glass vessel, and sealed in place, to bring the electrical current into the interior of the lamp. There is a thin filament usually made of tungsten, suspended between the electrodes. More than two electrodes may be present, for example in a "3-way" lamp and there may also be other non-electrically connected wires provided for mechanical support of the tungsten filament.

The incandescent lamp works by passing an electrical current through the filament, typically made of tungsten, which then glows white hot emitting light. This is not an efficient process as approximately 95% of the energy supplied to the lamp is emitted as heat. The filament must be contained in an evacuated bulb, or a bulb filled with an inert gas, as any contact with oxygen will cause the heated tungsten filament to evaporate and break the electrical circuit thus rendering the lamp useless.

Other Lamp Types:

There are many other types of lamps ranging from xenon arc lamps used in movie projectors, to metal halide, mercury vapour and sodium types, to fluorescent types, to light emitting diodes [LEDs]. It is beyond the scope of this paper to cover all of these types in detail but it will cover fluorescent lamps as Magnetic Induction Lamps are a modified form of the fluorescent lamp. For details on other types of lamps, the reader is referred to http://en.wikipedia.org/wiki/List_of _light_sources which has a list of many different types of lamps with links to details of each type.

Fluorescent Lamps:



A fluorescent lamp is a type of gas discharge tube where an electrical current excites mercury vapour in an inert gas producing UV light, typically at the 253.7 nm and 185 nm, wavelengths. The UV light is up-converted by a coating of phosphors, deposited on the inside of the tube wall, into visible light.

At each end of the fluorescent lamp, there are small tungsten filaments which are coated with a blend of metallic salts such as barium, strontium and calcium oxides. The filaments are provided to bring the electrical current into the lamp and the metallic salts are designed to promote the emission of electrons in order to stimulate the mercury ions in the tube.

Fluorescent lamps are a negative resistance device [as more current flows, the resistance decreases allowing even more current to flow] thus the lamps require a ballast to control the flow of electrical current to the lamp.

The most common and simple type of ballast is a magnetic or "coil and core" ballast. This is a form of current limiting transformer which provides the lamp with the correct current needed for its operation. These ballasts are cheap to manufacture but inefficient as they emit a lot of heat (wasted energy) - typically between 12% and 16% of the energy consumed by the lamp is wasted in the core and coil (magnetic) type ballasts.

Newer types of fluorescent lamps use high frequency electronic ballasts. While these are more costly to manufacture, they are much more energy efficient, typically only wasting between 4% and 8% of the energy consumed by the lamp.

The choice of phosphor, or combination of phosphors, used in the coating on the inside of the glass tube influences the perceived colour of the light emitted. Certain phosphors emit red, green or blue light when excited by the UV light inside the tube. This allows manufacturers to offer "warm white", "cool white" and "daylight" types of lamps - where these designations refer to the approximate colour temperature of the florescent lamp - by mixing and matching the ratio of the Red, Green and Blue phosphors used in the coating.

Electrodeless Lamps:

Almost all of the light sources currently in use have one thing in common, metal electrodes sealed into the walls of the bulb to bring the electrical current inside the lamp chamber. Unsurprisingly, the main failure mechanisms in these lamps [other than breakage] is:

- Failure of the filament due to depletion of the filament material over time as atoms are stripped off (evaporated) by the electrical current (the dark bands seen at the ends of old fluorescent lamps are caused by evaporated filament material depositing on the inside of the phosphor coating);
- Vibration which breaks the filament, especially when it is hot as it is close to its melting point and thus more fragile;
- Failure of the seal integrity of the lamp typically caused by thermal stresses in the area where the electrodes go through the glass walls. The failure of the seal can either be sudden and complete or a "slow leak" over time allowing the entry of atmospheric gasses which contaminate the interior.

The dream of lighting inventors has been to produce a lamp with no internal electrodes to eliminate these common failure modes. In an electrodeless lamp the envelope [bulb] is completely sealed and thus there is no chance of atmospheric contamination due to seal failure and no electrodes to wear out over time.

In an electrodeless lamp, the main failure mechanisms [other than breakage] are:

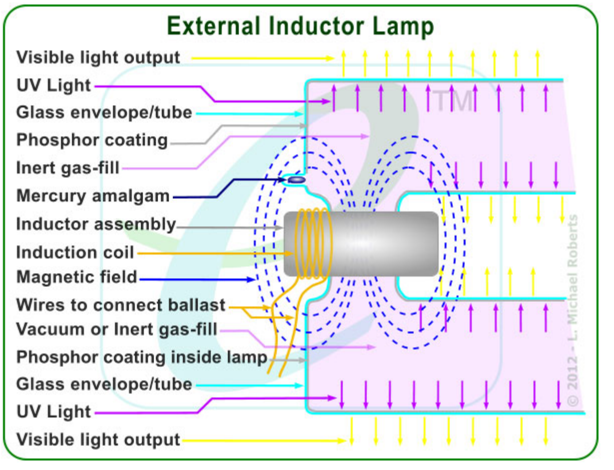
- Depletion of the mercury vapour inside the envelope [bulb/tube]. When the mercury ions are excited and bombard the phosphors [which then emit the light we see], a small percentage of them are absorbed by the phosphor coating over time. Once the mercury ions inside the tube are depleted, the lamp emits only dim light and has to be replaced.
- Failure of the electronics [ballast] used to drive the lamp. This is not a catastrophic failure mode as typically the electronics [ballast] are external to the lamp and can be replaced.

Electrodeless Magnetic Induction Lamps:

So how do you get an electrical current inside the bulb/tube (glass envelope) to excite the mercury ions? There are two types of practical electrodeless lamps available on the market today, microwave lamps and Magnetic Induction Lamps.

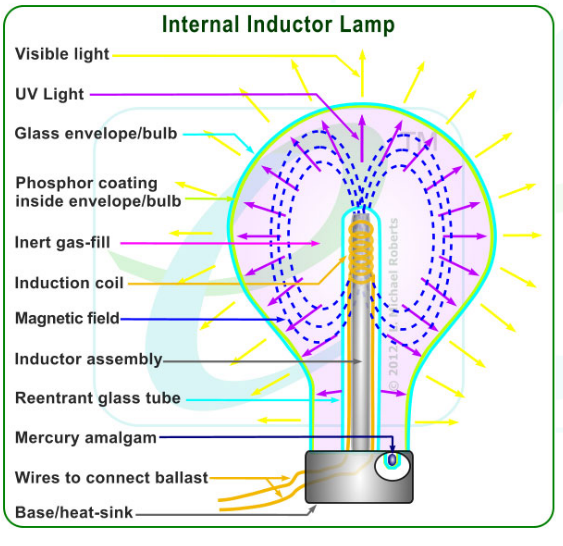
A microwave lamp bombards a capsule of sulphur with radio frequency energy which causes the sulphur to be heated becoming a light emitting plasma. The capsule has to be rotated to prevent uneven heating and must be cooled by a fan so the lamps contain mechanical parts which require frequent replacements. These lamps have not found wide acceptance outside research facilities due to their high cost and maintenance requirements.

Magnetic Induction Lamps are basically fluorescent lamps with magnetic induction coils wrapped externally around a part of the tube (see diagram on right). High frequency energy from the electronic ballast is sent through wires, which form a coil around the ferrite inductor. The induction coil produces a very strong magnetic field, which travels through the glass tube walls, and excites the mercury atoms in the vacuum or inert gas fill causing them to emit UV light.



The UV light is then up-converted to visible light by the phosphor coating on the inside of the tube. The visible light is emitted through the glass walls of the tube producing the light we see.

The system can be considered as a type of transformer, where the inductor is the primary coil, while the mercury atoms within the tube form a single-turn secondary coil - thus electrical energy is coupled through the glass wall to excite the mercury atoms.



In a variation of this technology, a light bulb shaped glass lamp, which has a test-tube like central cavity, is coated with phosphors on the inside and filled with inert gas and some mercury (see diagram on left). The induction coil is wound around a shaft which is inserted into the central test-tube like cavity and excited by high frequency energy, provided by an external electronic ballast.

The advantages of Induction Lamps are long life span due to the lack of internal electrodes, a very high energy conversion efficiency due to the high frequency electronic ballasts which are 95% to 98% efficient, and high S/P ratios. This design offers a considerable cost savings of between 33% and 75% in energy and maintenance costs, compared to other types of lamps they can replace.

As with conventional fluorescent lamps, varying the composition of the phosphors coated onto the inside of Induction Lamps allows for models with different colour temperatures.

Ballast:

Magnetic Induction Lamps require a correctly matched electronic ballast for proper operation. The ballast takes the incoming mains AC voltage [or DC voltage in the case of 12 and 24V ballasts] and rectifies it to DC. Solid state circuitry then converts this DC current to a very high frequency which is between 2.65 and 13.6 MHz depending on lamp design. This high frequency is fed to the induction coil wrapped around the ferrite core of the inductor. The high frequency from the ballast

200W Induction lamp ballast

creates a strong magnet field in the inductor, which couples the energy through the glass tube walls, and into the mercury atoms within the lamp tube.

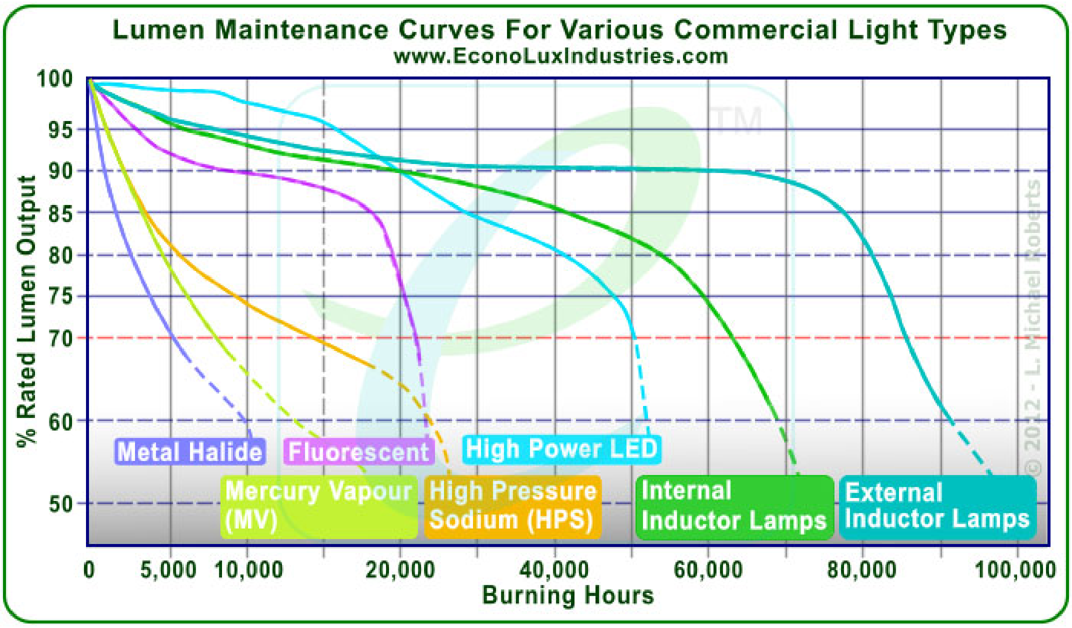
The ballasts contain control circuitry which regulates the frequency and current to the induction coil to insure stable operation of the lamp. In addition, the ballasts have a circuit which produces a large “start pulse” to initially ionize the mercury atoms and thereby start the lamp. The Magnetic lamps do not start at 100% output as it take a few seconds for the mercury bearing amalgam in the lamp to heat up and release more mercury atoms after the lamp starts.

