LIFETIME AND PERFORMANCE QUESTIONS IN LED LAMP DESIGNS

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Main reason to change to LED lighting is that LED lighting is more sustainable, but is that always true? Most lifetime and performance claims of LED lamps are fairytales based on wrong applied light source data. Verifying lifetime claims of →50.000 hours is difficult in real time with 8760 hours in a year. The truth is usually known earlier when the lamp fails before the end of the test or faded to a fraction of its initial intensity. We will discuss the various misunderstanding on specifications, lifetime and application of LED lamps.

Misunderstood claims on the lifetime of LEDs

First, one has to understand how the industry defined lifetime of LED lamps.

End of life of an incandescent lamp is when it dies. LED lamps usually don't just die.

They slowly fade out. Breakdown of the lamp occurs usually due to a failure in the electronics. The industry therefore defined end of life by B50/L70 which stands for breakdown of 50% of the lamps before end of the specified lifetime or when the lumen output dropped under 70% before end of the specified lifetime.

For accent and decoration lighting the lumen maintenance is even defined at 50% being end of life. This means that if we have 100 lamps with a specified lifetime of 35.000 hours, 49 of them could be dead before they reach 35.000 hours. Still the lifetime specification is met if the light output of the remaining lamps is larger than 70% of the specified lumen. To assure a long lifetime, a cool light source and cool electronics is best. The problem with LED lamps is not a heat problem but an efficiency problem. The more efficient the less heat is generated.

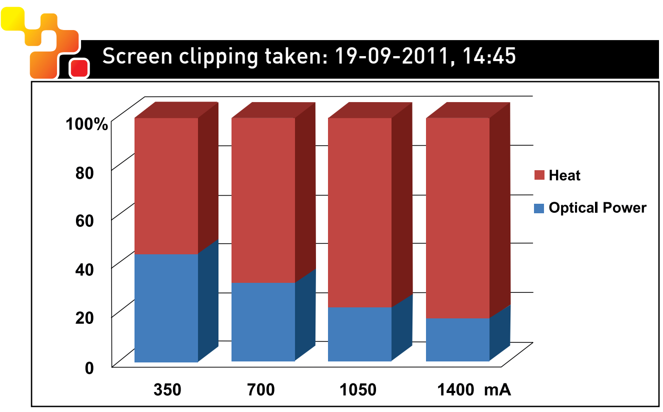
First question to clarify is therefore "How much heat is produced?"

One Watt is equivalent to 683 photopic lumen when a lamp is 100% efficient.

Lamp data from a sphere provide the optical output but also the radiated power. From a lamp with 6W power consumption is the measured radiated power 2.7W. This is 45% of the total energy.

Not all radiated power will be photopic effective power. A substantial part is radiated in the deep blue and as infrared heat. This does not mean that photopic efficiency is 45%. A good LED lamp with 68.3 lm/W photopic efficiency is 10% efficient.

A major factor to take into account is the current through the LED chip. The heat produced in the junction affects the efficiency. The influence depends from the packaging of the chip.

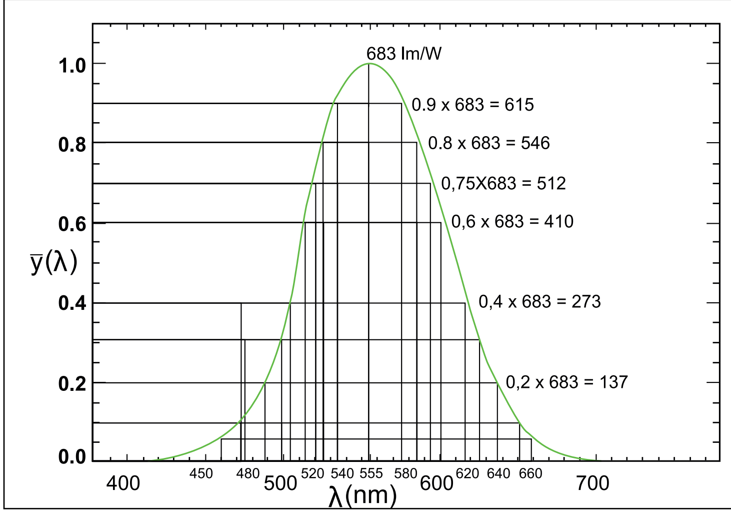


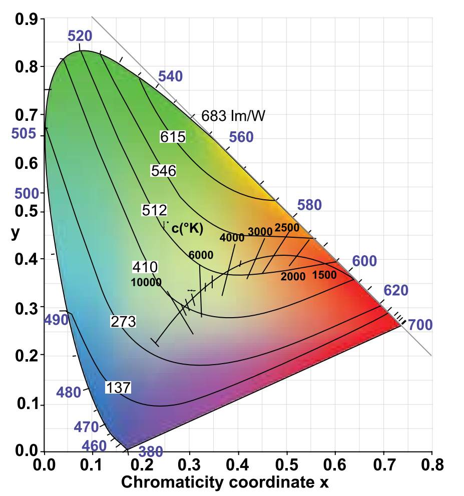
What is the physical maximum lm/W in practice?

