

# Study of temperature and performance for LED devices with white emission

## Estudo de temperatura e desempenho para dispositivos LED com emissão branca

Emerson Roberto Santos<sup>1,2</sup>, Thiago de Carvalho Fullenbach<sup>2</sup>, Antonio Celso Duarte<sup>2</sup>, Paulo Jorge Brasão Marcos<sup>2</sup>, Victor Sonnenberg<sup>2</sup>, Elvo Calixto Burini Junior<sup>3</sup>, Roberto Koji Onmori<sup>4</sup>, Wang Shu Hui<sup>1</sup>

### ABSTRACT

This work shows the study of commercial LED (light-emitting diode) devices with white emission and the influence caused by its temperature to reach maximum performance. In the experiments, two different conditions were compared: (a) LEDs polarized and immersed in the current water with 12.5, 25.0 and 50.0 mL and (b) LEDs polarized at atmospheric air. The results revealed that the current water could be a good method to a reduction of the LED temperature, increasing significant values of electrical current and luminance. The LEDs polarized into the current water revealed that 12.5 mL promoted the highest electrical current of  $\approx 228$  mA and maximum luminance of  $\approx 2,146,000$  cd/m<sup>2</sup>, while the LED polarized at atmospheric air presented only electrical current of  $\approx 68$  mA and luminance below of  $\approx 1,700,000$  cd/m<sup>2</sup>. This increase in performance showed a little difference of the chromaticity coordinates to obtain the purest white color emission.

**Keywords:** White LED, I-V curve, Water, Luminance, Temperature, Chromaticity coordinates.

### RESUMO

Este trabalho mostra o estudo de dispositivos comerciais de diodo emissor de luz (diodo emissor de luz) e a influência de sua temperatura para alcançar o máximo desempenho. Nos experimentos, duas condições diferentes foram comparadas: (a) LEDs polarizados e imersos em água corrente com 12,5; 25 e 50 mL; e (b) LEDs polarizados em ar atmosférico. Os resultados revelaram que a água corrente pode ser um bom método para redução da temperatura aumentando significativamente os valores de corrente e luminância. Os LEDs polarizados imersos em água corrente revelaram também que 12,5 mL promoveu maior corrente de 228 mA e luminância máxima de 2.146.000 cd/m<sup>2</sup>, enquanto o LED polarizado no ar atmosférico apresentou apenas corrente de 68 mA e luminância abaixo de 1.700.000 cd/m<sup>2</sup>. Este aumento de desempenho mostrou uma pequena diferença nas coordenadas de cromaticidade para obter a mais pura emissão de cor branca.

**Palavras-chaves:** LED branco, Curva I-V, Água corrente, Luminância, Temperatura, Diagrama de cromaticidade.

<sup>1</sup>Escola Politécnica da Universidade de São Paulo, Engenharia Metalúrgica e de Materiais - São Paulo, Brazil

<sup>2</sup>Faculdade de Tecnologia de São Paulo, Sistemas Eletrônicos, iCenter - São Paulo, Brazil

<sup>3</sup>Universidade de São Paulo, Instituto de Energia e Ambiente - São Paulo, Brazil

<sup>4</sup>Escola Politécnica da Universidade de São Paulo, Engenharia Elétrica - São Paulo, Brazil

**Correspondence author:** [emmowalker@yahoo.com.br](mailto:emmowalker@yahoo.com.br)

**Received:** 24/06/2019 **Approved:** 31/07/2019

## INTRODUCTION

LED (Light Emitting Diode) is an electroluminescent device that transforms electrical energy in the emission of light when it is polarized. This device emits several wavelengths to obtain different colors, including white emission<sup>1,2</sup>. The evolution of LED is described as a brief history<sup>3,4,5,6,7</sup>:

*Henry Joseph Round (England - 1881-1966)* was the first British researcher to report the description of electroluminescence (the basic principle of LEDs). He observed that certain semiconductors emit light when an electrical current pass through them. Henry was also a pioneer researcher on radios and verified this phenomenon when he applied voltage on semiconductors trying to improve the amplification of the radio signals. He published relevant results of this research in 1907.

