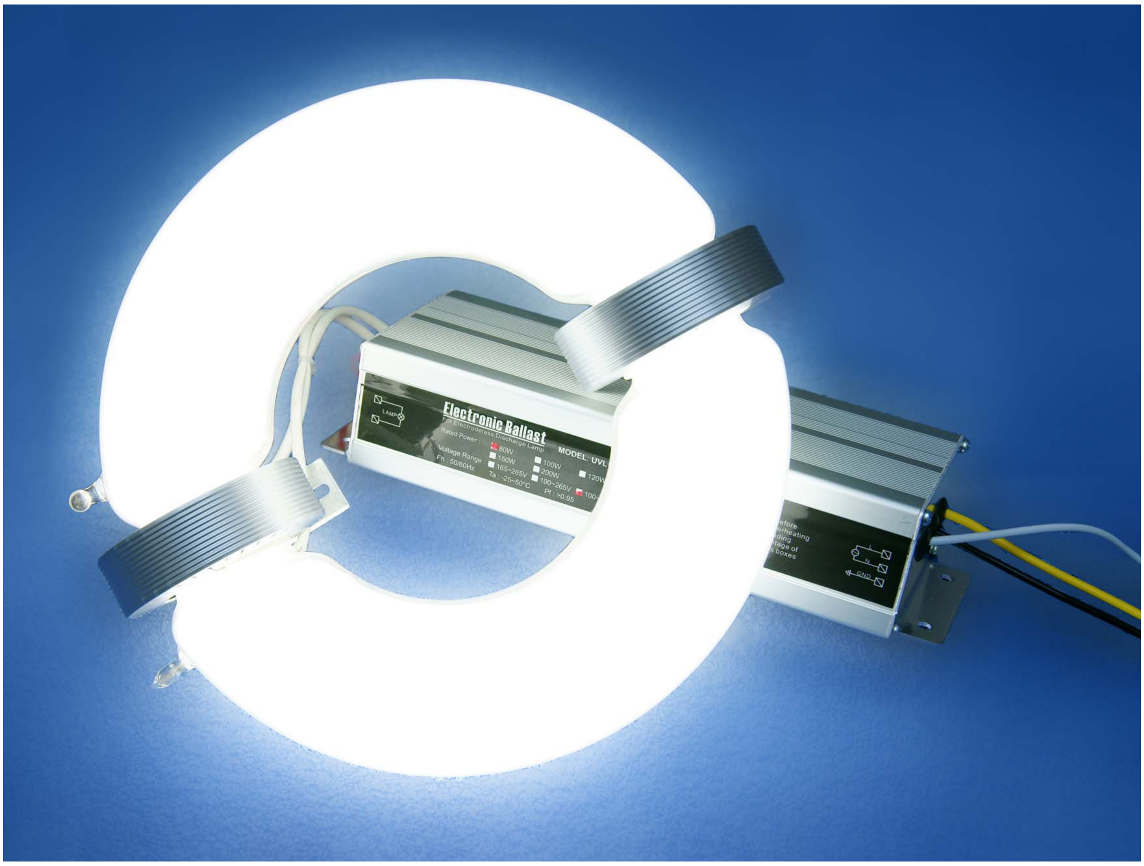
InduLux Technologies Inc.

How Magnetic Induction Lamps Work

By: Michael Roberts



MAGNETIC INDUCTION LAMP AND IT'S ELECTRONIC BALLAST

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About the Author - Michael Roberts

Michael Roberts was born of Canadian parents in the Republic of South Africa. He moved back to Canada, via a year in Europe, in his late teens to correct the situation. His father was an electronics engineer and radio amateur (ham) and he influenced Michael's early interest in electronics and mechanical devices. In school Michael studied the regular subjects along with art, art history, classical and vocal music and was involved in his school theatre productions. He found he was more interested in the lighting, sound and production aspects of the shows. Thus began a life-long interest in the technical aspects of show production, especially lighting.

Michael Roberts is the Chief Technology Officer for InduLux Technologies Inc., an R&D and intellectual property company focusing on energy efficient technologies - www.InduLuxTech.com Michael is presently working on advanced, high efficiency, magnetic induction lamp light sources. An induction lamp Highbay fixture he designed won the 2006 "Innovative Product Award" from the Huron Manufacturers Association.

