LED FACTS

LED comes with unverifiable claims. “No heat, 90% efficient, 100.000 hours lifetime”. Is it true, not true, a lie or just a question of interpretation and clever marketing? How do we know what’s a good LED and are the specifications true? Efficiencies and efficacies are often mixed. Examples of energy saving are exaggerated. This article is all about real ratios, savings, definitions and implications of LEDs.

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Physics defines 683 lumen of flux being equivalent to 1 Watt, but what is flux?

Flux is light flowing from a source from all sites. The intensity of the light we see is determined by the size of the source. When all flux comes from a small chip the intensity will be high. A large milky bulb will not be as bright but the flux can be the same. Flux can be divided in radiant and luminous flux.

The luminous flux is the part of the power which is perceived as light by the human eye, and the figure 683 lumens/watt is based upon the sensitivity of the eye at 555 nm, the peak efficiency of the photopic (daylight) vision curve. The luminous efficacy is 1 at that wavelength. At 610 nm is the sensitivity of the eye only half of the sensitivity at 555 nm. 1W is therefore at 610 nm equivalent to 342 lumen.

As we see here above, the luminous efficiency of lamps very much depends on the spectrum of the lamp. The lamp radiates a broad range of light frequencies which are not all 100% contributing to vision (at 555 nm). In general manufacturers define the luminous efficiency by the lamp lumen divided by the wattage multiplied by 683. For a 60W lamp of 600 lumen this results in: 600/ (60x683) = 0.0146 or 1.46%.

One should realize that this remains

a very inaccurate method to judge the light perception for the eye. We saw that the spectrum of lamps can differ drastically from cold bluish-white or dominant warm white. The calculated values are also based on photopic (daylight) eye sensitivity. The light levels with indoor lamps are however almost never equal to daylight levels. This complicates to define the really perceived light even more. The eye sensitivity at daylight is 683 lm/W at 555 nm but in darkness the eye sensitivity is 1745 lm/W at 505 nm. These dynamics result in errors of measuring or judging the perceived amount of light with more than a factor 3!

Conclusion: Light can only be calculated under photopic light intensities (daylight). Under home indoor conditions one should judge by experience. LED lamps have generally a completely different spectral composition than incandescent or fluorescent lamps and can therefore be perceived totally different. Part of the flux is not optimal visibility for the eye. The total radiant flux is approximately 3 times the luminous flux: (0.0146 x 60W) x3 =2.628W. All remaining power is converted into heat.

Heat management

The heat of an incandescent lamp disappears from the lamp as infrared radiation. The 60W bulb of our example produces over 57W of heat. The higher the temperature of the filament the more light. Under normal conditions the lifetime of the lamp will be 1000 hours. The wolfram white-hot filament produces light with a color temperature of 2700K full power. The luminous efficiency is 1.46%. Burning the same lamp dimmed at 30W makes the filament less hot but the light flux is then reduced to 20%. 1/5th of the 1.46% efficiency is reduced to 0.3%! Now the lamp is more an electric heater than a light source.

What are the energy ratios for a LED lamp?

The efficacy of a 6W LED lamp is currently up to 70 lm/W. This results in 420 lm total. The luminous efficiency is then 420/(6x683) = 0.1025 or 10.25%. Some LED fluorescent tube replacers meet already over 100 lm/W which results in 15% efficiency.

The radiated flux of many LED lamps contains a substantial amount of blue light at 450 nm. This wavelength does not contribute to the photopic luminous flux. Some light sources like in the Pharox lamps contain LEDs producing in majority red and green light. The heat of LED lamps is not radiated like with incandescent lamps. The heat is conducted through a heat sink which requires air flow for convection. LED manufacturers apply different techniques to increase the cooling surface and heat convection.

Five lamps of 60W generate 285W of heat. Five 6W LED lamps will produce 27W of heat for the same amount of light. The energy cost to pump the heat out of a room depends on the COP of the cooling system but is in practice approximately 50%. The energy saving by using LED lamps is therefore 50% more when air conditioning is used.

An immediate relation to LED heat management with heat sinks is the CO_2 footprint of the LED lamp.