*Oleg Vladimirovich Lósev (Russia - 1903-1942)* published the first research in 1927 related to LED devices. He knew about telecommunications and electronics. In experiments, Oleg perceived the same phenomena published by Henry Joseph Round. He assembled a crystalline diode with zinc oxide and silicon carbide that emitted photons with the polarization. Oleg also patented the light relay known as “Light Relay” to be used in telecommunications.

*Nick Holonyak (USA - 1928)* is an engineer and researcher that worked in the General Electric. He was considered the inventor of first LED as an electronic component. In 1962, Nick introduced an LED with low light intensity and red color emission.

After 1962, the LED with yellow emission is invented and early of 1970, the LED with green emission and wavelength around 550 nm. In the '80s with the introduction of AlInGaP technology, LEDs with red and amber emissions reach high levels of luminous intensity.

*Shuji Nakamura (Japan - 1954)* is electrical engineering that worked as a researcher in the Nichia Corporation. In 1999, he invented the LED of the high intensity with blue emission. He also mounted a LED with gallium nitride (GaN) and covered with yellow phosphorous layer obtaining white emission.

Since 2000, the white LEDs have been developed to replace the most common illumination sources, as incandescent and fluorescent lamps around the world<sup>8,9</sup>.

In the case of lamps, the application of LEDs has been most efficient, because they offer lower energy consumption and more economy spending less energy<sup>10,11,12</sup>. In addition, LED lamps have many other advantages, such as<sup>13,14,15,16</sup>:

- *Dimming effect* – the light intensity of LED can be varied from 1 to 100% (depending on the application);
- *Low operating voltage* - offers no danger to the installer;
- *Resistance to impacts and vibrations* – the device is a solid-state technology, for this reason, it does not use filaments, glasses and toxic chemical elements;
- *Ecologically correct* – LED does not use mercury, lead or other chemical elements that cause damage to nature;

- *“Green” engineering* - the electronic components of drives, as diodes, capacitors, resistors, coils and integrated circuits can be reused or recycled;
- *Dynamic color control* - it offers a varied spectrum of colors with different tones of the light emission;
- *Fast turn-on* – LED has rapid turn-on independent of its intern temperature. This aspect is very different of fluorescent lamps that need heat to obtain the maximum power emission of light;
- *Variable intensity control* - the luminous flux varies according to the electrical current providing a precise light intensity;
- *Vivid and saturated colors* - monochromatic emission provides realistic colors. LED does not use filters;
- *Direct flux of light* – the light of LED is directed with a small viewing angle;
- *Ballast* - LEDs does not require ballast as used in tubular fluorescent lamps.

Despite the white LEDs present good characteristics as previously mentioned, the maximum efficiency has been limited by heat sink generated that is dependent also by design of the lamp<sup>17</sup>. LEDs with white emission still have low efficiency transforming 20 to 30% of the input power into visible light and the remaining part 70 to 80% into heat and the lumen-depreciation values are very much dependent on what temperature the chip's junction reaches in its application<sup>18</sup>. Then, this aspect has directly contributed to the decrease of performance, as little lifetime with significant depreciation of the efficiency caused by variations of the electrical current in drivers<sup>19</sup>. This problem has been frequently observed in LED lamps by several consumers. But, in the packaging of these products has been reported higher lifetimes<sup>20</sup>. For example, the Fig. 1(A-D) show some packaging of commercial LED lamps



**Figure 1:** LED lamps manufactured by some companies with different lifetimes.

supplied by different companies. For each packaging is reported different lifetime described in years or hours (depending of the company)<sup>21,22,23,24</sup>.

Extensive lifetime of lamps has been limited by some problems caused by the maximum temperature of LED that is a parameter not easy to be controlled.

Moreover, the use of bad quality of electric components needs to be considered<sup>25</sup>. The common problem caused by degradation mechanism of the active layer of LEDs is due to increased non-radiative recombination which lowers the production of light and power efficiency caused by a defect as dark spot propagation. It is one of the suspects to increase the nonradiative recombination which converts most electron-hole recombination energy to heat by lattice atoms<sup>26</sup>.

However, this problem caused by temperature has been related by the dark spots on the active area (constituted by phosphorus layer) causing the premature failure of the lamp<sup>27</sup>. Due to the all LEDs to be electrically connected in serial position on the printed circuit board, when a LED is damaged, it turned-off all other LEDs interrupting the flux of electrical current of the lamp.

