LED Technology in public lighting installations – facts or fiction

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Abstract – **This paper deals with constant attempts to present LEDs as miraculous sources globally and to clear the way for their domination on the global lighting market. Although it must be emphasized that LED technology really represents future of the artificial lighting, still these sources are not so powerfull (especially when it comes to outdoor lighting) comparing to conventional HID sources, especially High Pressure Sodium lamps.**

Keywords – **LED and HID sources, system efficacy, ballast and driver efficiency, optical and thermal efficiency, mesopic vision, scotopic/ photopic ratio.**

I. INTRODUCTION [1]

The first LED ("**L**ight **E**mitting **D**iode") was discovered in 1906. when H. J. Round reported electroluminiscence as phenomenon using a crystal of silicon carbide and crystal detector. In the next 50 years nothing significant happened in this area, not until serious researches begun in semiconductor technology. In 1962. GE company introduces first red LED with efficacy 0.1 lm/W and in 1965. first yellow LED as well. In 1976.the first colour control concept was implemented by Jerry Laidman from Sound Chamber company (light intensity of each LED was controlled by using Pulse Width Modulation technique). The first commercial LEDs were commonly used as replacements for incandescent and neon indicator lamps, but real breakthrough with efficiency and light output came through in 1990's. The first high-brightness blue LED was demonstrated by Shuji Nakamura of Nichia Corporation in 1994 and was based on InGaN. Finally, in 1997. Nichia company introduces the first white LED by coating blue LED with yellow phosphor (yellow light combined with blue light produces light that appears white). To conclude, from the middle of the last century to 2007., LED efficiency increased around 1000 times (from 0.1 lm/W to 100 lm/W for Nichia cold white LED with colour temperature cca. 4500K). Today in 2013., LED efficacy is still increasing, it has already reached 150 lm/W and it's getting closer to fascinating value of 200 lm/W, which would put LEDs in front of all other light sources (Low and High pressure sodium, Metal-halide, Fluorescent, Incadescent, Halogen, Xenon lamps, etc...).

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II. SYSTEM EFFICACY

Looking at the brochures of many different manufacturers (even some well known), one might think that luminaires with LED sources can replace HID (High Intensity Discharge) luminaires of even 3-5 times higher power? Very often it can be read that energy savings with LEDs reach 50% and sometimes even up to 80%. Needless to say, none of these brochures provides any information about lighting level – will it stay the same while power is decreasing? In Table 1 [2,3,4,5,6] values of luminous flux for some well known types of LED chips are obtained:

TABLE 1
LUMINOUS FLUX OF MOST COMMONLY USED LEDS

Company	Type	CCR	Min. flux [lm] 25°C /350mA	Max. current [mA]
CREE	XP-G2	Cool White (5000-8300)K	147	1500
CREE	XP-G2	Neutral white (3700-5300)K	138	1500
CREE	XP-G2	Warm white (2600-3700)K	129	1500
CREE	XP-E2	Ultra White (5000-10000)K	142	1000
CREE	XP-E2	White (5000-5700)K	124	1000
CREE	XP-E2	Warm white (2600-3700)K	116	1000
OSRAM	Golden Dragon Plus	Ultral White 6500K	116	1000
OSRAM	Golden Dragon Plus	White 5600K	100	1000
OSRAM	Golden Dragon Plus	Warm white (2500-4800)K	85	1000
OSRAM	OSLON SSL 80	Ultra White (5700-6500)K	119	1000
OSRAM	OSLON SSL 80	Neutral White (4000-5000)K	115	1000
OSRAM	OSLON SSL 80	Warm white (2700-4000)K	78	1000
LUMILEDS	Rebel ES	Cool White 5650K	135	1000
LUMILEDS	Rebel ES	Neutral white 4100K	130	1000
LUMILEDS	Rebel ES	Warm white 3500K	103	1000

These data are taken from manufacturers technical brochures for 2013. and it can be seen that luminous flux per chip doesn't excee 147lm in case of cool white LEDs (colour temperature in 5000-8300K range). According to manufacturer technical brochure [2], these values are calculated in the laboratory conditions for PN junction temperature of 25°C and forward current of 350 mA. Usually, in public lighting installations (especially in urban areas) it is most common thing to use light sources of warm or neutral white colour. If, for example, XP-G2 chips produced by Cree company are taken into account, it can be seen from Table 1 that luminous flux of neutral white LED (3700-5300)K is 138 lm. However, this flux is valid only for PN junction temperature of 25°C, while in reality these temperatures are much higher and can go up to 150°C –usually we take this temperature is 85°C. Before going any further, let us define luminous efficacy, which is a measure of how well a light source produces visible light. It is the ratio of luminous flux to total power consumed by the light source [lm/W]. According to the Figure 1 [2], at this temperature system efficacy decreases for cca. 16.5 % (from cca 116% at 25°C to cca. 98.5% at 85°C).