Michael travels to China frequently and regularly visits all of the major induction lighting factories. He has worked with a number of Chinese induction lamp manufacturers on improvements to the technology as well as fixture designs optimized for use with magnetic induction lamps.

Michael is an inventor with two granted patents in UV water treatment technology. He also invented the world's first UVC induction lamp. He presently has various patents pending on Magnetic induction lighting technology, and specialty induction lighting fixtures. He works as a consultant to manufacturers and distributors of magnetic induction lighting products worldwide, some of which are also licensees of his Intellectual Property. He is also an author whose works have been translated into a number of languages.

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Introduction:

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

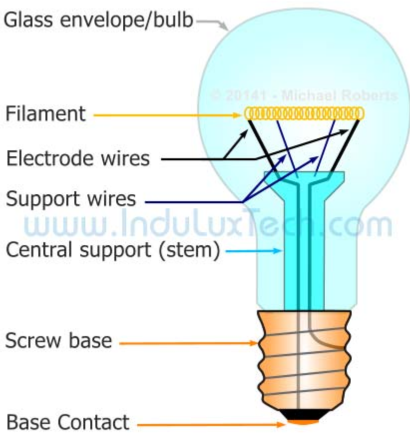
Interestingly, Canadians Henry Woodward and Matthew Evans filed a patent in 1874 for a light bulb, which used a carbon filament in a nitrogen atmosphere. They were unsuccessful in commercializing the lamp but caught the interest of Edison who considered this Canadian technology so intriguing, he bought 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 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. 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.

"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.

Incandescent Lamps:

We will begin our review with the most common form of electrical light we are all familiar with, which is the incandescent lamp. 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 filament.



INCANDESCENT LAMP DIAGRAM

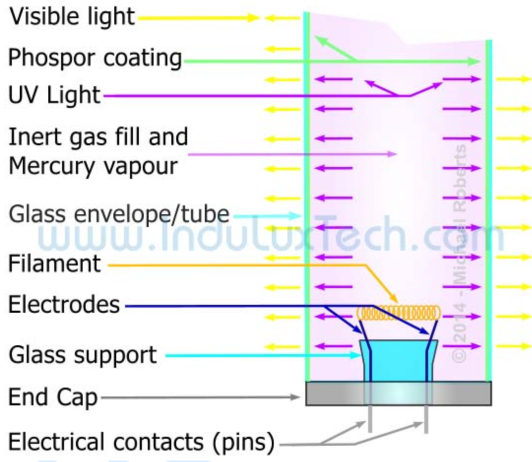
The incandescent lamp works by passing an electrical current through the filament, typically made of tungsten, which then glows white hot emitting light. This is not an efficient process as approximately 95% of the energy supplied to the lamp is emitted as heat. The filament must be contained in an evacuated 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:

We will take a closer look at fluorescent lamps, since they are related to Induction Lamps, as both produce light by a similar mechanism, although the method used to transfer the energy to the inside of the tubes is different. 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 on the inside of the tube into the visible light emitted from the lamp.



FLUORESCENT LAMP DIAGRAM

At each end of the typical fluorescent lamp, there are small tungsten filaments which are usually 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 current to the tube. The most common and simple type of ballast is a magnetic or “coil and core” type 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 heat (wasted energy) - typically between 12% and 16% of the energy consumed by the lamp is wasted in the core and coil type ballasts. The Governments of the USA and Canada are limiting the availability of inefficient T12 “core and coil” ballasts after April 2010 in order to improve the energy efficiency of fluorescent lighting.

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 5% and 8.5% 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 lamp 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 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 tube);
- 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 or filaments 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]. 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 envelope are depleted, the lamp emits only a very 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 (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.