Environmental and health effects

Carbon footprint

As we have seen LED lamps require heat sinks. In many cases these heat sinks are casted out of aluminum. Aluminum is produced by melting bauxite. This requires much energy and therefore creates much CO_2 emission. To cast LED lamp heat sinks, the bauxite blocks are to be melted again which requires 15 kWh per kilogram. Down lighter heat sinks often weight more than 0.5 kg and consume 7.500W to melt the aluminum. It is much better to make the heat sink from plates by aluminum stamping. The total amount of CO_2 involved in the production of the lamp is then much lower. The total amount of CO_2 emission caused by the production of a lamp is called the Carbon footprint.

Are LED lamps toxic?

Research was done in the US on Christmas tree lighting with different colored LEDs. The lights were crunched and grinded to powder and tested on possible toxic elements. There are two types of risk, the epitaxial material which is the actual LED semiconductor material and the used materials in the packaging of the chip. The leads and package contain metals like copper, nickel and sometimes even lead. The semiconductor layers of power chips are between 10 and 20 µm thin. The size is about 1 mm . The epitaxial material itself contains traces of dope with cyanide, indium, nitrides and other toxic elements. However, the amounts measured are so low that they do not create levels of danger when landed on landfills. Since most LED lamps are completely recyclable, the chips package, which is the complete light source with additional metals, will be melted as well in the recycling process.

Tests of European products showed no unacceptable levels of toxic materials or metals. The lamps are marked as RoHs compliant. For the US market there appeared to be levels of lead above the accepted level in the state of California. In the US there is no legislation in place which bans the use of lead in electronic equipment. Many Chinese lamps neither meet RoHs standards too. It was found that the levels of lead, copper and nickel were much lower at high brightness LEDs. LED manufacturers should stay alert on the choice of materials and toxic risks. LED lamps should be produced without harm to the environment or health. The mercury in fluorescent tubes and CFL's create a large risk to environment and health.

Is blue light in LEDs harmful for the eye?

ANSES, a bureau of the French government produced in the middle of 2010 a report with a warning for eye damage when staring in LED lamps with high intensity blue LEDs. It will cause eye damage. The risk is especially high with young children. Almost all white LED light is created from blue high power chips with a phosphor to convert it to white.

From April 2011 the French government proposes a ban on all LEDs for domestic use which classify in laser class 2 and 3 of the eye-biometric rating at one meter distance.

It is always good to be aware of any risks and take them very seriously. The first general directive in the lighting industry states one should never stare from a short distance directly in any bright lamp. Intensities of Class 2 and 3 will only be reached when bundling the beam of high power LEDs. Non beamed lamps with frosted or milky glass will usually fall in class 0 and even when the bulb of this type of lamp is broken the light sources are generally a spacial distributed light source ending in class 1. Care should be taken with high power lamps with bundled optics and where the LED chips can be seen directly. Do not stare from a close distance into such lamps!

LED lamps often wrong specified

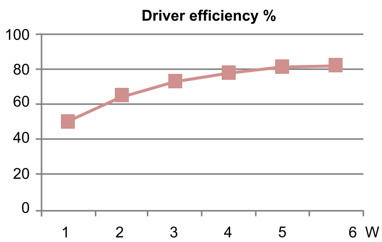
The industry is specifying light output of LED modules at a junction temperature of 25°C (Tj=25°C). This is not a realistic figure since the junction temperature is under normal operation between 85 and 120°C. Light output is 15 to 30% less at such temperatures. Light source suppliers can't specify the actual light output since they don't know how the light source will be mounted and cooled. It could be glued, screwed with pressure, with or without thermal paste, isolating capton, thick or thin, small or large heat sink. Often suppliers calculate the lumen output based upon the LED modules applied.

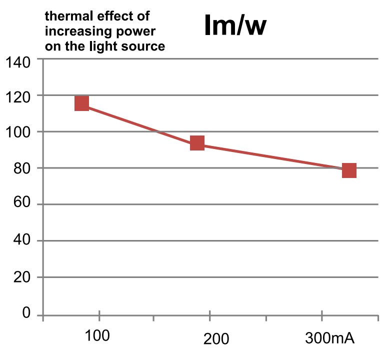
Assume a halogen replacement lamp with 3 power LEDs of 1.2W with an efficacy of 100 lm/W (at Tj 25°C). Many suppliers will specify such lamps as 3.6W with 360 lm.