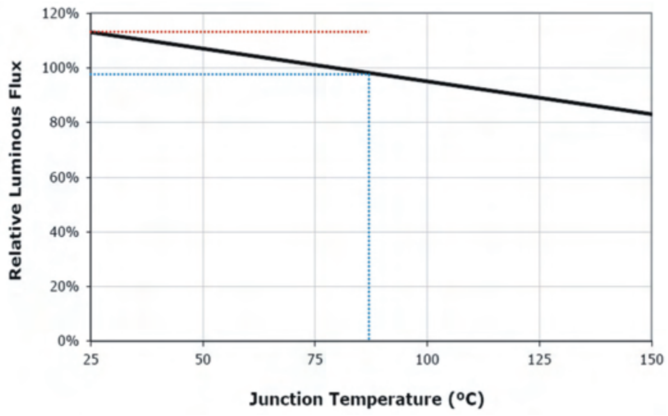

Fig. 1. Relative Flux vs. junction temperature (I_F = 350mA)

Based on value determined from curve above, real luminous flux at junction temperature of 85°C should be cca. 115 lm. However, although values of luminous flux can be determined from the curve in manufacturer technical brochure, these values are also given in table 2 shown below [2]. This value of 122 lm is higher then previous one and represents decrease of cca.12%. Since the idea of this paper is to prove that LEDs are not so efficient sources as it can be heard everywhere, less harsh value (the one that favors LEDs) of 122 lm is taken into calculations. Since power of single LED is cca. 1W (without driver losses), efficacy of single LED is 122 lm/W at 85°C, which represents thermal efficiency of 88%!

TABLE 2
LUMINOUS FLUX CHARACTERISTICS OF CREE XP-G2 LEDS

Colour	CCT range		Base order codes Min. Luminous Flux @350 mA		
	Min.	Max.	Group	Flux [lm] @85°C	Flux [lm] @25°C
Cool White	5000K	8300K	R3	122	138
			R4	130	147
			R5	139	158
Outdoor white	3200K	5300K	R2	114	129
			R3	122	138
			R4	130	147
Neutral white	3700K	5300K	Q5	107	121
			R2	114	129
			R3	122	138

Efficacy of one luminaire with LED sources is not just a question of LED efficacy, but it is also affected by efficiency of LED drivers and efficiency (transmission coefficient) of lenses (collimators) and glass protector as well. If we take the most common (and the best at the same time) case where only LED chips are placed on PCB (Printed Circuit Board) without any electronic device (so called "passive PCB"), and all other necessary electronic devices are gathered and incorporated into "driver", efficiency of such driver (power supply constant current source) is often over 90%!

Figure 2 [7] shows typical electrical circuit and some of the most popular drivers that can be found on the market:

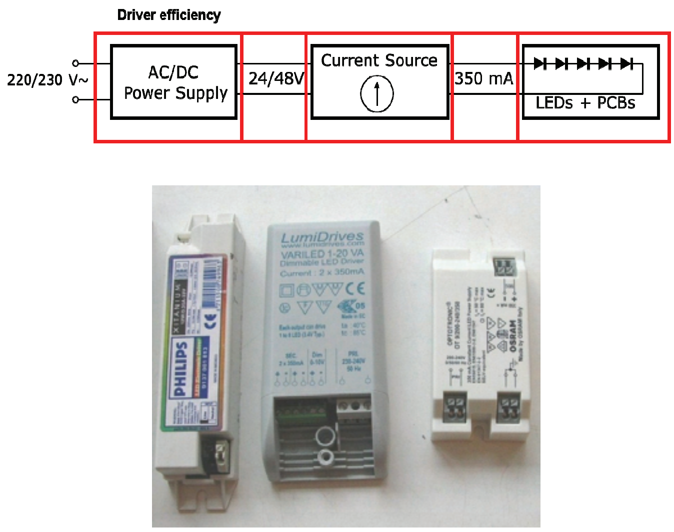

Fig. 2. Typical LED circuit and the most popular drivers on the market

Unlike conventional HID sources (most commonly High pressure sodium and Metal halide lamps) Led optical system usually doesn't contain reflector (although lately there are more such solutions (e.g. Hella Germany) where each diode has its own reflector – still very expensive solutions), but the light distribution control is done by using optical lenses (collimators) and glass protectors. Efficiency of collimators is usually around 85- 92% and by incorporating losses due to Fresnel reflection (cca. 8%), it can be assumed that LED optical system efficiency is aproximately 80%!