The white-emitting LED has been used as an active electric component since 1990, and then it has presented very reliability in the method of operation, but in the last years, many unknown companies in the branch of lighting have implemented LEDs in lamps offering products with low performance. Then a very common problem is related by intern temperature reach by these devices. The temperature limit and heat extraction of the LED are aspects that need to be improved to reach maximum performance. For this reason, the operation of these devices can be better understood to find better efficiency by electrical, optical, and thermal analyses. All these characteristics together have a direct influence on the behavior of devices<sup>28</sup>. Then, LEDs obtained of a company were tested in two conditions: polarized into the current water used as cooling method and polarized at atmospheric air.

## MATERIALS AND METHODS

In this experiment were used LEDs supplied by a Chinese Company called as Shenzhen Changfang Semiconductor Light Corporation LTD. with technical specifications as SD5050WN-S6-50 model; color temperature of 2,700 to 2,800 K and; threshold voltage of 3.0 to 3.3 V. Figure 2 shows the image of LED turned-off with active area diameter of 4.0 mm.

Each device has three light sources electrically connected in serial position. Figure 3 shows the LED polarized at 2.45 V (and electrical current below of 1,0 mA).

The LED devices were polarized with adjustable digital power source varying the voltage and collecting the respective direct electrical current to obtain the curve of diode. These pieces of equipment were manufactured by Hikari Company, model HF-3205S and Keithley Company, model 2400 connected by Labtracer 2.0 software set as diode. To obtain the luminance ( $\text{cd}/\text{m}^2$ )

and chromaticity coordinates (x and y) results, a chromameter manufactured Konica-Minolta Company, model CS-200 was set with angle of  $0.1^\circ$  and distance up to 15.0 cm between lens and active area (to obtain the focus).

Each LED was welded using a commercial tin-lead alloy with copper wire and painted with nail polish to avoid the electrolysis (formation of bubbles for LEDs polarized into the current water). Devices were immersed in different volumes of current water: 12.5, 25.0, and 50.0 mL placed into the Becker. The active region of LED kept in physical contact with the glass of Becker to obtain the precision measures of the light output, and the tip of the thermocouple was wholly immersed into the current water to obtain the temperature. In the experiment of LEDs polarized at atmospheric air, the tip of the thermocouple was positioned on each active area. The temperatures were obtained with multimeter manufactured by Minipa Company, model ET 2042-E connected by thermocouple K type (cromel/alumel with a temperature range of -473 to 1573 K). The diagram of chromaticity coordinates (x and y) was obtained with free software of colorimetry available on the website of the University of Barcelona (Spain)<sup>29</sup>. All experiments were performed at room temperature.



Figure 2: LED turned-off with active region diameter of 4.0 mm.