Literature defines the output increase of LEDs by Haitz's Law. The output increases by a factor of 20 while cost decreases by a factor of 10 every 10 years. A close look will show that this law does not fit reality.

The theoretical maximum photopic luminous flux is defined at 680 lm/W at 555 nm wavelength.

At other wavelengths the photopic flux is less. Based on the combination of wavelengths one can draw connections from the RGB points which finally result in a combination of white on the blackbody curve. The theoretical maximum Photopic flux for 6000K white is between 410 and 512 lm/W. Over 10.000K the maximum theoretical result will be less than 410 lm/W.





Phosphor conversion technology is based on blue photons at 440 to 450 nm which are converted to visual light in the range of 500 to 620 nm. The short wavelength high energetic 'blue' photon with a band gap of 3.7 EV hits a phosphor particle which emits in return a lower energetic Photon of 3 EV and longer wavelength. This collision results in 20% energy loss, the so called Stokes shift, which can be calculated by the conversion rate 555/440.

On top of that the conversion efficiency of Phosphors is not 100% but more in the range of 60 to 70%. This results in a conversion efficiency of 0.80 x 0.6 = 0.48% for the yellow wavelength.

The practical limit of the maximum luminous flux of LEDs with a theoretical maximum of 500 lm/W and a conversion efficiency of 48% is therefore 240 lm/W.

For longer wavelengths in the 620 nm, the Stokes losses are 620/440 = 70%. The efficiency of rare earth metals like Europium to create red is close to 55% which results in a total conversion efficiency of 0.7 x 0.55 = 38%. The 62% energy loss is dissipated in the phosphor resulting in substantial lifetime reduction. This simple calculation proofs that Haitz's law is not applicable for the simple reason that the output cannot increase by a factor of 20 in 10 years. Currently the efficacy is 120 lm/W. The maximum achievable in practice is double output of the current output.

Influence of thermal management on lamp performance

Thermal management determines lifetime and efficiency of a LED product.

Philips: Proper thermal design is imperative to keep the LED emitter package below its rated operating temperature.

Cree: The majority of LED failure mechanisms are temperature dependent. Elevated junction temperatures cause light output reduction and accelerated chip degradation.

Osram: In order to achieve reliability and optimal performance a proper thermal management design is absolutely necessary.

Nichia: For high power LED applications, the designer must consider how to manage heat in order to enhance the performance of the LEDs. If heat management is not considered, the lifetime of the LED will be significantly decreased, or the LED will fail.

Seoul Semiconductor: Heat causes bad reliability and changes of electrical and optical character negatively. So power LEDs must dissipate heat from chip in that package.

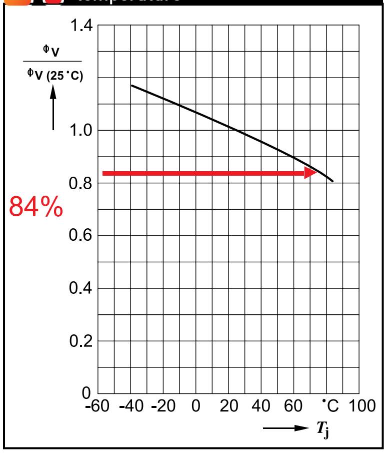
Less educated lamp manufacturers

often calculate the performance of lamps by the number of LEDs they apply, resulting in many unrealistic specifications.

Lets have a look at a lamp with five power LEDs of 80 lm/W. According to the data sheet of the manufacturer a LED provides 80 lm/W at 350 mA. The maximum current for the LED is 700 mA.

You could just calculate Power = Vf x I

Flux drop under increase of temperature



= 3.2 volts x 0.7amps = 2.24W

Light Output = 80 lm/W x 2.24W = 179.2 lumen

Total Light Output = 5 x 179.2 lumen = 897,5 lumen

Input Power = 5 x 2.24W = 11,2 W. The lamp efficiency would be 80 lm/W and less professional producers will specify the lamp as such.

The problem is that it's different in the real world.

LED manufacturers specify the lumen/W output of a light source at a junction temperature of 25°C.

This is measured with a pulse of a tenth of a second at the specified current. Tj is in practice never 25°C. Under operational conditions the junction temperature will be in the range of 85 to 100°C.