The close regulation of the lamp by the electronic ballast, and the use of microprocessor controlled circuits, allows the induction lamp ballasts to operate at an efficiency of between 95% and 99% (depending on the model). Thus only around 1% to 5% of the electrical energy sent to the light is lost in the induction lamp ballast compared to the 12% to 16% wasted in traditional “core and coil” (magnetic ballast) designs.

Lumen Maintenance:

Lumen maintenance - the rate at which light output decreases over time - is another important factor in lighting systems. As lamps age, the amount of light they produce decreases as does their energy conversion efficiency. This is due to various factors such as filament depletion, gas-fill “clean up” where the molecules of gas are slowly absorbed into the structure of the lamp over time, changes in internal pressure, etc.

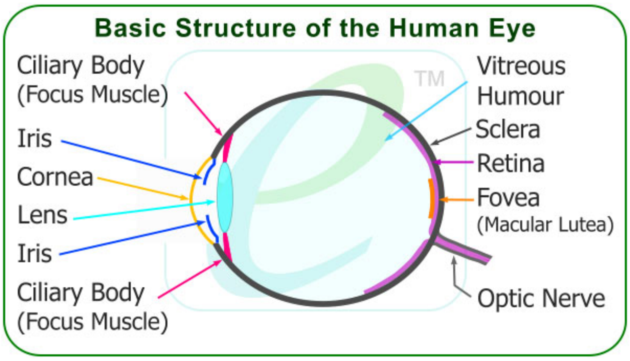
The changes in lumen output of a light source (lumen depreciation), can be plotted as a “Lumen Maintenance Curve” which shows how the light output decreases over the lifespan of the lamp. The chart below shows the expected lifespan and rate of decay in the output of various kinds of lamps commonly used in commercial/industrial lighting applications, including the EconoLux Magnetic Induction Lamps.



NOTE: The induction lamps have the highest rate of lumen maintenance (least light output decline over lifespan) due to their lack of internal electrodes or filaments.

Human Vision: How We See What We See

The human eye is an organ that detects light and provides us with vision to see the world around us. The main components of the human eye, in the order that they are encountered by a ray of light, are:



- The Cornea - a transparent curved membrane which covers the front part of the eye to provide protection to the other components of the eye.
- The pupil - a black circular opening in the middle of the eye which regulates the amount of light entering the eye. When light levels are low, it opens to admit more light; and closes down in diameterto admit less light in bright conditions. The diameter of the pupil also controls the "sharpness" of the images perceived by the eye [visual acuity].
- The Iris - this is the most visible part of the eye from the exterior and consists of pigmented [coloured] fibrous cells which connect to the sphincter muscles which control the diameter of the pupil and thus the amount of light admitted into the eye.
- The lens - a transparent bi-convex structure in the eye which, along with the cornea, refracts light to bring it to a focus on the retina. The curvature of the lens and hence its focus are controlled by the ciliary muscles which contract and relax to adjust the focus of the eye.
- The vitreous humour - a clear watery fluid which fills the space between the lens/pupil/iris and the retina.
- The retina - This is the complex light detecting layer at the back of the eyeball covering approximately 72% of the sphere of the eye. The retina consists of rod and cone cells which respond to different frequencies [colours, wavelengths] of light in different ways. Cone cells are adapted to detect colours, and function well in bright light; rods cells are more sensitive, but do not detect colour well as they are adapted for low light. The human retina contains about 125 million rod cells and 6 million cone cells.

The retina can be subdivided into two main areas;

- The Fovea [also known as the fovea centralis] - This is the central part of the retina located near the optic nerve which transmits images to the brain. The fovea takes up less than 1% of the area of the retina but the signals it sends take up over 50% of the visual cortex in the brain.[5] The Fovea is a region packed with cones and has virtually no rods. Humans have three different types of cones (trichromatic vision) in the eye allowing us to perceive Red, Green and Blue light which the brain integrates to form full colour images of the world around us. The cones in the fovea are smaller and more densely packed in a hexagonal pattern than the photosensitive cells in other parts of the retina. The Fovea is responsible for fine vision and colour discrimination. Since it takes up such a small area of the retina, we move our eyes when reading or doing other tasks requiring fine vision so that the image falls on the fovea.

- The balance of the Retina is responsible for our peripheral vision. This region consists mostly of rod cells which are about 20 times as numerous in the eye than cone cells. There are about 100 million rod cells in the human retina which are more sensitive to a limited range of light than cone cells and are thus responsible for our "night vision".[6] The Nobel prize winner George Wald[7] and others conducted experiments which showed that rods are more sensitive to the blue area of the spectrum, and are relatively insensitive to wavelengths of light above about 640 nm (red).

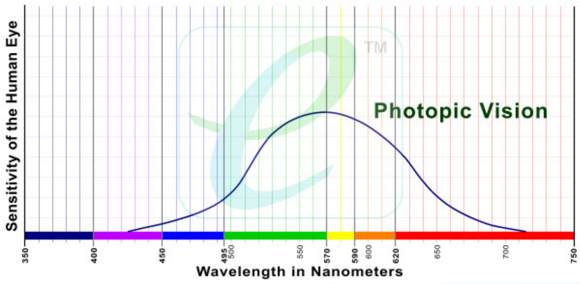
Photopic, Scotopic and Mesopic Vision:

Human vision sensitivity - which can be plotted as wavelength sensitivity curves on a graph - is divided into two main categories, Photopic vision and Scotopic vision:

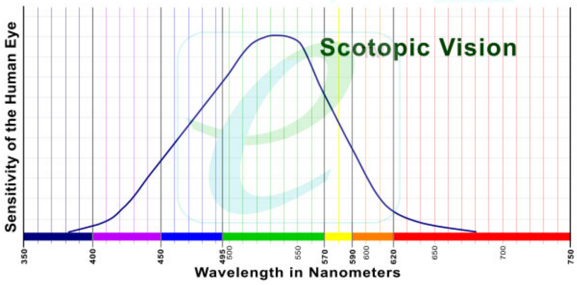
Photopic vision *is the scientific term for human colour vision under normal lighting conditions during the day.*

Scotopic vision *is the scientific term for the visual perception in dim light, "night vision".*

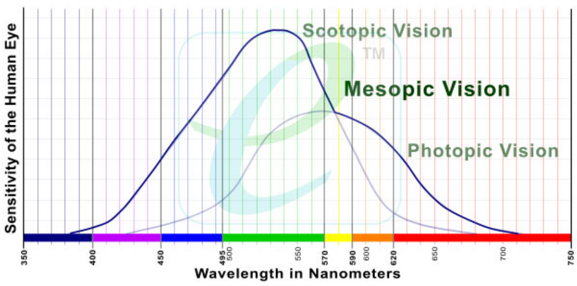
Mesopic vision *is the term for a combination of Photopic vision and Scotopic vision which takes into account the combination of the higher total sensitivity of the rod cells in the eye for the blue range, with the colour perception of the cone cells.*



Photopic vision - This is the scientific name for human vision under well lit conditions such as daylight or bright artificial light. The cone cells are responsible for sensing light in three different bands of colour, Red (around 575 nanometres), Green (around 535 nanometres), and Blue (around 445 nanometres). We use Photopic vision in daylight and the CIE response curve, used in light meters, has a spectral sensitivity curve close to Photopic vision.



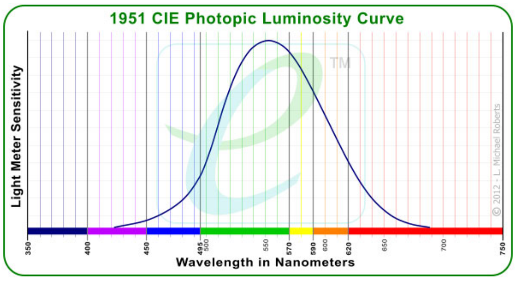
Scotopic vision - This is the scientific name for the generally monochromatic vision of the eye in low lighting conditions, so-called "night vision". The rod cells are responsible for Scotopic vision and they are more sensitive to blue light than other colours. The CIE response curve for light meters does *not* take Scotopic vision into account.



Mesopic Vision - This is the scientific name for a relatively new way of looking at human vision which takes both the Photopic and Scotopic visual response curves into account. This is somewhat complicated as it adds the extra element of wavelength sensitivity into account.

Light Meter Calibration:

Traditionally, light measuring meters have been calibrated based on the measurement of the visual efficiency of the human eye as confined to a visual field of 2 degrees. The 2 degree field corresponds to the area covered by the fovea which is rich in cone cells. This visual field of 2 degrees covers only about two hundredths of one percent of the total field of vision of the human eye and ignores the contribution of the rod cells and Scotopic vision.



The calibration curve used in typical light meters peaks around 550 nanometres which is in the green region (graph on right). Thus light sources which emit a large amount of green are seen by light meters as "brighter" than other light sources which, while they may have less green, have other components in the blue and red part of the spectrum that are equally - or more - important for good vision.

You can see this for yourself in the newer xenon and blue tinted car headlights. Most people perceive these as much brighter than conventional headlights, and drivers who are using them say they can see further and better at night. Measuring the headlights with a conventional light meter would show that they are actually about the same brightness as regular headlights. The reason they appear brighter ,is that you are driving at night with dark adapted vision when rod cells make a greater contribution to night vision. The headlights contain much more blue light, which is perceived by the rod cells and contributes to better visual acuity.

Similarly, EconoLux Industries Induction Lamps are perceived by most people to be much brighter than the typical metal halide, low pressure sodium or high pressure sodium lamps they are replacing. When measuring the induction lamps with a light meter, they show a lower output on the meter than conventional lamps, even though they appear brighter to the eye.

This is because the meters, calibrated to the 1951 CIE Photopic luminosity curve (graph above), are ignoring the additional blue components in the lamp output, which stimulate the rods and are seen by the scotopic vision of the human eye.

Scientific research has shown that blue light plays an important role in human vision. In natural daylight conditions, there is a large blue component from the diffuse scattering of blue light in the atmosphere (Rayleigh scattering), which is why the sky appears blue.

In a study published in 1996, subjects were asked to watch a small colour TV in a room where the experimenters could control the quality and colour temperature of the light falling on the walls (room illumination).[8] During the experiment, the level of lighting in the room was measured at the subject's position and that data was correlated with the readings taken from an infrared pupilometer (a device which remotely measures the pupil size of the subjects).

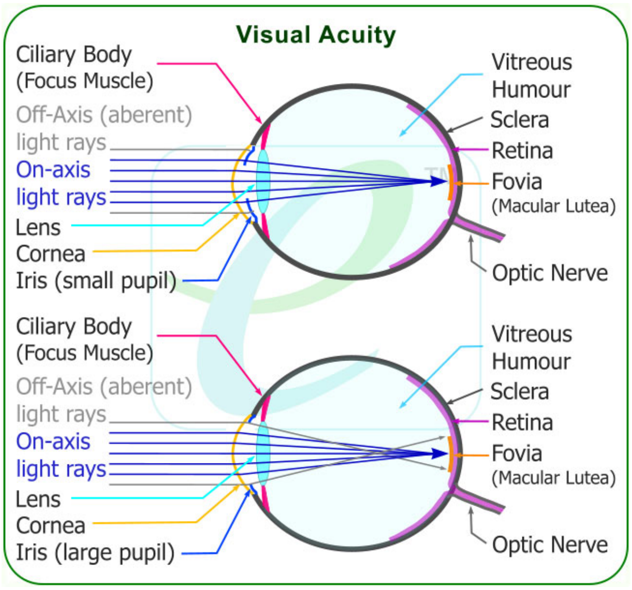
Pupil size is important for visual acuity, particularly in work related tasks. A small pupil size "stops down" the eye, just as a small aperture size does in a camera. A smaller pupil size provides better visual acuity and improves the depth of field thus permitting better vision at typical interior light levels.