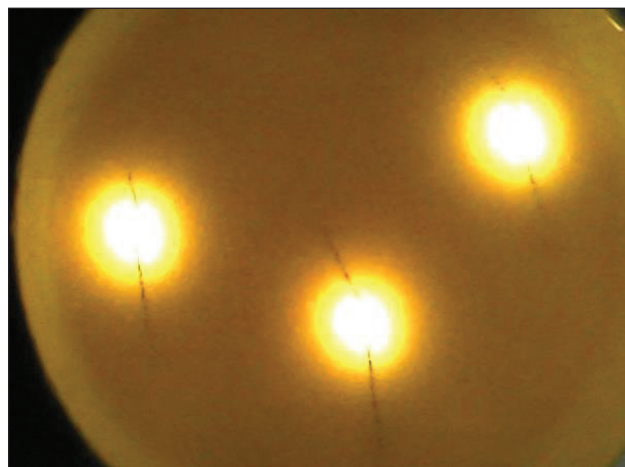


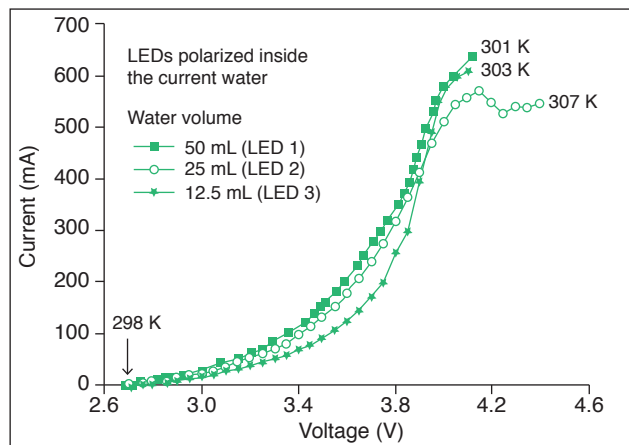
Figure 3: LED device polarized at 2.45 V, active region with three light sources turned-on inside the same encapsulation.

## RESULTS AND DISCUSSIONS

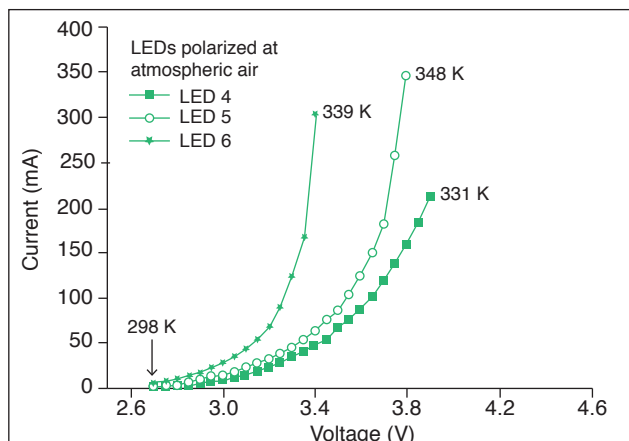
The study of electrical and thermal behaviors of LED devices polarized immersed into the current water and polarized at atmospheric air revealed distinct performances. In this case, the level of the electrical current obtained of LEDs immersed into the current water was most elevated, reaching values above  $\approx 500$  mA, while the devices polarized at atmospheric air reached  $\approx 350$  mA. The LEDs immersed into the current water with 12.5, 25.0, and 50.0 mL revealed influences caused by a heat sink of a device to the liquid elevating the temperature of the water. A little difference in temperature was observed of 12.5 and 50.0 mL from 301 to 307 K, respectively. Figure 4 shows the I-V curves of LED device polarized into the current water using different volumes: 12.5, 25.0 and 50.0 mL and Fig. 5 shows the I-V curves of LED device polarized at atmospheric air. Both figures show the initial and final temperature obtained.

The evident influence of temperature elevation was most pronounced to the LEDs polarized at atmospheric air as showed in Fig. 5 than that LEDs immersed into the current water as showed in Fig. 4.

Variations of the electrical current for LEDs polarized at atmospheric air were observed around of  $\approx 350$  mA revealing



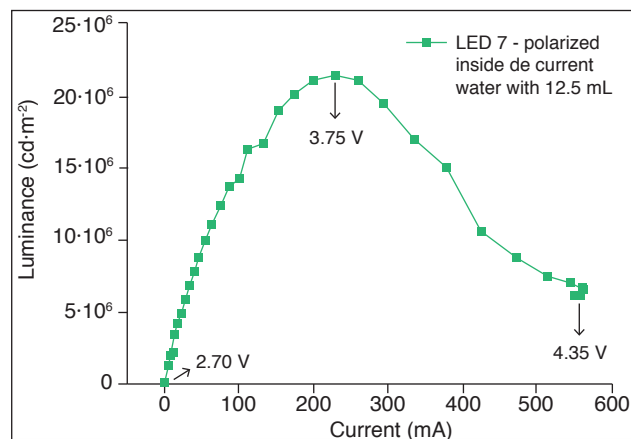
**Figure 4:** LEDs polarized into the current water using different volumes: 12.5, 25.0 and 50.0 mL with electrical current vs. voltage and initial and final temperatures.



