Three generations of luminous devices: a comparison in search of energy efficiency and ecology care

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ABSTRACT

In this work a comparison is made between three generations of luminous devices, in order to have a quantitative estimation about the advantages of the new technologies on illumination sources based on Light Emitting Diodes (LEDs). The features that are compared of each type of light source are: the luminous efficacy, the average timelife, the cost, the compliance with human vision requirements, the color rendering index (CRI), and the impact on environment after disposal. From the results obtained we can conclude that in the foreseeable future the most convenient technology is that of solid state LEDs. Some quantitative and numerical-based arguments are presented in order to support such conclusions.

Key words: Light sources, luminous efficacy, solid state lighting, light emitting diodes (leds), organic leds.

INTRODUCTION

One of the first applications of electricity was in lighting homes and public spaces. Since the invention of incandescent lamps in the late nineteen century, many attempts have been made to develop a durable, low cost and efficient source of light which could reproduce some of the main characteristics of sunlight. Incandescent lamps are considered to be the first generation of these technologies and, in spite of its very low luminous efficacy and reduced lifetime, are still of extended use the world over due to the product low price. A second generation started at the beginning of 1940 with the fluorescent lamps, which increased luminous efficacy by a factor of 3 or 4, but with the disadvantage of a higher price, lower Color Rendering Index (CRI) and unwanted disposal characteristics due to the use of dangerous gases or vapors (mercury, sodium, etcetera). The third generation of lighting technologies is that of solid state devices which include both inorganic and organic light emitting diodes (LEDs and OLEDs, respectively). The solid state devices were used initially only for very low power applications, like indicator lights, solid state dials. By about year 2000 a sudden increase in the light intensity has considerably extended the range of applications of LEDs. At the same time a great variety of colors and hues has been achievable with correspondingly increasing CRI.

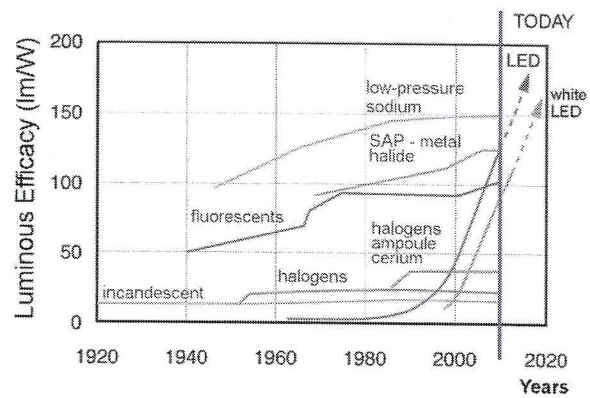

Figure 1. Historical and predicted efficacy of light sources (adapted from references [1], [2])

A COMPARISON BETWEEN LIGHTING TECHNOLOGIES

In what follows we present a comparison between the currently used lighting technologies attending three main aspects: technical performance, price, and environmental impacts.

Technical comparison

As can be observed from Table 1, efficacies for current incandescent and halogen-incandescent light sources typically range from 10 to 20 lm/W. On the other hand, efficacies for fluorescent lamps can go from 25 to 118 lm/W, depending on length, wattage, and color temperature; in these figures ballast losses are not included. However, the inclusion of ballast losses in fluorescent systems results in overall efficacies as high as 108 lm/W.

High Intensity Discharge (HID) lamps (including mercury vapor, sodium vapor, and metal halide lamps) are the most efficacious lamps currently on the market, with efficacies ranging from 30 to 120 lm/W, while efficacies for HID systems can be as high as 115 lm/W (Table 1). However, the highest efficacies are often achieved at the expense of color quality.

The new light sources based on LEDs, however, have the potential to surpass the efficacy of the most efficient conventional light sources. Commercially available LED lamps are able to achieve efficacy values in the 90 to 100 lm/W range. Some prototype lamps have also been reported with efficacies exceeding 150 lm/W [3]. LED-based lamps are usually integrated by LED packages (components) or LED arrays (modules), LED driver, ANSI standard base and other optical, thermal, mechanical and electrical components. This explain the high cost we refer to in what follows.