"Pupil size changed with both light level and the type of spectrum illuminating the subject's eyes. However, when the average pupil size variation was compared with the test illuminance variation at the eye (measured with a conventional light meter) there was no correlation. On the other hand, a near perfect correlation was obtained when the same data were compared to a different type of illuminance based on the relative sensitivity of the rods to different wavelengths of light called the rod spectral sensitivity function or Scotopic response function. Because pupil size follows the Scotopic spectrum, this study demonstrates unequivocally and in an objective manner (subjects cannot voluntarily change pupil size) that rod photoreceptors are active at typical interior light levels."

Dr. Sam Berman, Lawrence Berkley National Laboratory [9]

Current lighting system installations attempt to reduce pupil size and improve vision by raising light levels. This approach does not utilize the response of the rod cells to blue light which has been scientifically shown to control pupil size. Increasing light levels as a way to improve vision just adds glare and wastes energy!

Visual Acuity:



In the top diagram on the left, we see that when the pupil of the eye is small, it blocks off-axis (aberrant) light rays.

This allows the on-axis light rays to come to a sharp focus on the retina providing maximum visual acuity.

In the lower diagram on the left, the pupil is open wider allowing the on-axis rays to enter the eye, as well as off-axis rays.

The off-axis rays admitted by the wider pupil help to produce a poorer quality image on the retina thereby reducing visual acuity.

This information is not unknown to lighting professionals. At the 1992 Illumination Engineering Society (IES) meeting in San Diego, California, 100 lighting professionals were asked to view two rooms illuminated using indirect fluorescent lights and then to choose the brighter of the two. The illumination in the two spaces was designed to be equal in colour so as to equally excite the cone cells of the eye. However, one of the spaces was illuminated with a light source that had more blue light (scotopically enhanced light).

Ninety-eight of the lighting professionals chose the space with the scotopically enhanced light as brighter even though it actually measured 30% less bright than the comparison space on a conventional light meter! Only two people failed to select the scotopically enhanced (but lower level of illumination) as brighter, and those two people had some degree of colour blindness.

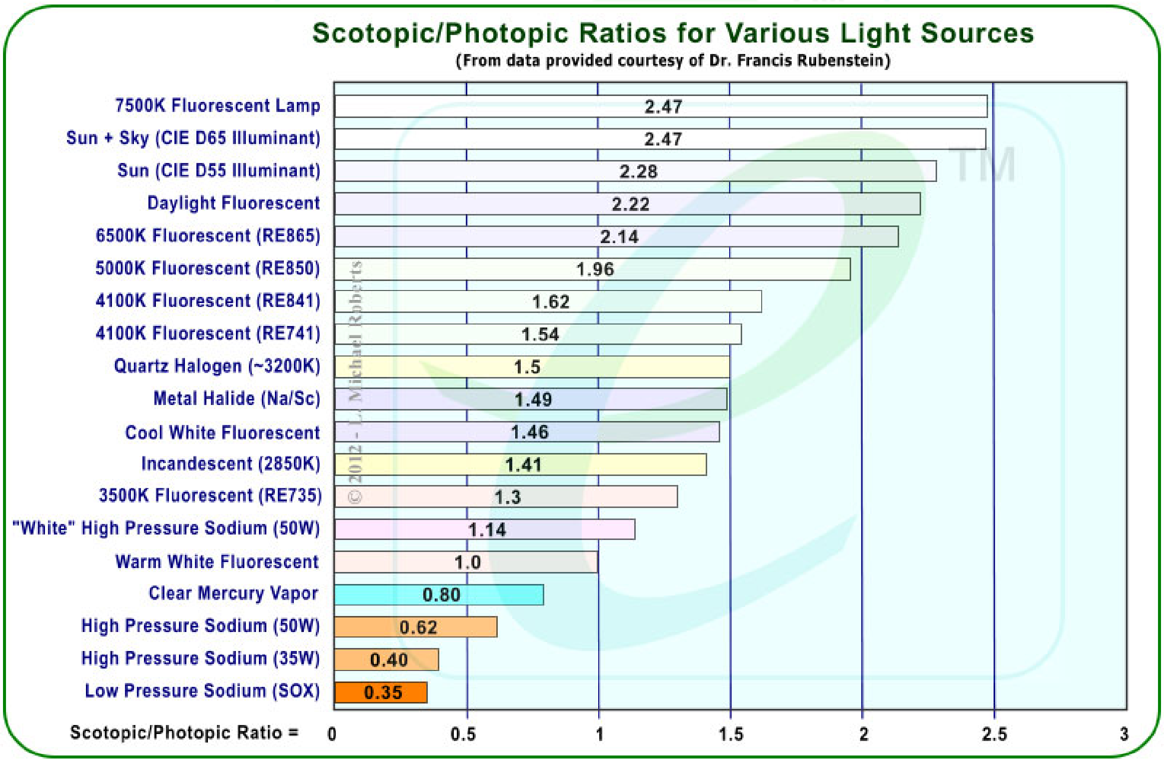
Scotopic/Photopic Ratio

The ratio of the Scotopic light Vs. the Photopic light in a lamp is called the Scotopic/ Photopic ratio - S/P ratio for short. The S/P ratio determines the apparent visual brightness of a light source. This is why the a 200W Induction Lamps from EconoLux Industries appears as bright, or brighter, to the human eye than a high pressure sodium or metal halide lamp of twice the wattage.

The S/P ratio of a lamp is important as it provides a number (correction factor) which can be used to multiply the output reading of a lamp, made using a conventional light meter, to determine how much light useful to the human eye (Visually Effective Lumens/Lux sometimes called "Pupil Lumens") a light source (lamp) produces.

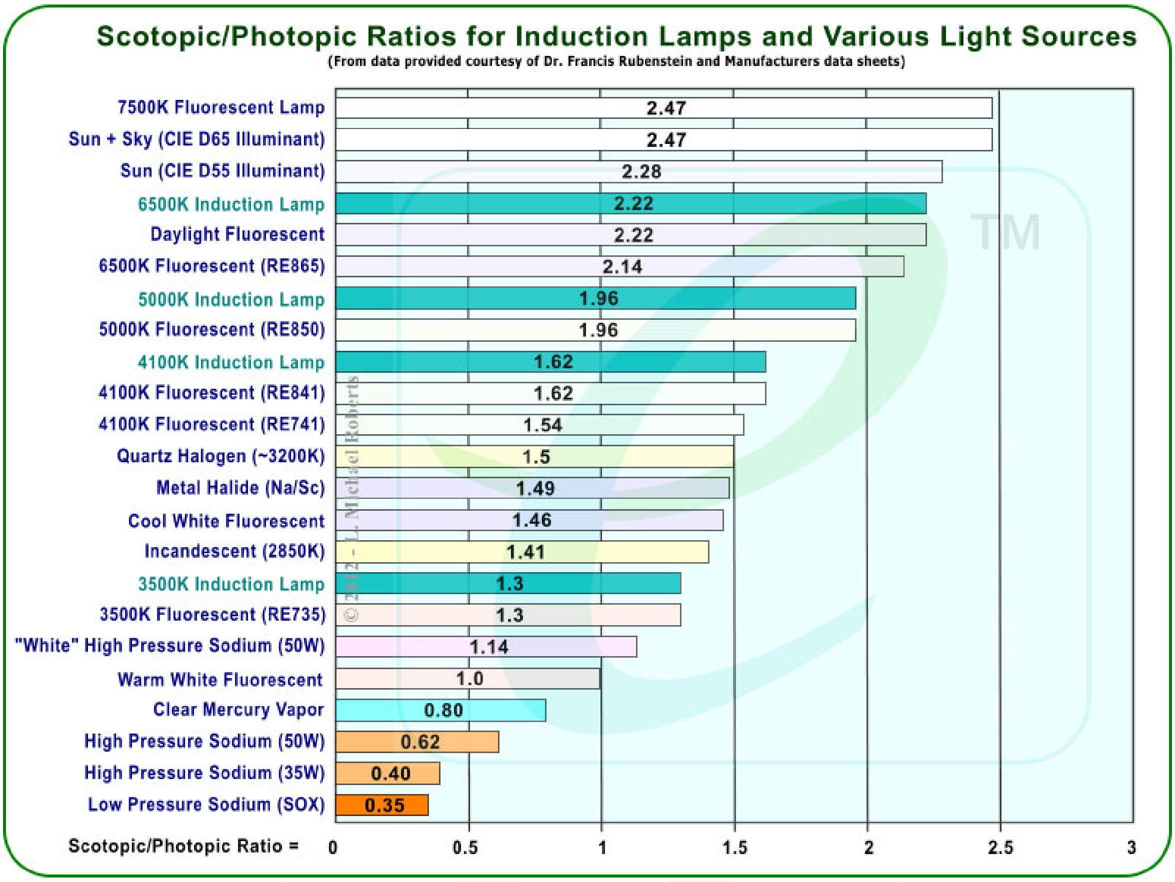
The S/P ratio of a light sources can be determined by measuring the output in Lumens or Lux using a light meter (or a spectrometer) calibrated first to the Photopic vision sensitivity curve (which is almost identical to the CIE light meter calibration standard), and then measuring the same lamp with instruments calibrated to the Scotopic vision sensitivity curve. The resulting numbers form a ratio which can be expressed as a single number (EG: 1.96).

The chart below gives the S/P ratios of various common conventional light sources from data provided courtesy of Dr. Francis Rubinstein of the building technologies division of Lawrence Berkeley National Laboratory in California.



The table on the next page gives a comparison of EconoLux Magnetic Induction Lamps S/P ratio (derived from our integrating sphere test data), compared to other common industrial lamps (based on data from the table above provided by Francis Rubinstein of Berkley Labs). Due to the scotopically enhanced light produced by the Magnetic Induction Lamps, they appear brighter to the eye and enhance visual acuity.

The S/P ratio of a light source is closely related to the colour temperature of the lamp. Lamps with higher Kelvin numbers tend to have more blue in the output and thus they stimulate the rod cells in the eye more than a "warmer" lamp with a lower Kelvin number. Lamps with high blue output are said to be "Scotopically enhanced" light sources.



For example, a low pressure sodium lamp (typically the orange lamps used in older street-lights) is almost monochromatic, producing most of its light in the 590 nm (yellow/orange) range. Thus it has almost none of the green and blue seen in most other light sources. The S/P ratio of the lamp is 0.35[10] A 5,000K Magnetic Induction Lamp outputs a far broader spectrum of light, including a lot of blue, and has an S/P ratio of 1.96. The S/P ratio is used as a multiplier (correction factor) to determine the amount of light the lamp is emitting that is useful to human vision. If the Sodium lamp has a rated output of 140 lumens per watt, and the induction lamp has a rated output of 80 lumens per watt, we can apply the respective S/P ratios as follows:

- 120 W Low pressure Sodium lamp [SOX 120] X 140 Lumens/W[11] = 16,800 Lumens X 0.35 = 5,880 lumens of light useful to human vision.
- 120 W Induction lamp X 80 Lumens/W = 10,200 Lumens X 1.96 = 18,816 lumens of light useful to human vision - more than 3 times as much useful light for the same electrical energy (ignoring for the moment the loss in the typical “core & coil” ballast found in the Sodium lamp and the 1%~5% energy loss in the Induction Lamp electronic ballast).