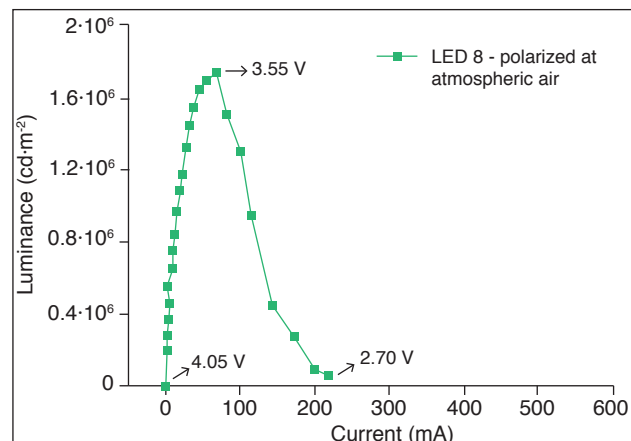
**Figure 5:** LEDs polarized at atmospheric air with electrical current vs. voltage and initial and final.

the phenomenon of degradation caused by Joule Effect with a drastic decrease of performance and low transference of heat from LED to the atmospheric air. The difference of the initial and final temperature observed to the analyses for LEDs polarized at atmospheric air was most significant than that immersed into the water.

The study of optical characteristics for both conditions also revealed significant differences. In this case, the LEDs immersed into the current water with 12.5 mL reaches highest electrical current of  $\approx 228$  mA and maximum luminance peak of  $\approx 2,146,000$   $\text{cd/m}^2$ , as shown in Fig. 6. This performance was better than that the LED polarized at atmospheric air with electrical current of  $\approx 68$  mA and maximum luminance peak below of  $\approx 1,700,000$   $\text{cd/m}^2$ , as showed in Fig. 7. The higher peak of voltage was obtained for the LED immersed into the current water polarized at 3.75 V, while the LED polarized at atmospheric air reached 3.55 V. This value is very different as reported by the company (from 3.0 to 3.3 V, it did not reveal the condition that the LEDs were tested). The Fig. 6 shows the results of luminance vs. electrical current to the LED polarized into the current water with 12.5 mL and the Fig. 7 shows results of luminance vs. electrical current to the LED polarized at atmospheric air.



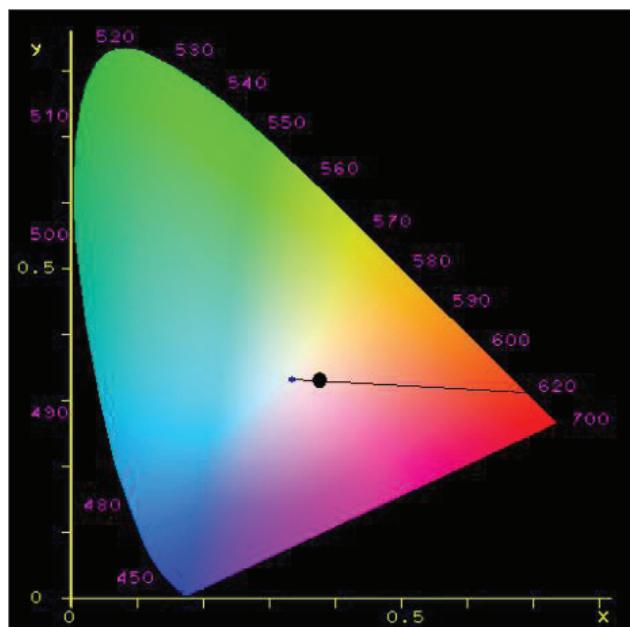
**Figure 6:** LED polarized immersed into water with 12.5 mL. Luminance vs. electrical current results.



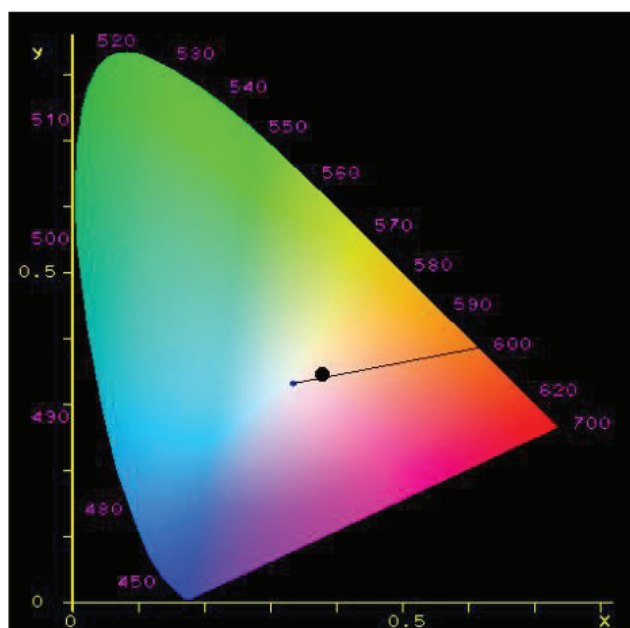
**Figure 7:** LED polarized at atmospheric air. Luminance vs. electrical current results.