Table 1. Global comparison between the three generations of light sources up to 2010

Product Type	Luminous Efficacy	Luminous Output	Wattage	CCT	CRI	Lifetime
LED White Package (Cool)	130 lm/W	130 lm	1 W	5650 K	70	50k hours
LED White Package (Warm)	93 lm/W	205 lm	2.2 W	3500 K	80	50k hours
LED A19 Lamp (Warm White)[41]	64 lm/W	800 lm	12.5 W	2700 K	80	25k hours
LED PAR38 Lamp (Warm White)[42]	52.5 lm/W	1050 lm	20 W	3000 K	80	25k hours
OLED Panel[43]	28 lm/W	50 lm	2W	2700-6500 K	80	8k hours
HID (High Watt) Lamp and Ballast	120 lm/W 111 lm/W	37800 lm	315W 341W	3000 K	90	20k hours
Linear Fluorescent Lamp and Ballast	118 lm/W 108 lm/W	3050 lm 6100 lm	26W 56W	4100 K	85	25k hours
HID (Low Watt) Lamp and Ballast	104 lm/W 97 lm/W	7300 lm	70W 75W	3000 K	90	12k hours
CFL	63 lm/W	950 lm	15W	2700 K	82	12k hours
Halogen	20 lm/W	970 lm	48 W	2750 K	N/A	4k hours
Incandescent	15 lm/W	900 lm	60W	3300 K	100	1k hours

(Source: reference [4])

The cost issue in Mexico

The prices of light sources are typically compared on a *price per kilolumen* basis. The first costs for principal replacement LED lamps have dropped considerably during 2011 and 2012, but are still high in comparison with conventional lamps (Fig. 2). Up to 2012, LED lamps prices remained around twelve times the price of a halogen bulb and around three times the cost of an equivalent dimmable CFL, but the price of LED lamps is expected to continue its rapid decline and the performance is expected to continue to improve. As a consequence LED light sources are projected to become increasingly competitive on a first cost basis. A new breakthrough is commercially available since March 2013: a 40W LED replacement for less than 10 dollars and 25,000 hours lifetime; the 60W replacement is priced at less than 13 dollars [5].

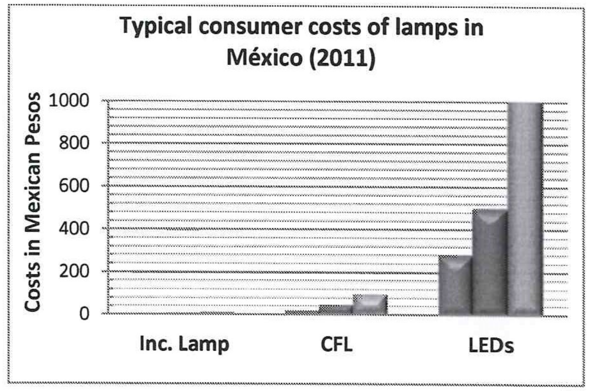

Figure 2. Typical lamp costs for consumers in Mexico (2011 prices for 40, 60 and 100 W devices)

While the first cost of a lamp is an important parameter, it is the lifecycle cost that ultimately determines the overall economic benefit. A typical analysis on initial investment, maintenance and energy cost is useful for comparison purposes. Figure 3 gives a comparison based only on the cost of energy for Mexico.

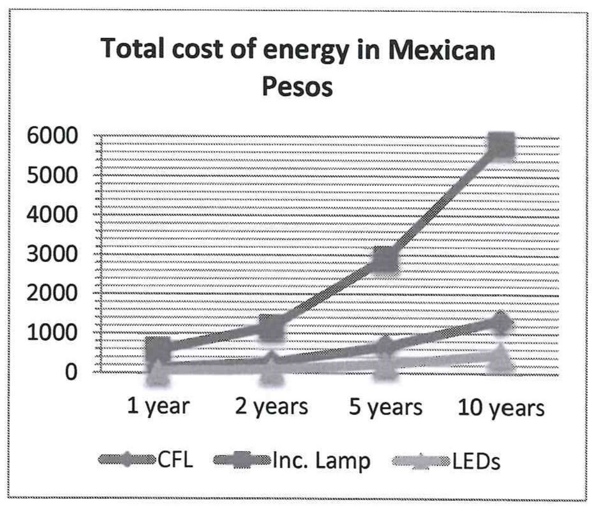

Figure 3. Cost of Energy required for a 14-hours-daily operation during 1 to 10 years, in Mexican pesos (of November 2011).

From the figure it is clear that the most expensive technology in the long run is that based on incandescent lamps. As he first cost of LED lamps reduce, which is the tendency at present, the solid state technology will soon prevail on the market. This vision is reinforced by the environmental consideration.