This explains why the Magnetic Induction Lamps always appear much brighter to the eye than most other light sources, even when those light sources have higher wattages, because the induction lamps produce more light that is useful to the human eye. Using the S/P ratio, we can see why Induction Lamp based Highbay fixtures can reduce energy consumption by replacing a conventional lamp of a much higher wattage:

- 400W Metal Halide lamp [M 400] X 54.6 Lumens/W[11] = 21,840 Lumens X S/P of 1.49[10] = 32,541 useful lumens
- 200W Magnetic Induction lamp X 82 Lumens/W = 16,400 Lumens X S/P of 1.96 = 32,144 useful lumens

Note: The calculations above do not take into account actual electrical energy consumption and ballast overhead, which, if included, would show the Induction Lamp to be even more efficient.

Measuring Light: Lumens, Lux, Foot-candles and CRI

In the lighting industry, the most common light measurement units are the Lux, the Lumen and the Foot candle. The Lux and the Lumen are both recognized parts of the International System of Units [SI units] which is the modern form of the metric system.[12]

- **Foot-candle** (sometimes **footcandle**; abbreviated fc, lm/ft^2, or sometimes ft-c) is a non-SI unit of illuminance or light intensity widely used in photography, film, television, and the lighting industry. The unit is defined as the amount of illumination the inside surface an imaginary 1-foot radius sphere would be receiving if there were a uniform point source of one candela in the exact centre of the sphere. Alternatively, it can be defined as the illuminance on a 1-square foot surface of which there is a uniformly distributed flux of one lumen. The foot-candle is equal to one lumen per square foot and is an Imperial unit.
- **Lux** (symbol: lx): Is the SI unit of illuminance. It is used in photometry as a measure of the intensity of light, with wavelengths weighted according to the luminosity function, a standardized model of human brightness perception. In English, "lux" is used in both singular and plural. $1\ lx = 1\ lm/m^2 = 1\ cd \cdot m^2 \cdot m^{-4}$
- **Lumen** (symbol: lm) is the SI unit of luminous flux, a measure of the perceived power of light. Luminous flux differs from radiant flux, the measure of the total power of light emitted, in that luminous flux is adjusted to reflect the varying sensitivity of the human eye to different wavelengths of light. $1\ lm = 1\ cd.sr = 1\ cd \cdot m^2 \cdot m^{-2}$

Typical Light Meters

Foot-candles are still occasionally used in building lighting applications, although they are more common in film and television applications. Since the foot-candle is not an SI unit, it is falling out of use in building lighting applications.

Typically measurements and government guidelines for lighting levels are specified in Lux. For example, the Ontario Government recommends a lighting level of between 300 and 500 Lux for workers using computer work stations.[14] The U.S. Department of Labour Occupational Safety & Health Administration (OSHA) recommends light levels ranging from a low of 54 Lux in general areas to a high of 323 Lux for First Aid stations, infirmaries and offices.[15]

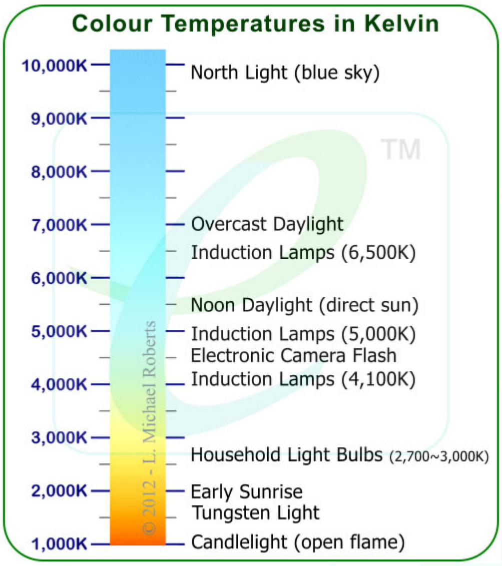
Lumens are most often used when discussing the conversion efficiency of lighting sources. For example, commercially available LED lamps have conversion efficiencies in the rage of 35 to 65 Lumens/Watt while Magnetic Induction Lamps have conversion efficiencies ranging from 60 to 90 lumens per watt (L/W) depending on the model - generally, the higher the wattage the Induction Lamp, the better the conversion efficiency. A high pressure Sodium lamp typically produces between 100 and 150 lumens per watt but with a low S/P ratio.

Since the lumen is adjusted to take into account only the Photopic sensitivity of the human eye, visual acuity under a Sodium lamp would not be good as it is lacking in the blues and greens needed to stimulate the Rod cells (scotopic vision). Vision under an Induction lamp, of the same or less wattage, will be better due to the additional blue and green output which contribute to the Scotopic vision. Because of the calibration curve of the meters, the Sodium lamp appears to be more energy efficient when in actual fact; all those extra lumens are contributing little to human vision due to the limited spectrum produced by the lamp.

Colour Temperature and CRI:

The colour temperature of a light source is measured in degrees Kelvin. Colour temperature is based upon the principle that a black body radiator emits light where the colour depends on the temperature of the radiator in degrees Kelvin. Light sources with temperatures below about 3000 K appear "warm" [have a more red/orange look] while light sources above 7500 K appear "cold" as they contain more blue.

A typical incandescent light's colour temperature is determined by comparing its colour [hue] with a theoretical, heated black-body radiator. The colour temperature of the light at which the temperature in Kelvin of the heated black-body radiator matches the colour [hue] of the lamp. 6500 K is the D65 European standard for "daylight" thus a lamp with a colour temperature of 6500K would be considered a daylight lamp in Europe, while a 5,000K lamp is considered a daylight lamp in North America.



The CRI of a lamp is the Colour Rendering Index (sometimes called Colour Rendition Index). CRI is a method devised by the International Commission on Illumination (CIE) to measure the ability of a light source to reproduce the colours of various objects being lit by the Light. The best possible rendering of colours is specified by a CRI of one hundred, while the worst possible colour rendering would be specified by a CRI of 0.

The higher the CRI of a lamp, the higher the "quality" of the light produced and thus the better the reproduction of colours under that lamp. EconoLux Induction lamps have a CRI of between 80 and 84 depending on the model and colour temperature.

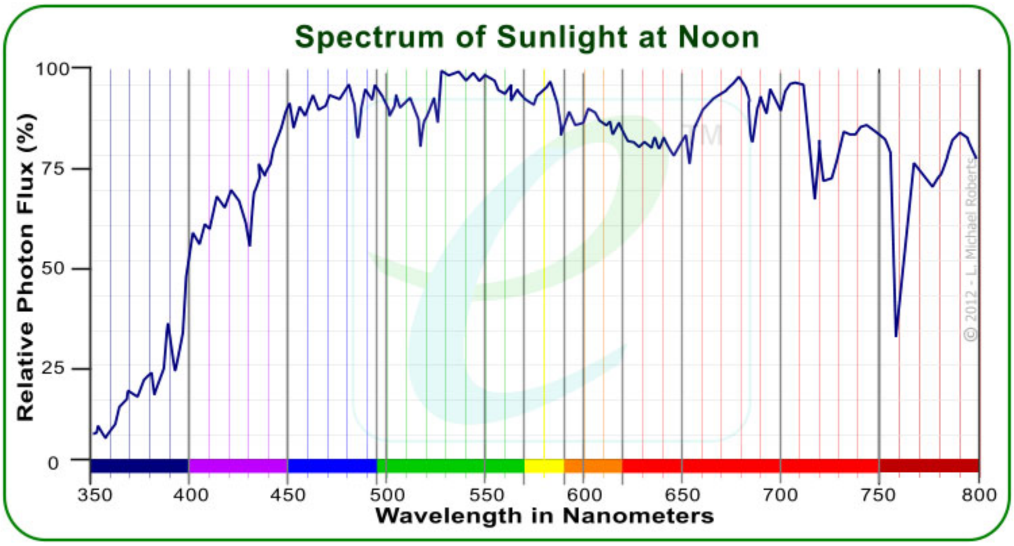
Colour rendering: *Effect of an illuminant on the colour appearance of objects, by conscious or subconscious comparison, with their colour appearance under a reference illuminant.*[16]

Spectral Distribution:

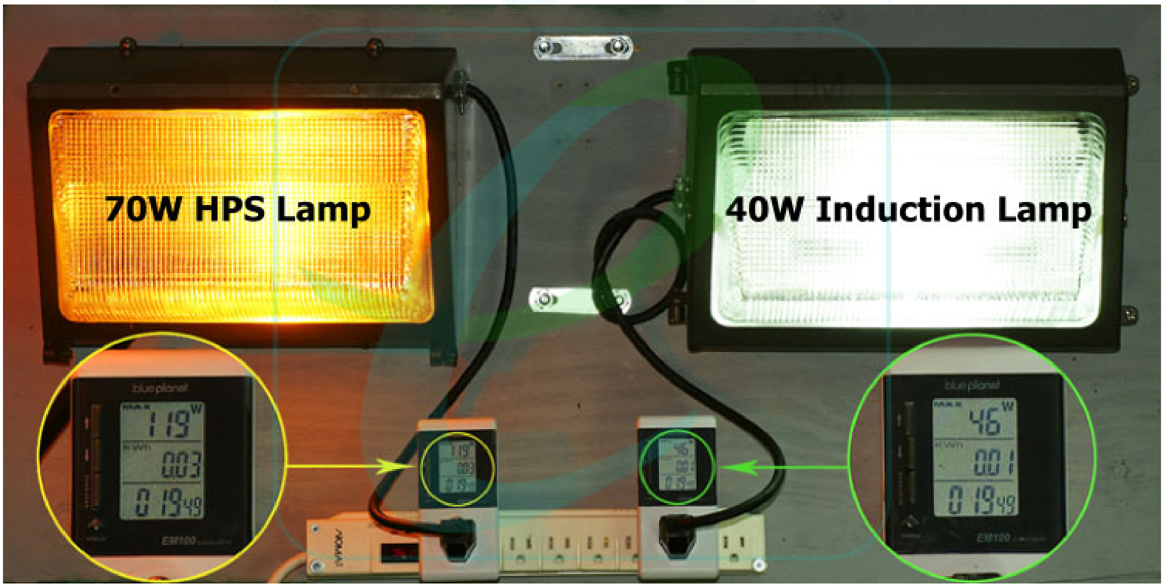
The spectral distribution of a lamp's output is a measurement of how much of each wavelength [colour] it produces. This can be measured with a spectrometer which is a device that measures the amount of light output at each wavelength and the results can be plotted on a graph showing intensity vs. wavelength.

The Earth is located about 149.6 million kilometres form the Sun, so it receives only a small fraction of the total energy radiated into space by the Sun. This energy is the source of all life on earth powering, wind, waves, photosynthesis in plants and many other biological processes.

Sunlight is the light source we are all most familiar with, thus artificial light sources [lamps] are often compared to the Sun or daylight conditions (see graph on next page).



The graph above shows the typical spectrum of sunlight on Earth at noon, on a cloudless day. Due to factors such as the amount of water vapour, particulate matter (dust), and pollution in the atmosphere, and the angle of the sun which affects the depth of atmosphere the sunlight must transit; the spectrum of sunlight can vary widely during the daylight hours. Thus the sunlight spectrum is usually taken when the sun is at the zenith (directly overhead).[17]



The photo above shows a comparison of two Wallpack type fixtures - commonly used for perimeter, exterior security, and underpass lighting.

Left: A 70W High Pressure Sodium (HPS) lamp. The wattmeter (insert) shows that with the ballast included, it is actually consuming 119W of power. The 70W HPS lamp is rated at 74.5 L/W thus it is producing 5,215 meter Lumens. When adjusted for the S/P ratio of 0.62, the lamp is producing 3,233 VEL

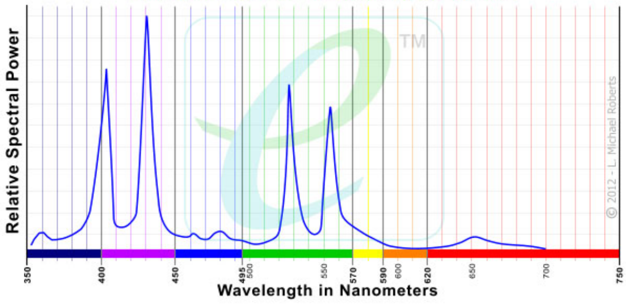
Right: A 40W, 5000K, Induction Lamp. The wattmeter (insert) shows that with the ballast included, it is actually consuming 46W of power. The 40W Induction lamp is rated at 73 L/W thus it is producing 2,920 meter Lumens. When adjusted for the S/P ratio of 1.96, the induction lamp is producing 5,723 VEL.