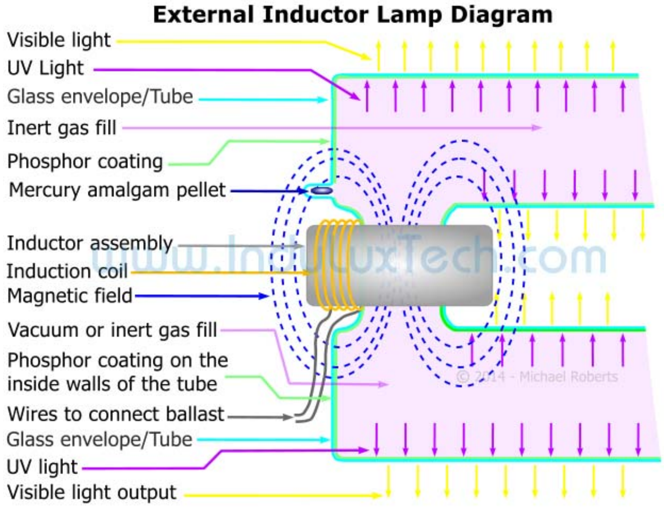
A microwave lamp bombards a capsule of sulphur with radio frequency energy which causes the sulphur to be heated becoming a light emitting plasma. The capsule has to be rotated to prevent uneven heating and must be cooled by a fan, thus the lamps contain mechanical parts. These lamps have not found wide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

Magnetic Induction Lamps (see examples in photo on left) are fluorescent type lamps with a coil wrapped around a ferrite core, which is either attached to the exterior of the lamp tube, or inserted into a cavity in the center of the lamp. High frequency energy from the electronic ballast is sent through the coil wound around the inductor to produce a magnetic field. The induction coil produces a very strong magnetic field which travels through the glass tube walls and excites the mercury atoms (provided by the amalgam) inside the lamp.

There are two main types of induction lamps:

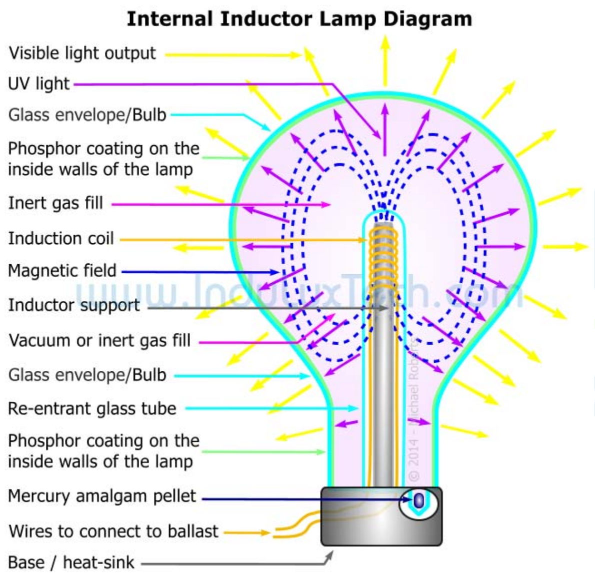
- Internal inductor lamps which are generally globe shaped and have the ferrite core and coil inserted into a cavity in the center of the lamp; and
- External inductor lamps where the ferrite core and the magnetic coil are wrapped around the exterior of the glass tube.

External inductor lamps are basically fluorescent lamps with magnetic induction coils wrapped 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 envelope/tube walls and excites the mercury atoms causing them to emit UV light inside the tube. The UV light is up-converted to the visible light we see by the phosphor coating on the inside of the tube.

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



In a variation of this technology, a light bulb shaped glass lamp, which has a test-tube like central re-entrant cavity (glass tube), is coated with phosphors on the inside and filled with inert gas and a pellet of mercury amalgam (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, to produce a strong magnetic field.

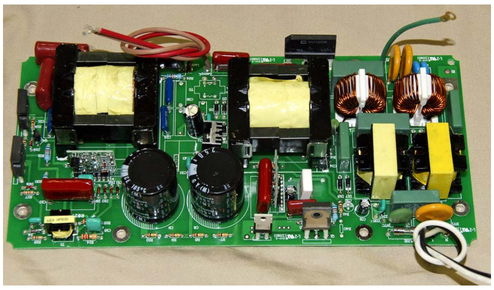
The advantages of Induction Lamps are long life span due to the lack of internal electrodes and very high energy conversion efficiency due to the high frequency electronic ballasts which are 95% to 98% efficient. These benefits offer a considerable cost savings of between 40% and 75% in energy and maintenance costs compared to other types of lamps which the induction lamps can replace.