The results of voltage vs. electrical current to the LED devices polarized with maximum performance revealed a low change of chromaticity coordinates  $x$  and  $y$  for both conditions. In this case, the LED immersed into the current water presented a trend to emit the pure white color (with chromaticity coordinates of  $x = 0.333$  and  $y = 0.333$ ) in comparison with the LED polarized at atmospheric air. Figure 8 shows the results of chromaticity coordinates to the LED immersed into the current water with 3.75 V, 227.94 mA,  $x = 0.3758$  and  $y = 0.3347$ ; and Fig. 9 shows the results of the LED polarized at atmospheric air, with: 3.55 V, 67.153 mA,  $x = 0.3814$  and  $y = 0.3413$ .



**Figure 8:** LED immersed into the current water polarized at: 3.75 V, 227.94 mA,  $x = 0.3758$  and  $y = 0.3347$ .



**Figure 9:** LED polarized at atmospheric air polarized at: 3.55 V, 67.153 mA,  $x = 0.3814$  and  $y = 0.3413$ .

## CONCLUSIONS

An exploratory study with commercial LED devices polarized in two different situations was carried out. The LED devices were polarized: (a) immersed in current water testing different volumes of 12.5, 25.0 and 50.0 mL and (b) polarized at atmospheric air (the common method). The results revealed that the current water used as a cooling method improved significantly the extraction of LED heat increasing its efficiency significantly. The minimal condition of volume with 12.5 mL was already possible to obtain the highest electrical current value and, consequently, the highest luminance level, when it was compared with LED polarized at atmospheric air. This maximum performance with the increase of electrical current and also luminance above of 18% (compared by both methods) provided a low difference in the chromaticity coordinates improving the light emission of LED to obtain the purest white color emission that is the proposal of the LED device company.

## ACKNOWLEDGMENTS

The authors are grateful to the financial support from the Brazilian agency CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) by post-doctoral scholarship.

They also thank Escola Politécnica da Universidade de São Paulo for providing installations and equipment.

## REFERENCES

1. Nakamura S, Chichibu SF. Introduction to nitride semiconductor blue lasers and light emitting diodes, CRC Press, 2000.
2. Philips, Fortimo LED downlight module system, Application Guide (DLM), 2008.
3. Roun HJ. A note on carborundum. Electrical World, 1907; (49)1-309.
4. Novikov M A. Oleg Vladimirovich Losev: Pioneer of Semiconductor Electronics (Celebrating One Hundred Years since His Birth); Physics Solid State 2004; (46)1-4. <https://doi.org/10.1134/1.1641908>
5. Schubert EF. Light Emitting Diodes. 2 rd. edition Cambridge University Press: New York, 2006.
6. Stringfellow GB, Craford MG. Semiconductors and semimetals, Academic Press: San Diego 1 rd. edition, 1997.
7. Nakamura S, Fasol G. The Blue Laser Diode GaN Based Light Emitters and Lasers. Springer-Verlag: Berlin 1 rd. edition, 1997.
8. Jaehee C, Jun HP, Jong KK, Schubert E F. White light-emitting diodes: History, progress, and future. Laser Photonics Review, 2017; 1-17. <https://doi.org/10.1002/lpor.201600147>
9. Energy Star. The light bulb revolution. EPA predicts widespread consumer adoption of LED lighting by 2020 if utility programs persist. Catalogue 2017.
10. Inmetro, Lâmpada LED, 10 páginas. Accessed in 17/06/2019. Available at: [inmetro.gov.br/inovacao/publicacoes/cartilhas/lampada-led/lampadaled.pdf](http://inmetro.gov.br/inovacao/publicacoes/cartilhas/lampada-led/lampadaled.pdf)