The EconoLux induction lamp **produces 43.5% more light** useful to human vision (VEL), while **consuming 61% less energy!**

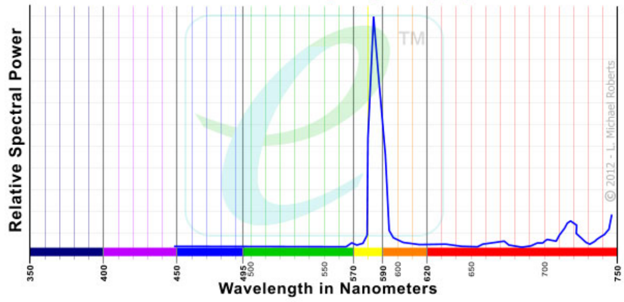
Below we have a series of graphs giving the spectral distribution (output) of various types of lamps commonly used in commercial and industrial applications (from manufacturer's data sheets), and the spectral output graphs for various colour temperatures (Kelvin) of EconoLux Magnetic Induction Lamps.

Typical Commercial / Industrial lamp types:

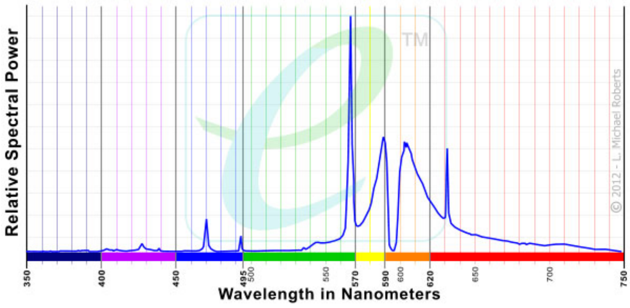
Mercury Vapour Lamp (MV) Spectrum



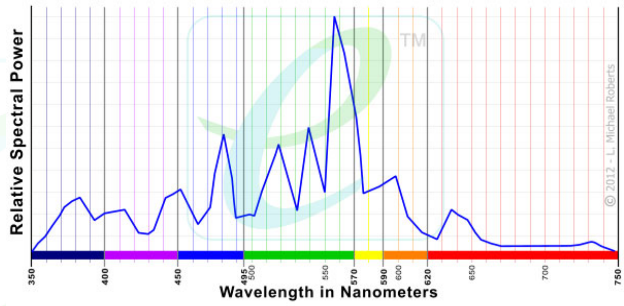
Low Pressure Sodium (SOX) Lamp Spectrum



High Pressure Sodium Lamp (HPS) Spectrum

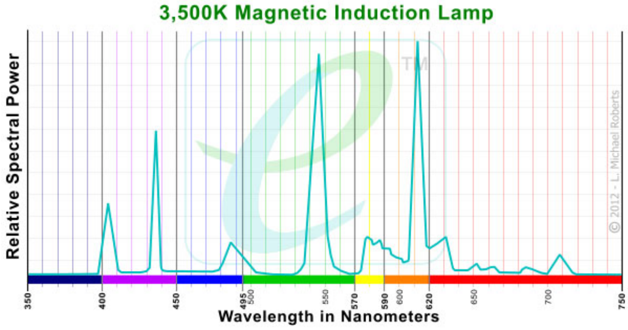


Metal Halide (MH) Lamp Spectrum

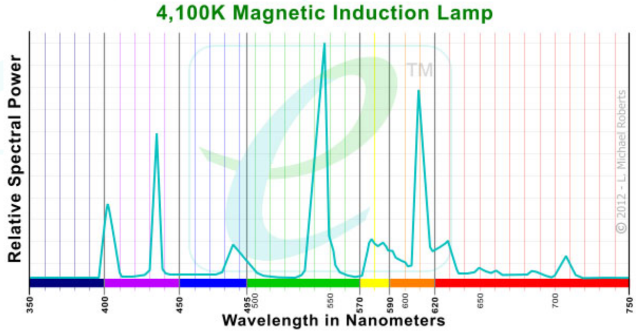


EconoLux Magnetic Induction Lamps:

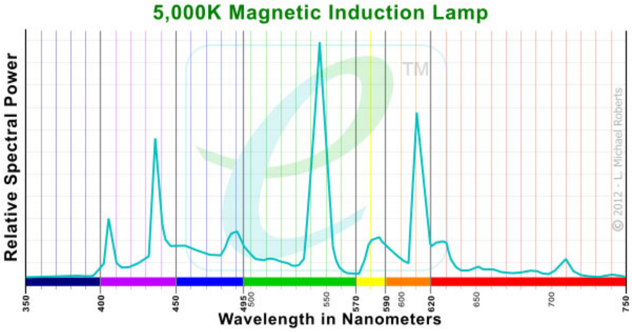
3,500K Magnetic Induction Lamp



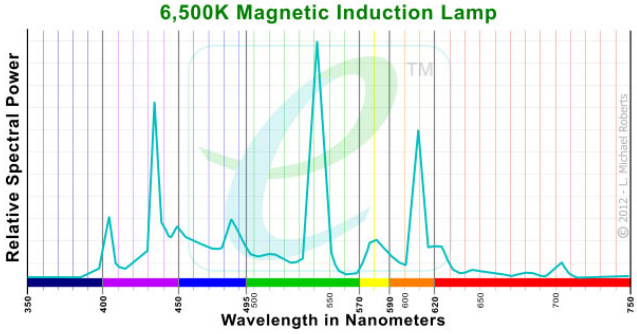
4,100K Magnetic Induction Lamp



5,000K Magnetic Induction Lamp



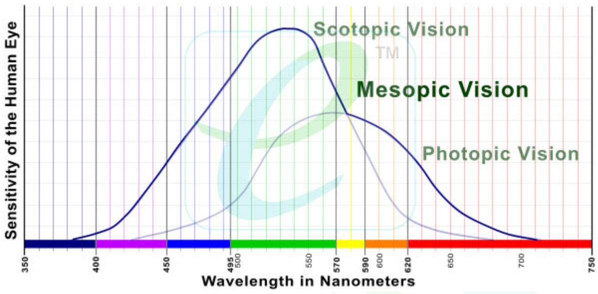
6,500K Magnetic Induction Lamp



Visually Effective Lumens/Lux A.K.A Pupil Lumens

While there is plenty of scientific evidence that we need to change the way in which we measure artificial lighting, there is, as yet, no industry wide agreement on the methodology or terminology for doing this. The author has chosen to use the term "Visually Effective Lumens" or "Visually Effective Lux", depending on the unit used for taking the light measurements, to describe the result of applying a correction factor to the readings taken by conventional light meters. This is contracted to VEL to describe the corrected readings as there is, as yet, no industry wide nomenclature. Some manufacturers are using the term "Pupil Lumens", (sometimes shortened to PL) to describe this correction process but again, at this time, no industry wide definition in use.

From the charts showing the sensitivity curves of the human eye's Photopic and Scotopic response, we can determine that some lamp types are going to appear brighter to the eye and give a better quality of light than others. Lamps which produce the maximum output in the spectrum where the human eye is sensitive to light, both Photopic and Scotopic vision, produce the most useful light and can be said to provide the most "Visually Effective Lumens" or "Visually Effective Lux" [VEL].



VEL is light that has an effect on both the eye's photopic and scotopic vision - Mesopic Vision. Lamps that are producing most or all of their light in spectral regions where human vision can make use of them, as opposed to lamps that produce their light only a narrow spectrum, are a better choice for lighting applications.

Obviously, the most ideal type of artificial light would mimic sunlight as closely as possible. At this time, the only artificial light source that comes reasonably close to actual sunlight (in spectral output) is the microwave sulphur lamp. This technology has not matured to the point where it is economically viable, except in certain niche applications.

The next best choice is a light source that has as wide a spectral output as possible, and with a large amount of blue output, so that scotopic vision is used and pupil diameter is reduced to improve visual acuity. The Magnetic Induction Lamps are the most economically viable and effective artificial light source as they offer long life, low energy consumption and have outputs which deliver the maximum amount of light usable to the human eye - Visually Effective Lumens [or Visually Effective Lux if one is using Lux as the measurement unit].

The Meters Are Wrong!

Current light meters, which measure according to the CIE curve, are wrong! They are measuring only the Photopic response of the human eye, in a very narrow cone of vision, and are NOT taking into account the contribution of Scotopic vision. Further, the scientifically proven control of the pupil by the blue components of Scotopic vision - which is important to visual acuity - is being completely ignored.

Lighting level regulations which are based on illuminance levels measured with conventional (CIE calibration curve) meters are forcing people to waste energy! In some situations, lighting companies have had to install a higher wattage of induction lighting than is necessary for good vision, even though people can see better under the induction lamps and perceive them as brighter than the lamps they are replacing. This had to be done to satisfy the light meters, which are ignoring Scotopic vision.

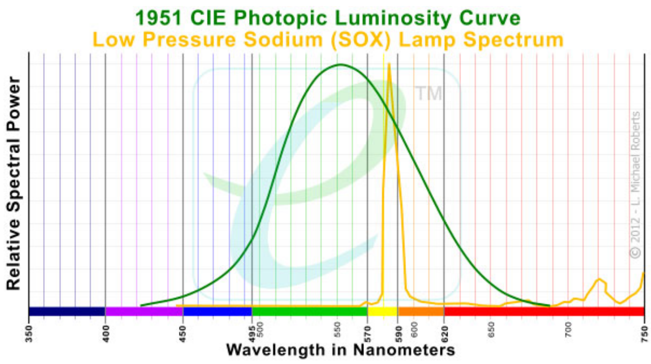
A far better method of determining the light levels would be to take the measurements and then multiply them by the S/P ratio of the light source, in this case Induction lamps, to determine the visually effective lumens or Visually Effective Lux (VEL - sometimes referred to as "Pupil Lumens" or PL). Once the VEL/PL for the Induction Lamps has been calculated, then only install sufficient lighting to meet the required levels using VEL rather than the conventional meter reading only.

Ask yourself this question… "Are we lighting spaces to satisfy the vision needs of the people using them, or the needs of light meters using a 1951 calibration curve, which ignores the findings of modern science?"

Why The Light Meters are Wrong - A Practical Example

By using light meters which are calibrated with the 1951 CIE Photopic Luminosity Curve (which only takes Photopic vision into account), important aspects of human vision sensitivity, and scientific evidence regarding the role of Scotopic vision in visual acuity are being ignored. This has led to the creation of some interesting phenomena and misconceptions about lighting levels and light quality.

As an example, for years, and even today, Low Pressure Sodium lamps (LPS/SOX) have been touted at the most "energy efficient" light source as they appear to provide the highest lumens per watt when measured with conventional light meters.



Looking at the diagram on the right, we can see why this claim is made, despite the fact that the light is almost monochromatic. The yellow/orange light of LPS lamps does not allow for quality vision. You will note from the graph that the LPS lamps (orange line) have a very large and well defined output spike around 589 nm. This spike occurs near the peak of sensitivity of the CIE Luminosity curve (blue line) of around 550 nm. As a result, the LPS lamps score high in the Lumens/Watts readings, while actually producing nearly monochromatic light, where people have difficulty distinguishing colours, and which is not pleasant to work under.