As with conventional fluorescent lamps, varying the composition of the phosphors coated onto the inside of the Induction Lamp tubes allows for models with different colour temperatures. Most induction lamps in use are "scotopically enhanced" types and are primarily 5,000K models. Some 6,500K induction lamps are also used in applications where high visual acuity is required, as those more closely simulate daylight and provide the best value-for-money.

Ballasts:

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 MHz 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 creates a strong magnet field in the inductor which couples the energy through the glass and into the mercury atoms inside the tube or lamp.

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. Induction 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 lamps start at between 75% and 85% of output and warm up to full output almost imperceptibly within a minute or two.



INDUCTION LAMP BALLAST CIRCUIT BOARD

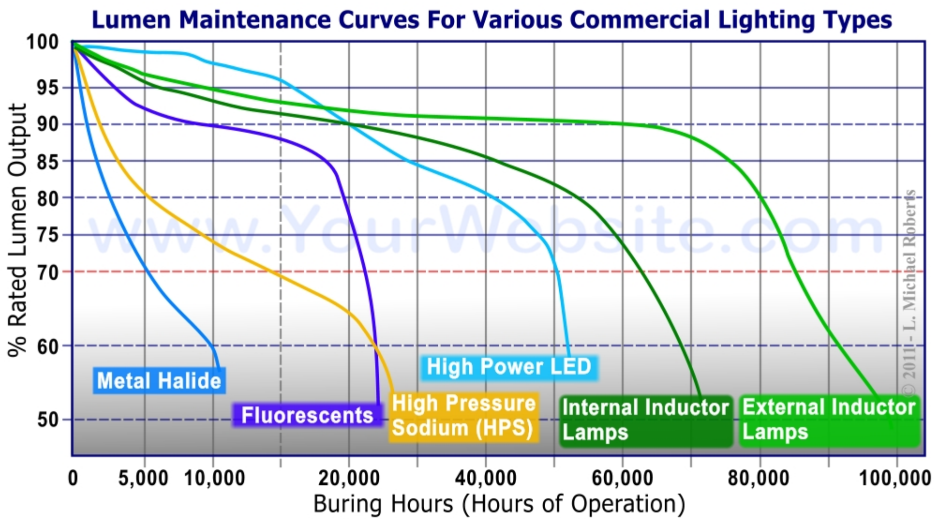
The close regulation of the lamp by the ballast, and the use of microprocessor controlled circuits allows the ballasts to operate at an efficiency of between 95% and 98% (depending on the model) so that only around 2% to 5% of the energy is lost in the induction lamp ballast compared to the 12% to 16% wasted in traditional "core and coil" designs.

RFI (radio Frequency Interference):

Some of the earlier, internal inductor lamps introduced into the market, produced RFI (Radio Frequency Interference). These older models would cause noise on adjacent AM radios, walkie-talkies and some sensitive lab or medical equipment. Almost all newer Magnetic Induction Lamps have FCC (or other) certification which means they produce no more Radio Frequency Interference (RFI) than a computer or microwave oven. They will not affect the use of two-way radios or cell phones operated in the area lit with modern Induction lamps.

Lumen Maintenance:

Lumen maintenance - the rate at which the light output of a lamp 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. This slow decay in output levels can be plotted on a graph as a "lumen maintenance curve" showing how will a particular type of lamp maintains its output.