11. Lúmens e watts? Como escolher corretamente lâmpadas econômicas LED. Accessed in 17/06/2019. Available at: <http://www.ledplanet.com.br/blog/lumens-e-watts-como-comprar-lampadas-economicas-led/>
12. Santos TS, Batista MC, Pozza SA, Rossi LS. Análise da eficiência energética, ambiental e econômica entre lâmpadas de LED e convencionais. *Engenharia Sanitária e Ambiental* 2015; 4(20):595-602. <https://doi.org/10.1590/S1413-41522015020040125106>
13. Ingrid T, Ricardo R, Luis OR. Iluminação LED: sai Edison, entram Haitz e Moore – benefícios e oportunidades para o país. *BNDES Setorial*, 2015; (43):363-412.
14. Gordon K. LED application series: Using LEDs to their best advantage. U.S. Department of Energy – Energy Efficiency and Renewable Energy, 2008, 4 p.
15. Faria AC. Iluminação sustentável: os benefícios do uso da tecnologia LED nos projetos de iluminação. Dissertação de mestrado do curso [Ecologia e Produção sustentável] – Pontifícia Universidade Católica de Goiás, 2014.
16. Lâmpadas LED - o que são? Diferenças e vantagens. Accessed in 17/06/2019. Available at: <http://www.fazfacil.com.br/reforma-construcao/lampadas-led-o-que-sao/>
17. Andonova A, Kim N, Vakrilov N. Estimation the Amount of Heat Generated by LEDs under Different Operating Conditions. *Elektronika ir Elektrotechnika* 2016; 22(2):49-53. <https://doi.org/10.5755/j01.eie.22.2.14591>
18. Bommel WV, Rouhana A. Philips – Lighting Hardware, lamps, gear, Luminaires, controls. Catalogue 2011.
19. Souza ACBP, Junior AVP, Martins CC, Guedes JCS, Campos TV. CIEESE, PROCEL, Eletrobrás-Cepel, Guia orientativo para iluminação com a tecnologia LED; 160 p.
20. Quanto tempo dura uma lâmpada LED. Accessed in 18/06/2019. Available at: <https://www.ledplanet.com.br/quanto-tempo-dura-uma-lampada-led/>
21. The Race to the Bottom: LED Bulbs and DFM: <https://www.sparkfun.com/news/1821>. Accessed in 16/06/2019.
22. Lowest damage. Accessed in 18/06/2019. Available at: <https://www.ledlightskit.com/lowestdamage.php>
23. C by GE - C-Life A19 Bluetooth Smart LED Light Bulb – White. Accessed in 16/06/2019. Available at: <https://www.bestbuy.com/site/c-by-ge-c-life-a19-bluetooth-smart-led-light-bulb-white/6300445.p?skuid=6300445&intl=nosplash>
24. 7W ES LED Light Bulb. Accessed in 16/06/2019. Available at: <https://www.wayfair.co.uk/lighting/pdx/symple-stuff-7w-es-led-light-bulb-evli1055.html>
25. Zaroni DP. Aplicação de LEDs de luminescência branca para iluminação. Dissertação de mestrado do curso [Engenharia de Materiais] – Universidade Federal de Itajubá, 2013.
26. Fan J, Yung KC, Pecht M. Failure Modes, Mechanisms, and Effects Analysis for LED Backlight Systems used in LCD TVs. *Proceedings Prognostics & System Health Management Conference*; 2011 May 24-25; Shenzhen, China.
27. Castro DB. Iluminação por LEDs. *Revista On-Line IPOG Especialize*, 2013; 01(05):1-13.
28. Junior EMS, Antunes FLM, Perin AJ. LEDs para iluminação: características e normas, II Congresso Brasileiro de Eficiência Energética; 2007, September 02-07; Belo Horizonte, Brasil.
29. JOptics. University of Barcelona. Departament de Física Aplicada i Òptica. Grup d'Innovació Docent en Òptica Física i Fotònica. Accessed in 18/06/2019. Available at: <http://www.ub.edu/javaoptics/index-en.html>