Ambient temperatures higher than 25°C will result in lower light output. Led output goes down when current goes up. Drivers in lamps have in the best case efficiencies of 90%.

In our previous example this would result in

5 LEDs x 80 lm/W * 2.24W * 0.75 x 0.84 = 564,5 lm

Input power = 5 * 2.24W / 0.9 = 12,45 W

This results in a real lamp efficiency of 45.3 lm/W only.

Sustainability

Sustainability of a lamp is not determined by the reduction of energy consumption only.

Good LED products offer 80 to 90% energy reduction.

Life Cycle Analyses show the real sustainability of a product.

It is the sum of the energy saving, the carbon footprint at the making of the product, lifetime, recyclability and environmental damaging effects. Some producers apply enormous amounts of casted aluminum which results in a carbon footprint of multiple kilowatts to melt the aluminum. Light product weight, low energy in production and high quality are needed to meet world class performance and savings.

Lifetime has an important impact on the sustainability. Incandescent lamps last 1000 hours only.

CFL's have an average lifetime of 4000 hours. Claims of 50.000 hours by many LED manufacturers result in disappointing experiences. This is the reason to test real lifetime with a minimum of 6000 hours.

The lumen depreciation and failure percentage will be extrapolated to the point of 70% lumen maintenance.

Light source lifetimes are generally specified between 30.000 and 50.000 hours.

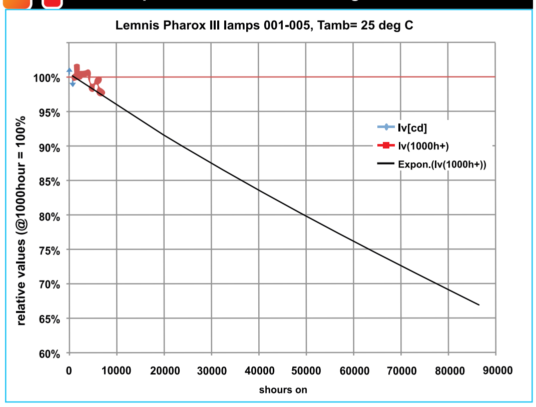
Light source producers don't know how good or bad the light sources modules will be implemented in the application. Therefore in practice, many lamps show real lifetimes being much less than specified for the light source. The lifetime test should be performed over multiple lamps on lumen output, CRI and efficacy after 6000 hours. Besides right material choice and functional design of the lamp is thermal management the most important parameter for lifetime.

Thermal picture of the Pharox lamp

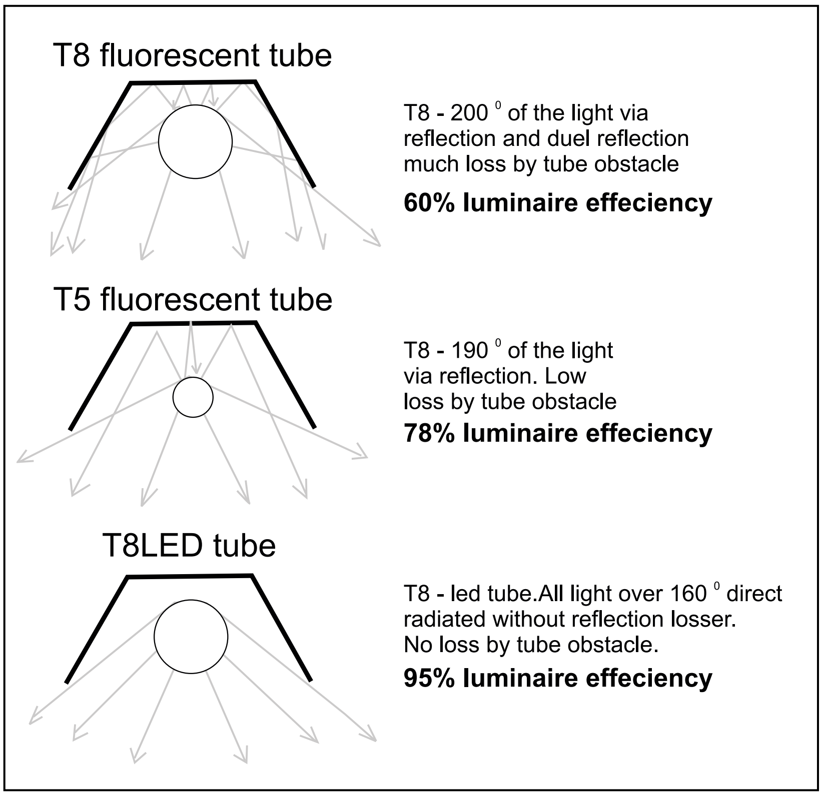
Independent laboratory tests of five Lemnis Pharox lamps show 80.000 hours real lifetime.