Manufacturers continue to tout LPS/SOX lamps as "energy efficient" even though we know that the light they produce is not as useful to the human eye as other light sources which have a broader spectrum output or are scotopicly enhanced.

Induction Walkway Lighting - IKEA Shanghai

Psychological effects of light

It is well known that the quantity, and quality, of artificial light in a space has direct psychological effects on the people using that space. Proper levels of lighting lead to reduced fatigue and eye strain, and contribute to better overall morale and performance by the people working under artificial lights.

The most well known example of the psychological effect of light is Seasonal affective disorder, or SAD. SAD, also sometimes known as winter depression or "winter blues", is a mood disorder. Most SAD sufferers experience normal mental health throughout most of the year, but they experience symptoms of depression in the winter months when there are less hours of daylight. SAD is rarely found in tropical latitudes, but is well known at latitudes north of 30°, or south of 30° where the length of the daylight cycles is more variable between the summer and winter months.[18]

> *"More than 60 controlled studies of light therapy have been conducted by researchers around the world. Although there are general limitations to each study (e.g., small sample size, brief treatment periods), several qualitative reviews have concluded that light therapy is an effective treatment for SAD, with response rates of 60% to 90% in controlled studies. Two meta-analyses also confirm the efficacy of light therapy against plausible placebo controls."*
>
> A Summary of the Report of the Canadian Consensus Group on SAD, Editors - Raymond W. Lam, MD, FRCPC and Anthony J. Levitt, MD, FRCPC. [19]

SAD Light Therapy

The most effective treatment for SAD is exposure to bright light. Scotopically enhanced light, which is perceived as brighter and which is closer to sunlight in spectral output than regular artificial lights, has been shown to be effective in treating or preventing SAD.[19]

Many people also complain of symptoms of eye strain such as fatigue, red-eye, headache, pain around the eyes, blurred vision, and occasionally double vision, from working under monochromatic light or in low light level conditions. Installing scotopically enhanced lights, which appear brighter, and which have a high CRI, can alleviate many of these symptoms.

Recent research has shown that there is a non-image-forming process in the human eye which responds to changes in environmental light irradiance (light levels).[20] This non-visual response has been shown to control the synchronization of the circadian rhythm - the body's internal "clock".[21] It also produces an increase in core body temperature[22], affects pupil constriction, reduces slow eye movements and enhances alertness.[23]

UK researchers published the results of a study on scotopically enhanced workplace lighting in 2007.[24] In this study, the typical fluorescent lamps on one floor of a call centre were replaced with lamps that had a high correlated colour temperature (Scotopically enhanced lights). On another floor in the same call centre, the already installed 2900K fluorescents tubes were not changed. The lighting was carefully adjusted so that there was no readily apparent difference in light levels (311 Lux under the scotopically enhanced lights and 354 Lux under the regular fluorescents). Employees on both floors were give initial psychological tests at the beginning of the three month trial period and then re-tested at the end of the trial.

At the end of the study period, the researchers found improvements of 30% or more in the areas of improved concentration, reduced light headnesses, lethargy and sleepiness in the group working under the scotopically enhanced lighting. In addition, at the end of the study those working under the high S/P ratio lights showed significant improvements in vitality and mental health compared to the original testing. The control group, working under the regular fluorescents, showed no significant improvement.[25]

Keeping brightness levels high using lamps with a high S/P ratio appears to be beneficial in the workplace by not only decreasing eye strain and related symptoms; but by improving the visual acuity and alertness of those working under the lights.

Systems that improve lighting levels and/or reduce glare can also improve productivity by reducing eye strain and fatigue. These increases in productivity can be even more valuable than the energy savings.

http://www.parcon.uci.edu/paper/EmergingElectricalTechnologies/eehigh.htm

Hum, Buzz, Flicker and the "Wagon Wheel" Effect:

We are all familiar with the annoying humming or buzzing sound that can be produced by some high intensity discharge lamps using "core & coil" (transformer) type ballasts. Typically the 60 Hz North American AC current (50 Hz in other parts of the world) causes the ballasts to hum or buzz at a fundamental frequency of twice the line frequency - 120 Hz (or 100 Hz for 50 Hz power) - with a large number of harmonics.

While we have been unable to locate any scientific studies demonstrating the effects on people exposed to this noise for several hours a day, it is most certainly annoying and a distraction in the workplace. The electronic ballasts in Magnetic Induction Lamps operate at very high frequencies and do not contain a "core & coil" assembly so they operate silently lowering distractions and noise in the workplace.

Almost all AC powered lights produce flicker - intermittent or regular variations in the luminous intensity (output) of the lamp. Most people do not notice this as the "persistence of vision" effect smoothes over the variations in the light. Persistence of vision is what allows us to see 24 frames per second in a movie as continuous motion. In addition, the thermal lag [time it takes for the filament to heat up and cool down] in incandescent lights smoothes this effect but it is still occasionally detectable.

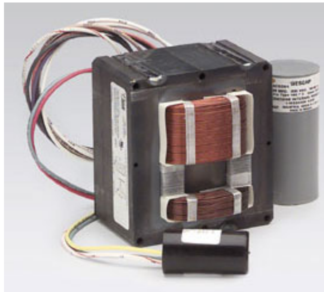
Typically, lights operated from "core & coil" ballasts will flicker at 120 Hz [in North America, 100 Hz in Europe]. A 60 Hz AC power line reverses polarity 120 times per second which is what causes this effect. Standard fluorescent lamps do not have any thermal lag so the flicker effect is often very perceptible to those working below such lighting. Since fluorescent lamps were first introduced people have complained of visual discomfort and headaches even though the flicker is not perceptible to most people.[26]

Research conducted by the Institute for Research in Construction division of the National Research Council Canada tested the effects of fluorescent light flicker rates on visual performance and visual comfort.[27] Subjects were given a test which determines visual acuity [VALiD] after a period of reading fine text for five minutes. The VALiD test was taken using various lighting conditions with both regular "core & coil" [120 Hz flicker] and high frequency [20-60 KHz] type ballasts driving the lights. The results found that the visual performance scores of the test subjects were significantly higher using lights with high frequency ballasts than the "core & coil" types. Magnetic Induction Lamps are equipped with very high frequency ballasts and produce no flicker perceptible to humans.

Flicker can have another detrimental effect due to the "stroboscope effect" which can make machinery appear to be moving slower than it is, or even moving backwards. This effect has been nicknamed the "wagon wheel" effect due to the appearance of wagon wheels turning backwards in movies because you are seeing only 24 images per second. An object, such as the rotating chuck on a lathe, can appear to be moving at a slower speed, or even appear to be stationary, if the speed of the rotating object is a multiple of the speed at which the light illuminating the moving object is flickering. This can present a safety hazard to those working with the machine. Since Magnetic Induction Lamps use a high frequency ballast, the flicker effect is almost totally eliminated leading to improved safety.

Ballast Efficiency and Power Factor

When manufacturers talk about the wattage of lights, they are generally referring to the wattage consumed by the actual lamp. This figure generally does not include the "ballast overhead" which is the amount of power consumed (or wasted) by the ballast. When measuring the energy consumed by a 200W lamp with an actual watt meter, the result is always a number higher than 200 watts.



Typically, "core & coil" ballasts have an overhead of between 10 and 20% of the energy consumed by the fixture. Thus a 200W metal halide lamp using a "core & coil" ballast with a 10% overhead is consuming 220W of energy in the fixture. As the lamp ages, this number creeps up slowly due to the extra energy required to power the lamp. Electronic ballasts are generally much more efficient than "core and coil" type ballasts usually in the rage of 4-9% ballast overhead. Thus a 200W metal halide lamp with electronic ballast which is 8% efficient will be consuming 216W of energy in the fixture.

Example of an induction lamp ballasts

The high frequency electronic ballasts driving EconoLux Magnetic Induction Lamps have a ballast overhead of between 1% and 5% (depending on model). A 200W Magnetic lamp thus consumes between 202W and 210W of energy in the fixture. While the difference between a lamp consuming 216W and a lamp consuming 202 watts [14 watts] may seem small, when multiplied by dozens or even hundreds of fixtures in a building, and considering the hours the fixtures are operated, this can present a significant annual energy saving.

The power factor in AC electrical systems is the ratio of the real power to the apparent power. Real power is the ability of the circuit to perform work in a particular time. Apparent power is the product of the current and voltage of the circuit. Resistive devices such as incandescent lights do not affect the power factor while any device containing transformers and capacitors will affect the power factor - "core & coil" ballasts are a type of transformer. Due to small amounts of energy stored in the lighting load and returned to the source, or due to a non-linear load that distorts the wave shape of the current due to coils, transformers or capacitors, the apparent power will be equal to, or greater than, the real power. Low power factor devices consume more energy and thus increase losses in a power distribution system, resulting in increased costs for electrical energy use.

Power factor is stated as the Cos Phi of a device. The closer to 1 the Cos Phi number is, the more efficiently the device is using the power provided and thus the more energy efficient the device. The EconoLux Induction Lamp electronic ballasts have a Cos Phi of between .95 and .99 (depending on model) which means they only waste 5% to 1% of the total energy consumed by the fixture in ballast losses.

Thermal Loads:

The wasted energy in ballasts and lamps usually manifests as heat. This is an additional "hidden cost" of inefficient lighting systems, as the extra heat has to be removed from the space with the building air conditioning system. Installing magnetic induction lamps will reduce the thermal load and thus the amount of energy needed by the air conditioning to remove excess heat. This is especially true of lighting fixtures used in refrigerated storage spaces and food lockers. Again, the amount of energy saved per lamp may be small but the multiplier effect of many fixtures in a building adds up over time.

Quality of Light:

Quality of light is a difficult concept to discuss as there is, at this time, no objective scientific way of measuring or quantifying light quality. There is a subjective judgement by people who observe that certain lights have a different quality of light than others.

People in a space lit by low Kelvin incandescent, compact fluorescent or other lamps, perceive the light as "warm"; while a space lit with high Kelvin lamps (such as "cold white" type fluorescents) is perceived as "cold". Other factors such as the almost imperceptible flicker from lamps using "core & coil" ballasts, glare from point source lights and poor light distribution from incorrectly placed fixtures, contribute to a perception of poor light quality in a space.

Magnetic Induction Lamps are a large area source (broad source) so inherently have less glare. They offer a high S/P ratio leading to better visual acuity and a reduction in eye-strain and fatigue related complaints. Even light distribution from the Induction Lamp fixtures, higher Kelvin with good spectral distribution and no flicker all contribute to a perception of "high quality" light from EconoLux Induction Lamps.

Left: Tube joining at the EconoLux Industries factory. The induction lamp tubes are molded, cleaned, coated and baked as "half-tubes" (you can see some on the table in front of the worker in the background). In this area of our factory, the half-tubes are mounted into a jig and then fused together using high temperature gas torches.

In this photo the workers are making 200W round induction lamp tubes. After the tubes are fused together, they are inspected and then go to the evacuation stations.

Right: Gas-fill inspection at the EconoLux factory. The lamps are still in the evacuation station where they are connected to equipment which is used to vacuum all of the air out of the lamps before our proprietary gas-fill is introduced.

In the photo, a worker is checking the gas-fill using a tesla coil to ionize the gas. Once this test is passed, the lamps are then sealed off and removed from the evacuation station. They then go to the finally assembly area to have the inductors installed.