After taking into account all aforementioned factors, it can be concluded that real light efficacy of one high quality LED luminaire (excellent thermal dissipation in luminaire and high quality LED chips, collimators and driver) is (Figure 3 [7]) :

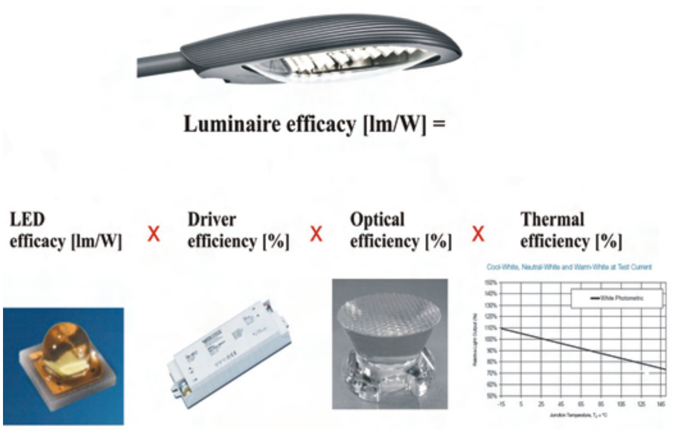

Fig. 3. Luminaire efficacy [lm/W]

In this particular case, system efficacy of one LED luminaire with Cree XP-G2 LED (and, for example, with Philips Xitanium driver and Carclo lenses used by Schreder, world known belgian luminaire manufacturer) is:

LED system efficacy =

LED efficacy x **driver efficiency** x **optical efficiency** x **thermal efficiency**

$$= 122\ \text{lm/W} \times 90\% \times 80\% \times 88\%$$

$$= \boxed{77\ \text{lm/W}} \qquad (1)$$

Now when we established efficacy of one quality LED luminaire, comparison should be made with other sources that are most commonly used in public lighting installations – above all High Pressure Sodium lamps. It is important to mentioned that metal halide sources are alos present in public lighting installations, but to a much lesser extent. Luminous efficacy of quality light source (e.g, lamp type NAV-T, manufactured by OSRAM [8]) is 94 lm/W 70W lamp power and 132 lm/W for 250W lamp power. Let's assume that for limitation of the amount of current in an electric circuit (so called stabilisation) magnetic ballast is used (still prevailing control gear in public lighting installations) and that average efficiency of quality magnetic ballast is over 85% (e.g., Philips BSN family [9]). Assuming that optical efficiency of quality system (luminaire) is aproximately 82% (reflector + protector), it can be calculated that aproximate luminous efficacy of quality HID luminaire with High Pressure sodium lamp is cca. 90 lm/W. This assumption is based on 10 years experience in lighting industry whereas these values are common knowledge and standard parameters for HID systems calculations (before LEDs came, HID sources prevailed for many years). Efficacy of one luminaire used in public lighting installation depends on optical efficiency, luminous efficacy of the light source and utilisation efficiency (utilisation coefficient – part of the luminous flux that reaches desired work plane, i.e. roadway that needs to be illuminated – Figure 4 [7]).

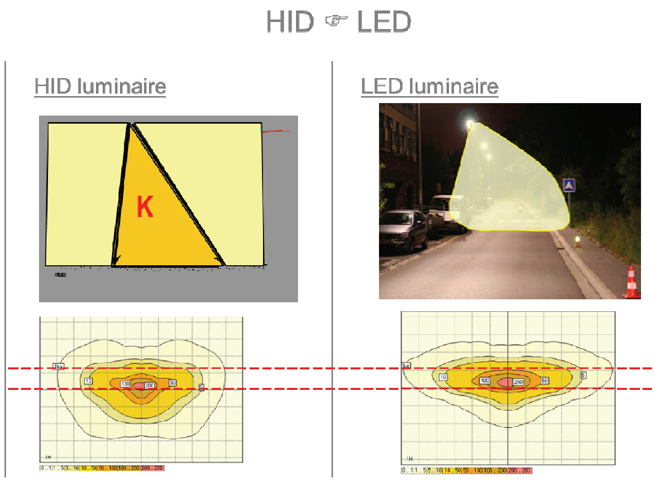

Fig. 4. Utillisation efficiency HID vs. LED

It can be assumed that average utilisation efficiency of one quality HID luminaire with HPS lamp is aproximately 45% (value that can be often found in well-known manufacturers technical brochures and calculation softwares [7]). If we assume that utilisation coefficient for LED system is 70% (much effective light distribution control, due to LED source geometry light is emitted only in lower half-plane), we will have the following case (Figure 5 [7]):