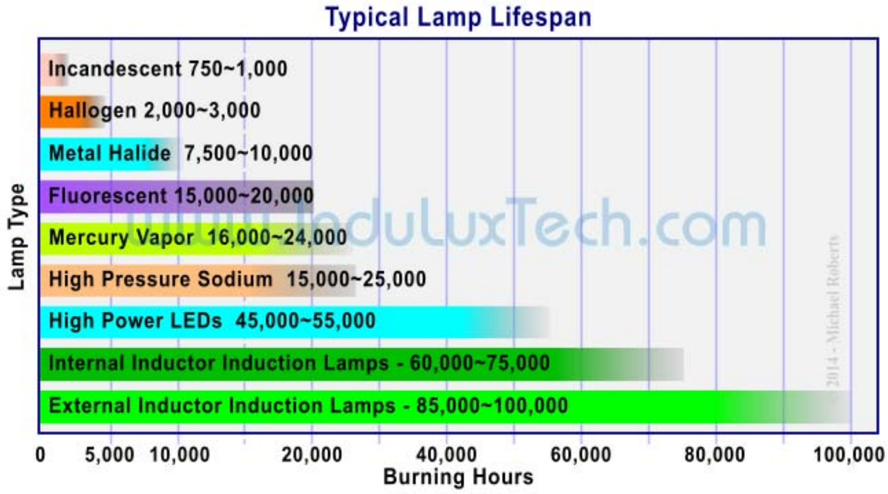


The chart (left) shows the expected lifespan and rate of decay in the light output of various kinds of lamps typically used in commercial/industrial lighting, including internal and external inductor Magnetic Induction Lamps.

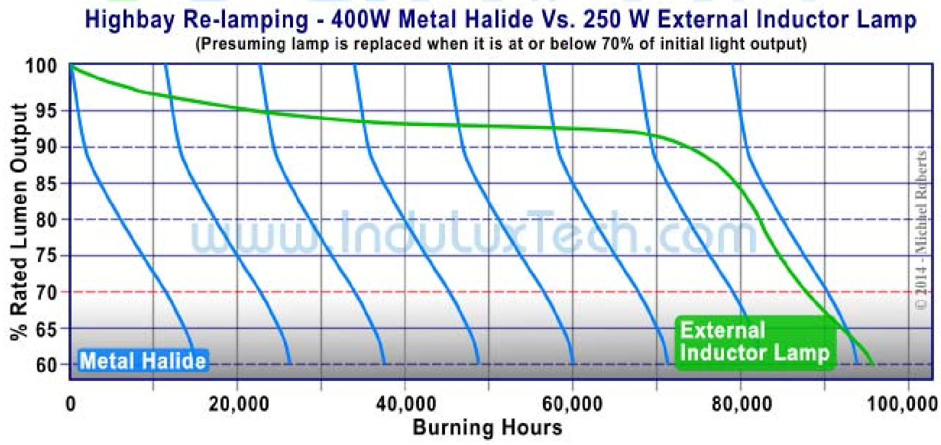
You will note that the Induction lamps have the highest rate of lumen maintenance (stay brighter, longer) due to the lack of internal electrodes or filaments.

Lifespan:

This chart compares the typical lifespan of various types of lamps used in commercial and industrial lighting applications. You will note that Induction lamps have an extremely long lifespan.



The chart below shows a practical example of lumen maintenance curves and how they affect lighting maintenance costs. It compares a lighting fixture using a 400W Metal Halide lamp, with an induction lighting fixture using a 200W Induction Lamp. The 200W Induction Lamp has functionally equivalent light output to the 400W Metal Halide and a lower rate of lumen decay (better lumen maintenance curve). Presuming that both types of lamps are replaced when they fall below 70% of initial output, we see that over 12 replacement MH lamps (bulbs) are required over the lifespan of one induction lamp.



Specialty Induction Lamps:

Not all induction lamps are of the white light emitting type primarily discussed in this paper. There are single colour type, UV emitting types and Grow/Plant-light types of induction lamps available. These lamps operate on the same principals as discussed in this paper, the major difference being the phosphor coating in the lamps:

Coloured lamps: Generally used for decorative applications and are usually available in Blue, Green or Orange/ Red colours, although other colours may be available as well.

UV Lamps: The UV band of the spectrum is divided into UVA, UVB, and UVC portions: UVA type lamps are generally known as "black lights" and are often used in entertainment applications. UVB induction lamps are usually used as "tanning lamps" as exposure to UV light in this region will cause a tan. UVC induction lamps are still quite rare and as "germicidal" lamps used for sterilization. The lamps are very dangerous as exposure to their output can cause skin cancer (melanoma).