Saving Energy and Money

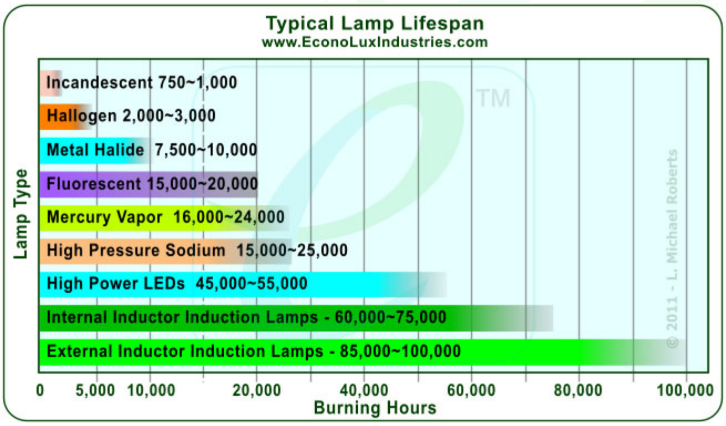
It is a well established fact that replacing lamps that are not energy efficient can save both money and energy. Energy savings are important not only from the financial perspective, but also from the perspective of reducing fossil fuels used to generate electricity, thus lowering CO_2 emissions, and contributing less to climate change and global warming. "Going green" can be important not only for the bottom line, but for promoting good corporate citizenship.


Example Induction High-bay fixture with close-up of wattmeter showing only 170W of power consumption.

If an example warehouse area has 20 metal halide high-bay lamps, with a nominal rating of 400 watts each, and using "core & coil" ballasts" (with a ballast overhead of 15%), then the total energy consumption is 9,200 watts or 9.2 kilowatts per hour (kWh). If these lights are in operation 8 hours per day, then the total electrical energy consumed would be 73.6 kWh per day.

Replacing these 20 fixtures with 200W Induction Lamp lighting fixtures, which use electronic ballasts that have only a 5% ballast overhead, reduces the total energy consumption to 4,200 watts (4.2 kilowatts per hour) for a total energy consumption of 33.6 kWh per 8 hour day. Less than half the energy consumption of the replaced Metal Halide lights.

The 40 KW/Hr of energy saved not only contributes to energy cost savings, but using the figure of 1.04 Kilograms (2.29 Lbs) of CO_2 emitted for each kilowatt hour of electricity generated [28], reduces emissions by 33.2 kilograms (73.1 Lbs) of CO_2 per day!



Maintenance costs are also significantly reduced by installing Induction Lighting. Sodium and Metal Halide lamps must typically be replaced every 18,000 to 22,000 hours as they burn out - some locations replace them on a shorter maintenance cycle when light output drops below 70%. This requires someone to set up scaffolding, a ladder or use of a "cherry picker" to get up to the fixture and replace the lamp. If the lamps are located over production equipment or other busy areas, this can also entail a disruption of normal operations. Since Induction Lamps last between 85,000 and 100,000 hours, re-lamping frequency and its associated costs are considerably reduced.

Further savings can come from the instant-on and hot re-strike features of Induction Lamps. In some spaces, lit by conventional lights, and which are not in continuous use, the HID lamps remain lit all day as it is inconvenient, and a waste of people's time, to wait for the lights to come up to full brightness each time people enter the area. While the induction lamps typically come on at about 80% of output, they warm up very rapidly - within 60-90 seconds - and the initial output is usually more than enough for people to see while the lamps warm up.

Thermal load reduction also offers another way to save energy and money. The Induction Lamps produce much less heat than the conventional lamps they replace, saving on air conditioning costs. The broad operating temperature range and low heat output of Induction Lamps makes them an ideal choice for refrigerated spaces such as food or flower storage areas.

Case Study:

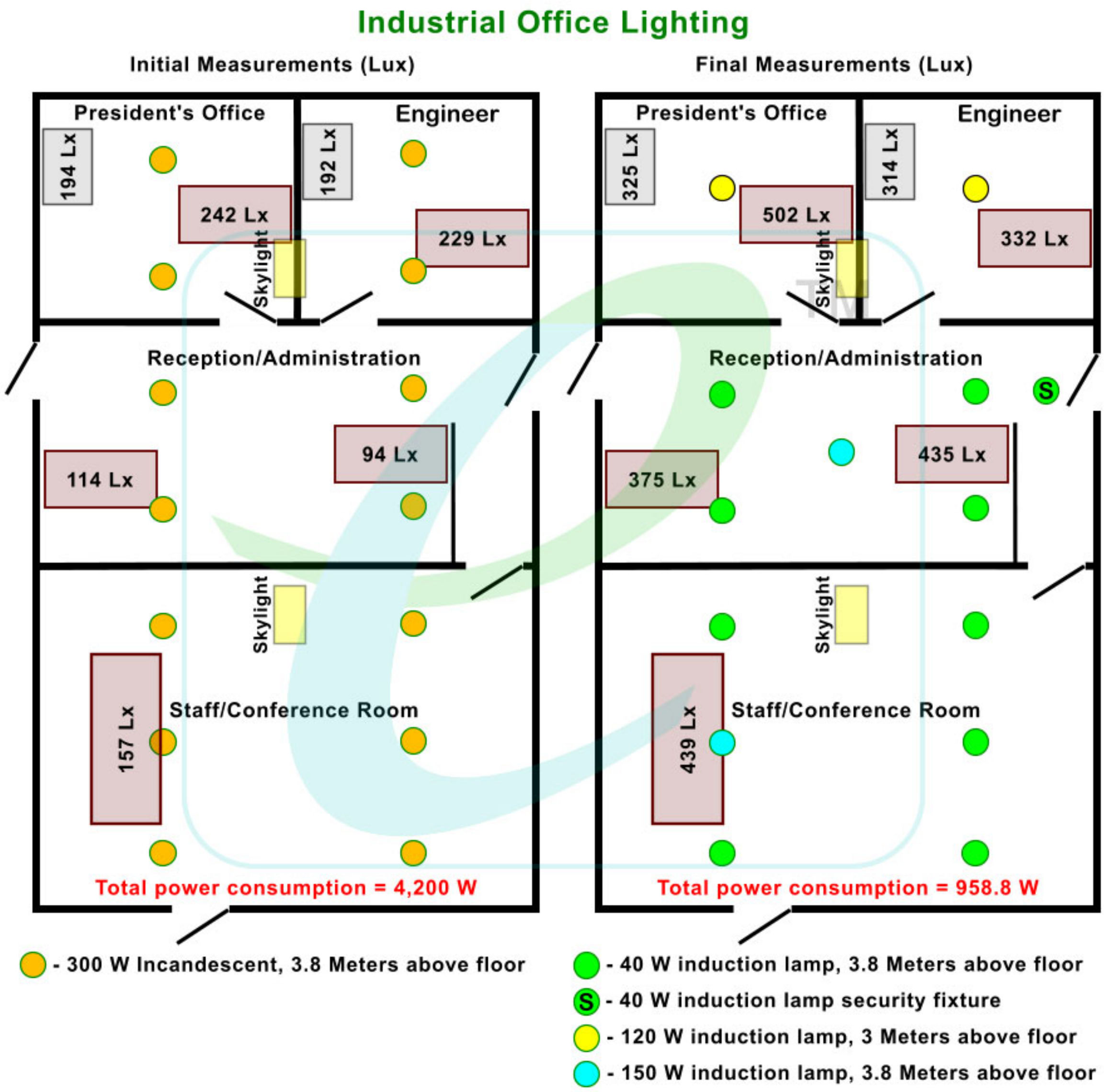
A high-tech company, who are fabricators of precision composite structures for such applications as wind turbine blades, were located in an older industrial building built in the early 1950's. The office area was lit with 14, 300 watt incandescent light bulbs (in original fixtures), which consumed a total of 4,200 watts of energy.

These were replaced with a mix of 40 watt, 120 watt and 150 watt Induction Lighting fixtures. The total lighting electrical load (including ballast overhead in the replacement fixtures) was reduced to 958.8 watts – **a 77% decrease in energy consumption.**

Replacement of the "warm" incandescent bulbs with the 4,100K Induction Lighting system **increased CRI to 82** for a bright and pleasant light level. Additional Magnetic Induction Lighting fixtures were selected and carefully located to enhance total lighting levels in the office, without glare, and to ensure all task areas comply with current Ministry of Labour recommendations.

The average lighting levels in the office were increased from 175 Lux to 389 Lux – **an increase of 45%** while decreasing energy consumption and reducing costs.

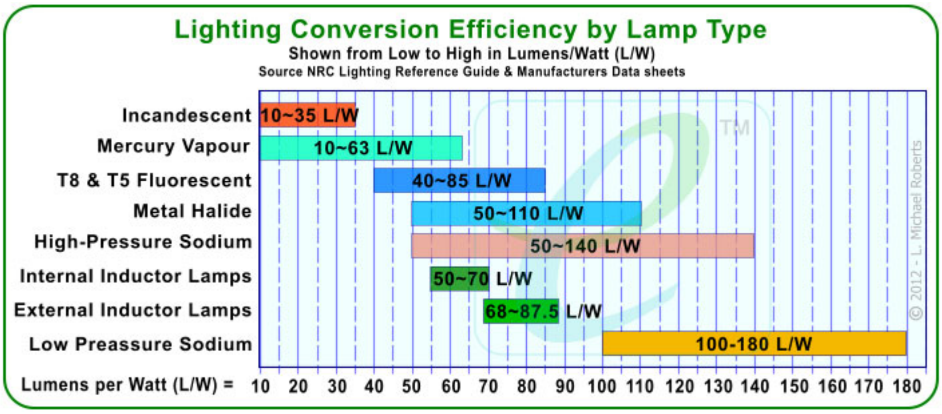
In addition, the company will realise additional savings through operational and maintenance cost reductions as the lamps will last 10 years, and they have created a more productive environment for all of the office workers.



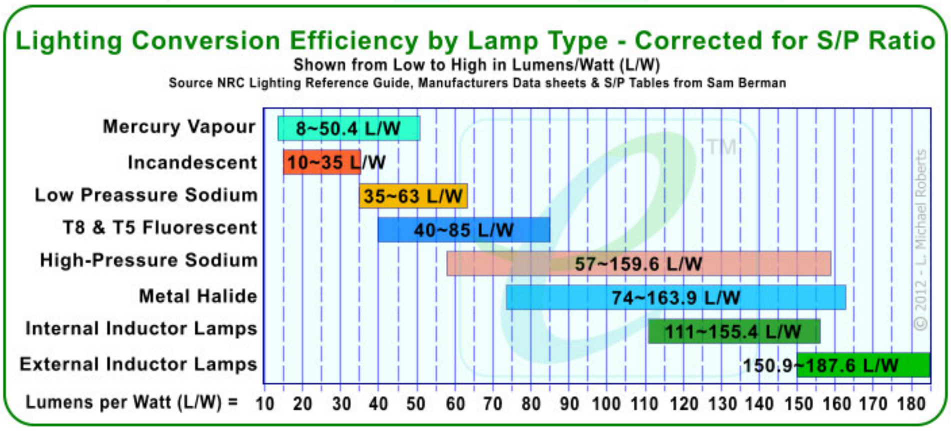
Note: before and after light levels in the diagrams above shown in Lux (Lx)

How Much Useful Light Do You Get for Your Money?

The following charts compare the lumens per watt (L/W) output of common industrial lamps of various types, with EconoLux Magnetic induction lamps. The first chart shows the lumens per watt output[29] for various types of lamps and Induction Lamps (ballast overhead is *not* included).



The chart below shows the actual amount of useful light you get when the conversion efficiency (Lumens/watt) shown in the first chart, is corrected for the S/P ratio of the lamps (ballast overhead is *not* included).



These charts demonstrate that Magnetic Induction Lighting is the best choice as it gives you the most light for your money, as well as offering maintenance and other cost savings.