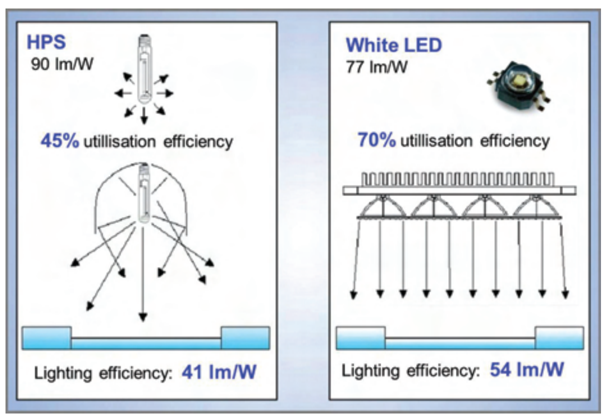

Fig. 5. Utillisation efficiency - HID vs. LED in real situation

And finally, Figure 6 [7] shows trends in increase of luminous efficiency from the middle of the twentieth century up to year 2013. with expected value of 160 lm/W.

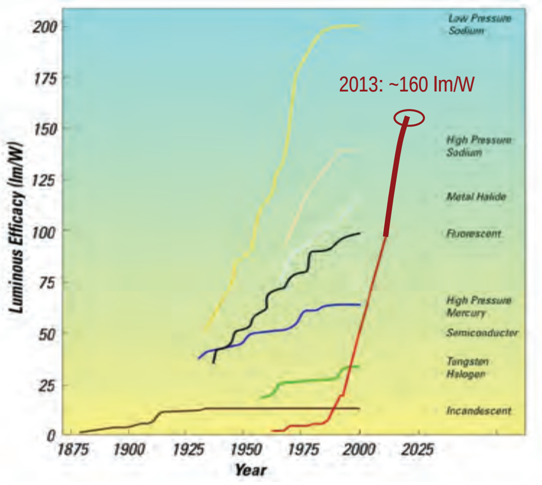

Fig. 6. Efficacy trends in LED industry

III. CONCLUSION

Although previous analysis is not highly accurate (certain asumptions and aproximations were made), it can be concluded with great certainty that **LED sources are not significantly more efficient than high pressure sodium lamps**!

According to analysis LED sources are aproximately 25% more efficient, but that doesn't justify replacement of HID luminaires with LED luminaires of much lesser power (definitely not 50% or 80% energy savings). Usually customers are not sufficiently technically educated and don't realize that energy savings are only valid if we suceed to maintain same lighting level after replacement. It means that, if we want to keep same lighting conditions on the roadway (same lighting class – luminance level Lav, overall and longitudinal uniformity, threshold increment TI according to relevant international recommendations), replacement can be done only in 1.25:1 ratio! Since this is not the case and a lot of money has been invested in LED technology, recently there is a trend of lowering required lighting level (international reccomendations given by CIE or CEN organisation) so that it become easier for LED lamps to achieve required level (Lighting class M3 or less). In that case, instead of high HPS powers (70, 100, 150, 250 and 400W), it will be possible to achieve desired lighting levels with LED luminaires of desired power (by simply determining the number of individual LED chips that we need).

It is also important to mention that if this analysis had been done 5 years ago, it would go in favor of HID sources since efficacy of LEDs increased cca. 40% in meantime. Also, analysis was conducted for high quality lighting equipment (well-known world manufacturers such as Philips, Schreder, Cree and Osram), results would also go in favor of HID luminaires in case of LED equipment of lesser quality.

If we look at the Figure 6, it is clear that LED still didn't reach its peak and if this trend continues, it can be expected that untill 2020. they globally reach magic value of 200 lm/W! While others are still trying, Cree company breaked this efficacy barrier 2 years ago and they are announcing new record with New XLamp MK-R [10].

ACKNOWLEDGEMENT

This paper was done in the framework of research on the project TR 35026, which was funded by Ministry of Education, Science and Technological Development of Republic of Serbia.

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