Grow/Plant Lights: Induction grow light lamps are used for agricultural applications (photo on right courtesy of EconoLux Industries). The most important characteristic of these lamps is a close match to the PAR curve (plant's light absorption curve). The offer the advantages of low "heat signature", long lifespan, and energy savings compared to the Metal Halide and High Pressure Sodium lamps usually used for plant cultivation

Summary

Magnetic **Induction Lamps** offer an **economically viable** and **environmentally friendly** way to **improve lighting conditions** while **reducing energy consumption**, **reducing Co2 production** from power generation, and **reducing operational and maintenance costs**. Cost **and energy reductions** can be **between 35% and 70%** depending on the application.

People who see the Induction Lamps remark at **how bright they appear** and the **improved quality of the light** because Magnetic Induction Lamps offer high Scotopic/Photopic 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.**

If we are lighting spaces for **the best vision**, then scotopically enhanced, energy efficient, low maintenance, environmentally friendly green lighting, such as **Magnetic Induction Lamps, are the best choice.**

Advantages of Magnetic Induction Lamps:

- **Very long lifespan** compared to conventional lighting technologies - 85,000 to 100,000 hours for external inductor lamps.
- **High energy conversion efficiency** ranging from 70 L/W in low wattage models to 90 L/W in high wattage models.
- Provides **substantial energy savings** of between 40% and 70% in most applications.
- Typically, induction lamps are **guaranteed for 5 years** but with an expected **lifespan of between 85,000 to 100,000 hours** (between 9.7 and 11.5 years of 24/7 operation), they substantially **reduce maintenance and re-lamping costs.**
- Induction lamps have **excellent lumen maintenance** characteristics producing higher light output for a much longer time than competing lighting technologies.
- Mganttic 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.**
- Magnetic induction lamps are **environmentally friendly,** as **they help reduce CO_2 emissions from power generation** thereby **assisting in reducing global warming,** and they contain a solid amalgam mercury which is completely recyclable, while other commercial lighting types contain hazardous liquid mercury.

Induction Lighting Application Examples

Roadway/Walkway Lighting:

The photo shows Magnetic Induction Lamps used for walkway illumination at one of the IKEA stores in Shanghai, China.

Based on information from the lighting installers, the 120W induction lamp fixtures replaced 250W HPS fixtures saving 161.5W of energy per pole. With 26 walkway poles, **IKEA is saving 3.3 Kilowatts of electricity each hour** the system operates. With an average use of 10 hours per day, 365 days per year, total **power saving are thus about 12.045 kWh per annum!**

Note the difference in colour rendering between the induction lamps over the walkway and the HPS street-lights on the left of the photo.

Wallpacks:

LEFT: A 70W High Pressure Sodium (HPS) Wallpack fixture. The insert photo of the watt meter shows that it is consuming 119W of energy (ballast Included) while producing 4,389 Visually Effective Lumens (VEL).

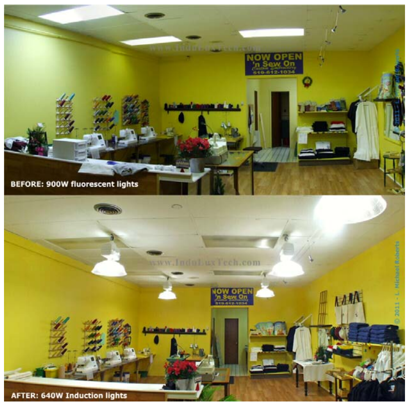
RIGHT: A 40W magnetic induction light Wallpack. The watt meter shows it is only consuming 46W of energy (ballast included) while producing 5,994 Visually Effective Lumens (VEL) of light.

The magnetic induction lighting technology Wallpack on the right is producing over **26% more light** while **using 62.2% less energy!**

Retail Lighting:

TOP: A retail store lit with typical quad tube 2 X 4 fluorescent troffers. The total lighting load in the retail store was 900W. Lighting was uneven with dark corners and poor colour rendering.

BOTTOM: Induction lamp low-bay fixtures with semi-transparent (prismatic) shades provided much more even lighting with better colour rendering. The 900W of fluorescent lighting was replaced with 640W of Induction lighting - a savings of 28.9% in energy costs, plus additional savings from re-lamping costs as the induction lamps won't have to be replaced for more than 10 years. The store is now brighter and more pleasant.



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