Environmental impact

One of the most important impacts on the environment occurs after disposal of the light devices, since some of them are made of materials that are harmful for living organisms or the ecology.

Table 2. Comparative environmental impact

Characteristic	Incandescent	Compact Fluorescent	LED ww
Effective Power	100W	23W	12W
PLS x 4 lamps	X 4 = 400W	x4 = 92W	4 = 48W
Disipated Power in 14 hours operation	5.6 kW/h	1.288 kW/h	0.672 kW/h
Kilograms of CO_2 emitted per day	4.2	≈ 1	≈ ½
Reciclable Components	- Aluminium - Glass - Tungsten - Other metals	- Aluminium - Mercury gas - plastics	- Aluminium - Aluminium (disipator) - Light difuser, - Basic electronics - Some Plastics
Non reciclable Components		- Glass contaminated with mercury - Burned electronic components - Burned plastics (close to the bulbs)	- Burned Electronic componentes - Burned plastics
Total reciclability:	~100%	<50%	>50%

From Table 2 it is clear that the least contaminant technology is that of the traditional incandescent bulb. The CFL devices, on the other hand, are the most harmful due to its content of mercury and other noxious substances required for its performance. In between we find the solid state technologies (LEDs), which are improving also in this respect mainly with the development of organic LEDs. It is important to point out that one of the major drawbacks of the compact fluorescent lamps is its content of mercury vapor, which according to a recent study [7] puts a risk on the user that is greater than considered before. When a CFL is broken it is important not to handle the debris before half an hour of the accident, in order to allow for the dissipation of mercury vapors. Normal commercial packages do not contain information for the consumers to alert on this danger. LED lamps are free from this risk.

Future trends

Philips, which is the European leading enterprise in the field of lighting, is being overpassed by South Asian companies like Panasonic that has been producing 8cm x 8cm panels of OLEDs with 30 lm/W efficacy at approximately 10,000 lm/W with a lifetime of 10,000 hours. Their roadmap for 2019 aims for an efficacy of 130 lm/W on a 60cm x 60cm panel with 40,000 hour lifetime from 15,000 lm/m^2. Samsung and LG in Korea are investing about 5,000,000,000 dollars per year in OLEDs technology. The LG roadmap is still more aggressive than that of Philips, aiming for efficacies of 135 lm/W and lifetimes of 40,000 hours on 20cmx20cm panels by 2015. They are also developing flexible and transparent panels.

DISCUSSION & CONCLUSIONS

Up to 26.3% of the electricity generated in Mexico is used in homes, which constitute about 83% of all edifications in the country. The remaining 73.7% is divided between the industrial sector (58% for both buildings and production processes), commerce (5.7%), agriculture (6.4%) and public services (3.6%), according to [6]. This implies that more than 20% of all electric energy is used for lighting, and due to the population increase and improvement of living standards, the electricity demand for illumination is growing more rapid than for other applications. In response to this situation, Mexican Federal Government has implemented a national program to replace incandescent lamps at homes. These are being substituted by the more efficient CFL at no cost for the citizens in exchange for the old traditional lamps. This is the so called Programa de Luz Sustentable (Sustainable Light Program) [8]. As mentioned before, this program should be complemented with an information campaign to alert the citizens about the risks associated with the disposal of CFL and all mercury-containing devices.

The so-called energy-saving lamps, that is to say, fluorescent lamps, are far away from being the best available solution. On the other hand, now it is possible to produce LEDs for almost any need; the color of the emitted light can be controlled at will to match any requirement [white (w), warm white (ww), day-light, etc.] by controlling the doping of the working substance; prices are going down and lifetimes are going up. If we take into account the current trends on costs and technological advantages, the increasing energy efficiency and the ecological compatibility, we can conclude that in the near future LEDs will replace all other types of man-made light sources. This will render the present Mexican Sustainable Light Program obsolete in a few years.

A final commentary in favor of LEDs: when light devices are used in networks where other sensitive instruments are connected, it is important that the disturbances introduced by the light sources into the net have minimum levels. This is accomplished more easily with solid state technology in comparison with fluorescent lamps. Recent studies [9] on the introduced total harmonic distortion (THD) show that LEDs are also more convenient in this respect.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support from the Secretaría de Investigación y Posgrado - IPN through Project SIP-20130818.

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