Environmental Aspects:

We have previously discussed the savings in electrical energy, and briefly mentioned the reduction of the CO_2 emissions produced in making the electricity used by lighting. However, Magnetic Induction Lighting offers another significant environmental benefit.

Almost all modern lighting technologies depend on using mercury inside the lamp envelope for operation. When considering the environmental impact of the mercury in lighting, we must take three major factors into consideration:

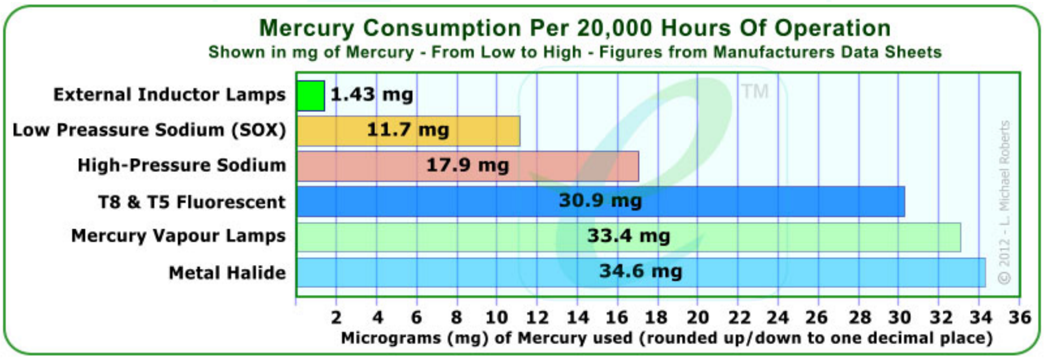
- The type of mercury (solid or liquid) which is present in the lamps,
- The amount of mercury present in a particular type of lamp, and
- The lifespan of the lamp which will determine the amount of mercury used per hour of operation.

Liquid mercury, which is the most common form of mercury used in lighting, represents the greatest hazard. If a lamp is broken, the mercury can find its way into cracks in concrete flooring or into spaces in other floor coverings. Over time, the volatile liquid mercury will evaporate into the atmosphere causing a local "hot spot" of low level mercury contamination. The more liquid mercury that is present in a lamp, the longer the resulting contamination (hot spot) will last. This is why lighting containing liquid mercury should be properly disposed of in accordance with local environmental regulations.

Mercury can be compounded, with other metals, into a solid form called an amalgam. This is the type of mercury used in EconoLux Induction Lamps. This is similar to the once widely used "silver" amalgam in dental fillings. This solid form of mercury poses much less of an environmental problem than liquid mercury. The small slug of amalgam can easily be recovered (always wear disposable gloves) in the case of induction lamp breakage, and therefore can be disposed of properly with little or no risk of creating a locally contaminated area. The solid mercury amalgam is also simpler to recover for recycling at the end of the lamp's life.

Mercury amalgam for expired Magnetic Induction Lamps, when kept separate from other waste, can be recycled safely. The mercury can be recovered from amalgam waste through a distillation process and then reused in new products. If amalgam waste ends up in an incinerated waste stream, the mercury can be released to the environment due to the high temperatures used in the incineration process. Increasingly, local communities are enacting restrictions on the incineration of wastes containing mercury.

Induction lamps use the least amount of mercury of any lamp technology, when considered based on both initial quantity in each lamp, and amount used per 20,000 hours of lamp life. Induction lamps are therefore much more environmentally friendly since they use very little mercury over their lifespan. Further, the mercury is in a solid amalgam form reducing contamination in the case of accidental breakage and making recovery for recycling simpler. The chart below puts this information into visual form for the most common types of industrial, commercial and retail lighting technologies.



"If the total amount of mercury contained in a typical fluorescent tube (approximately 20 milligrams), were to mix completely and evenly in a body of water, it would be enough to contaminate around 20,000 liters (4,400 gallons) of water beyond Health Canada limits for safe drinking water (0.001 milligrams of mercury per liter of water)"

Environment Canada[30]

Recycling:

Induction lamps have the further advantage that they are made of glass, they have metal components, the phosphor coating in EconoLux lamps is non-toxic, there is very little plastic (mostly the insulation on the induction coil), and the mercury amalgam is easily removed. As a result, the lamp can be broken down into its component parts at end-of-life, and the vast majority of those parts can be recycled.

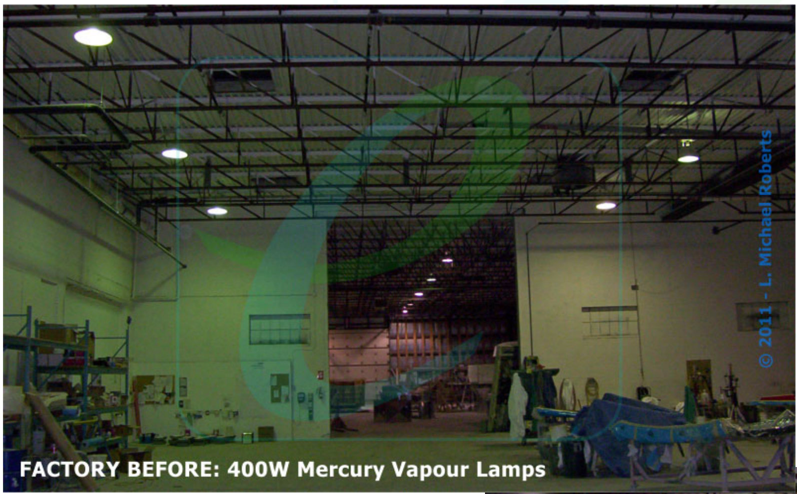
Summary

Magnetic Induction Lamps offer an economically viable way to improve lighting conditions while reducing energy consumption, and other operational and maintenance costs. People who see the Induction Lamps remark at how bright they appear and the improved quality of the light.

EconoLux Induction Lamps offer high Scotopic/Photopic (S/P) ratios. Scientific studies have shown that having a high S/P ratio is beneficial as it improves visual acuity, and can reduce fatigue and eye strain thereby improving working conditions. Studies have shown that working under higher brightness scotopically enhanced lighting can have beneficial psychological effects leading to improvements in productivity.

When the Magnetic lights are measured using conventional light meters, they often appear to be outputting less light than the fixtures they replace even though the light is visibly brighter. This is because the light meters are wrong! Unfortunately, today's light meters are calibrated according to a 1951 curve that does not take the role of Scotopic vision into account, and does not give a true reading of how much light useable to the human eye is available. This paper uses the concept of Visually Effective Lumens (VEL) which takes the S/P ratio of the lights into account and therefore gives a true measure of the light available to the human eye.

Ask yourself the question… "Are we lighting spaces to satisfy the vision needs of people, or the needs of meters using a calibration curve which ignores the findings of modern science?" If we are lighting for people, then scotopically enhanced, energy efficient, low maintenance, environmentally friendly lighting, such as EconoLux Induction Lamps, are the best choice.



FACTORY BEFORE: 400W Mercury Vapour Lamps

FACTORY AFTER: 200W Induction Lamps

Advantages of EconoLux Magnetic Induction Lamps:

- Very long lifespan compared to conventional lighting technologies - 60,000 to 85,000 hours for most internal inductor lamps, 95,000 to 100,000 hours for external inductor lamps.
- High energy conversion efficiency ranging from 60 L/W in low wattage models to 90 L/W in high wattage models.
- Provides substantial energy savings of between 35% and 75% in most applications.
- Typically, induction lamps are guaranteed for 5 years but with an expected lifespan of between 60,000 to 100,000 hours (between 6.8 and 11.5 years of 24/7 operation), they substantially reduce maintenance and re-lamping costs.
- Magnetic induction lamps have excellent lumen maintenance characteristics producing higher light output for a much longer time than competing technologies.
- Globe/light bulb shapes of internal inductor lamps are more aesthetically pleasing and have greater consumer acceptance than the "curly tube" CFL lamps.
- Induction lamps are "instant-on" type. They initiate at between 70% and 80% of output and take 45-120 seconds to reach full output. This instant on characteristic makes them ideal for use in applications with occupancy or motion sensors.
- Induction lamps provide "hot re-strike" (instant re-start) eliminating long lamp re-start times associated with other HID lighting technologies.
- Induction lamps operate at high frequencies and are flicker-free reducing eyestrain and improving workplace safety.
- Induction lamps have a high Scotopic/Photopic (S/P) ratio which improves visual acuity, reduces fatigue and eye strain thereby improving working conditions.
- Induction Lamps are environmentally friendly containing only solid amalgam mercury which is completely recyclable, other commercial lighting types contain hazardous liquid mercury. Al the other glass and metal components of the induction lamps can also be recycled at end -of-lamp-life.

Bank Exterior Induction Lighting - Hong Kong

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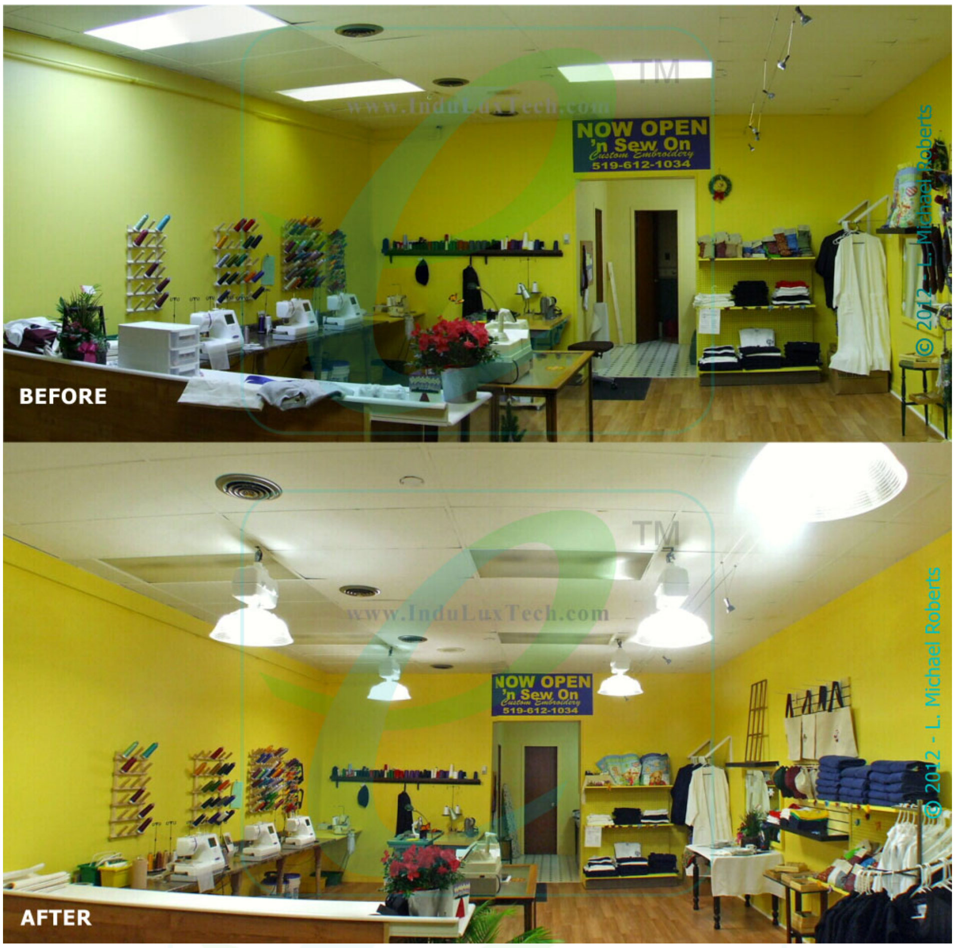
Note: Many of the references provide links to relevant websites. These links were current at time of publication but may have changed.



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