Luminaire efficiency

Extrapolation of the averaged illuminance



In many applications the good thing of LED lights is that the light is already directional. With conventional incandescent or CFL bulbs, ceiling lights require secondary optics to direct the light were its needed. The problem of such conventional light sources is that they are voluminous and create an obstacle for the reflected or redirected light. LED light sources are small and already directed. This results in less luminaire losses.



Comparison fluorescent tubes vs. LED tubes

Fluorescent tubes are cheap. Most fluorescent tubes are specified at 90 lm/W. This is not correct since ballast and luminaire efficiencies are not taken into account. An independent laboratory test with dual 36W tubes results in an efficacy of 38 lm/W only (www.olino.org).

Reason; the light of a fluorescent tube is radiated 360° round. EM

A 36W fluorescent tube is 3350 lm, so that's 3350/36=93 lm/W?

parameter	measuring lamp	remarks
Color temperature	3927 K	Clear white (neutral white)
intensity	1791 Cd	
angle	88 deg	
Power P	88 w	
Power Factor	0.96	With this power factor there is for each 1 kWh of nett power, 0,3 kVAhr of reactive power
Flux	3362 lm	Osram reports that a single tube produces 3350 lm. in this case were there are two tubes in a fixture, there is not 6700 lm output but only half. the rest is lost by reflections and absorbtion. This is normal for standerd fixtures
Efficacy	38lm/w	
CRI_Ra	81	Color Rendering Index

Bron: Olino

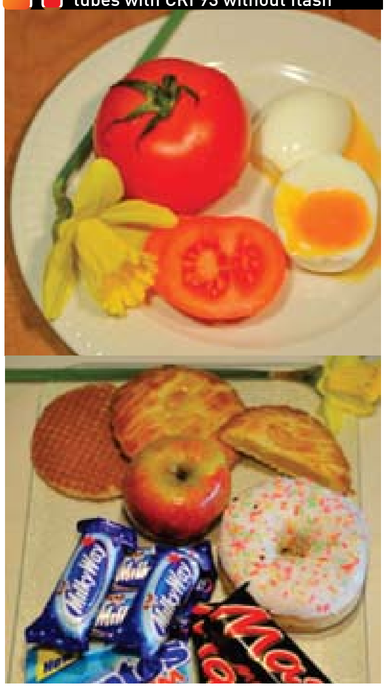
ballast losses are 20% and multiple light reflections cause much loss. A substantial part of the light is blocked by the tube itself.

T5 tubes, and lately also T8 tubes, operate on HF electronic ballasts with a higher efficiency of 90%.

LED tubes don't require a ballast. The ballast is in the tube. Therefore is a tube efficacy of a 110 lm/W, as the Lemnis LED tube, also the real efficacy. High CRI is an eye opener in retail environment.

The maximal color rendering of standard fluorescent tubes is around 80. Extended CRI tubes are CRI 86.

Pictures taken under T8 LED tubes with CRI 93 without flash



Performance in practice

The Lemnis LED tube is specified for a lifetime of 50.000 hours. The industry specification for lifetime of SSL is B50/L70. Standard fluorescent tubes will have an average lifetime of 12.000 hours. This means four times replacement for each LED tube. The fluorescent tube cost is not high but in modest proof areas the labor cost for replacement (maintenance) is high due to rigid fixtures.

At train platforms, parking lots, cold trains, conventional fluorescent tubes drop to 80% or even 50% light output at cold weather conditions. In terms of sustainability there is a substantial environmental pressure. Fluorescent tubes contain mercury and phosphors which are bad for health.

The energy saving with LED tubes will be substantial, considering an optimistic practical efficacy of 50 lm/W for the fluorescent tubes in the fixtures. The practical efficiency of the LED tubes in the fixtures is 100 lm/W. This results in a total energy saving of 50% for the same amount of light. Tubes with a high CRI have an almost full spectrum which is perceived and confirmed by independent tests as extremely pleasant.

Spectrum of a high CRI D840 fluorescent tube CRI =86
Spectrum of the Lemnis tube CRI =93

In general the CRI of LED tubes is in the range of 70 to 80. Heat management of LED tubes is also a serious issue. Real lifetime tests showed for more than 50% of the tested tubes a life time of not more than 5000 hours. The right choice of LED packaging and LED types for the right spectral composition, combined with good thermal management will result in a lifetime of over 50.000 hours.

The industry is defining many standards to assure quality. It is not always easy to capture all quality issues by standards. Practice is the best proof of quality. ■