The reality is that the real output is much lower. First of all 25% lower because of the heat. Second loss is the glass cover which accounts for at least 10% loss and last but not least the driver losses which account at least for 25% at 3.6W. Calculating these efficiencies results in 0.75 x 0.9 x 0.75 = 50%. The claimed light output of 360 lm will in practice only show 180 lm and the efficacy is only 50 lm/W.

Driver efficiency explained

One or two Watt LED lamps will not show a high efficacy (lm/W). An electronic driver requires energy to convert power line energy to a lower direct current for the LEDs. Such driver-converters require some own energy consumption to do the conversion. A minimum own energy consumption of 0.5W for the converter results for a LED lamp with a power consumption of 1W in 50% efficiency for the diver. A half Watt driver consumption on a LED lamp with two Watt power consumption lamp would mean 75% efficiency for the driver. In our example it would mean that the driver would show 90% efficiency in a 5W lamp. However, at higher power rates the own consumption of drivers will also increase. 80% efficiency is a more realistic value at 5W. At 10W lamp power one may see driver efficiencies of 83%. For clear understanding; efficiency is about % and efficacy about lm/W.





mA	lumen	vf (v)	P (w)	lm/W
100	246	21,4	2,14	114,9533
200	421	22,6	4,52	93,14159
300	568	23,5	7,05	80,56738

It is clear there is a trade-off. LED lamps with 1 or 2W power consumption will be quite inefficient due to low driver efficiency. In general such lamps are cheap but not effective for lighting purpose. Lamps with a minimum power of 4W and a real lumen output of 200 lumens are the minimum for lighting applications.

How can consumers rely on correct specs?

Lamp specifications should be provided according to real measured performance under same conditions. The Department of Energy (DOE) in the US defined specifications under the Energy Star qualification. These specifications are expressed in an energy label and LM79 and LM80 test procedures. An essential element is that light output of lamps should be measured after reaching the point of thermal stabilization and a real 6000 hours lifetime test to proof lumen maintenance and failure levels. The LED industry applies in general the rule of B50-L70 which means that at the end of the specified lifetime 50% of the lamps should still be working and the lumen output of those remaining lamps should be at least 70% of the initial flux. Within the European union the definitions on how to present correct lamp data are still in progress but agreed is that lamp performance should always be specified and measured thermally stabilized and not at Tj =25°C.

Considering the LED behavior and driver efficiencies we can compile all what we have learned before in a representative table with realistic specifications for today's LED lamps.

Realistic values for 3000K lamps							
Energy consumption (W)	1	2	3	4	5	6	7
Lumen specified	30	80	150	240	325	408	490
Lm/W	30	40	50	60	65	68	70
Realistic values for 5000K lamps							
Lumen specified	40	100	180	280	400	510	630
Lm/W	40	50	60	70	80	85	90

With the current speed of development of the technology one may expect that the efficacies of led lamps will annually increase with 10 lm/W over the next 6 years. There is a practical limit to the maximal lumen output as explained in one of my earlier articles. For a complete lamp the system efficacy limit will be at approx. 180 lm/W.

High Lumen output or long lifespan?

As we know by now, high temperatures and LEDs which are challenged to the edge will have a drastically reduced lifetime. When reducing heat and current the expected lifetime could well be up to 35.000 hours. Using such lamp for 4 hours per night at 340 days per year will make the lamp last for 25 years. Even when the lamp is used 24/7 it will last for 4 years.

The question here is what is the use of a lifetime of 25 years? The light output may have doubled in 5 years meaning with another lamp after 5 years the savings are two times higher for the remaining 20 years. The question is how much is that extra saving worth in money?

There are important variables such as the energy price, lifetime and efficacy.

For calculation purpose the energy price does not change. When we replace a 60 W incandescent lamp by a 6W lamp the annual energy saving is 73.44 kWh at an energy price of $ 0.12 per kWh which results in $ 8.61/yr. How much higher will the saving be compared to a 60W incandescent bulb if we use after 5 years a 3W lamp with the same light output? This will result in 77.52 kWh saving x $ 0.12 = $ 9.30/yr.

Replacing a LED lamp after 5 years by a two times more efficient lamp results in $ 0.90/yr. additional savings. These extra $ 0.90 savings per year will not pay the cost of a better lamp after 5 years. With increasing energy prices or CFL comparison the calculation will be entirely different.

The message here is that one should not wait a day longer to switch to LED lighting. Our earth and children of this earth will be grateful for your help in conserving energy.

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