# A Comparative Study Regarding Linear Fluorescent and LED Lamps for Indoor Lighting

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***Abstract*—A study methodology aimed to compare two low power lamp technologies, T8 fluorescent and linear T8 LED lamps, is presented. Electrical parameters and temperature measurements are compared as well as an analysis of the obtained results from digital simulations concerning photometric characteristics. A new method for measuring photometric parameters is proposed to replace the current standards. A payback retrofit study concerning LED technology to be applied in a typical educational building is also given.**

## I. INTRODUCTION

The indoor lighting is of great importance for humans since, if performed improperly, can impair the quality of work or any other activity performed in such an environment. Therefore, it is essential that the lighting equipment be as efficient as possible, observing the minimum levels of certain luminous parameters provided in the current national regulation [1]. Moreover, it would be preferable to employ an economic solution. It is estimated that about 30% of the electricity generated in the world in the recent years is destined to the artificial lighting [2]. Hence, to adopt efficient and standard compliant technologies could contribute to reduce the amount of energy used nowadays.

After the development of the blue light emitting diodes (LEDs) in 1997 and later the white LED, the so-called solid-state technology has gained particular interest in researches and applications of artificial lighting [3]. The LED based lighting is being increasingly employed for indoor applications to replace conventional technologies. This occurs because of its greater energy saving capability, long lifespan, reaching up to 100.000 hours [4], and photometric features that could improve the visual comfort, high color rendering index (CRI), wide range of correlated color temperature (CCT) and high luminous efficacy of up to 150lm/W [5].

Nowadays there are several LED luminaires competing in the market against fluorescent fixtures. The analysis of the LED photometric and electrical parameters in comparison to these linear fluorescent lamps has been treated as an important research topic of the U. S. Department of Energy [6].

This paper presents a comparative study between two indoor lighting technologies, namely T8 fluorescent lamps and its linear LED counterpart (popularly known as LED tubes), such as those shown in Fig. 1. Electrical and photometrical characteristics of these light sources will be assessed in face of the current standards for a particular field of work, besides the analysis of temperature on their structures.

The results obtained in laboratory were compared with those obtained using the DIALUX software program, which is able to simulate the environment under study, setting lighting scenes as close as a real condition. The temperature effects are evaluated in order to verify the impact of those technologies in a given environment.

Finally, the paper evaluates the replacement of the old fluorescent system, adopted in an educational building, by newer LED lamps. The calculations of the savings affecting the electricity bill will be presented and the approximate payback time concerning the investment made in the implementation of this project.

## II. ELECTRICAL PARAMETERS EVALUATION

Light emitting diodes are electronic devices that emits visible light when forward biased and are able to integrate modern lighting fixtures. A major advantage offered by the LED lighting technology is derived from its low power operation, as well as their directional lighting property and high luminous efficacy, which consequently may reduce the total wattage of a given installation when compared to fluorescent lamps.

In order to observe these and other electrical parameters regarding both technologies, experimental evaluations were performed in laboratory. Table I shows the information provided by the manufacturers of the two T8 lamps studied here.

Figure 1. Comparison of LED tube (upper) with T8 fluorescent lamp.

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TABLE I. PARAMETERS PROVIDED BY THE MANUFACTURERS.

| Lamp Technology | Power Rating (W) | Luminous Flux (lm) |
|---|---|---|
| ***LED*** | 24 | 1660 |
| ***Fluorescent*** | 32 | 2500 |

For the measurement of power parameters of the lamps (active input power and power factor), it was used a YOKOGAWA wattmeter model WT230. To measure other electrical parameters, it was used a TEKTRONIX oscilloscope model DPO 3014. In both cases, an almost ideal sinusoidal voltage of 220V RMS provided by a TENMA AC power source model 72-7675 (total harmonic distortion less than 0.5%) fed the lamps.

Table II lists the main parameters obtained by means of the measurements described in last paragraph. As indicated in table, LED current and voltage values are of DC nature while the fluorescent values are of AC nature.

The results shown in this table indicate that the LED luminaire drives less power from electrical network, but features a higher total harmonic distortion (THD) concerning its input current. For both lamps, there was a loss of around 3W of power in their AC interface circuits (driver and ballast). These ratings are primarily responsible for the decrease in performance of each system.

Equipment connected to AC electrical networks with an input current lower than 16 A, such as the lamps considered in this study, have their electromagnetic behavior limited by IEC 61.000-3-2 standard [7]. By using the equipment described in the beginning of this section it could be found that the LED linear lamp has not complied with the harmonic limits, as shown in Fig. 2. The reason of this bad performance could be explained by the lack of specific LED lamps (Brazilian) regulations by the time of the LED lamp sample has been donated to the laboratory. The authors are not informed if such type of products are still being commercialized nowadays. However, the approval of a technical standard has been discussed by the INMETRO [8], which regards to the quality of LED lamps with integrated control device.

On the other side, Fig. 3 shows that the fluorescent lamp under test found no conflict with the harmonic standard, presenting lower levels for all orders.

Brazilian regulation, however, establishes a minimum requirement for the power factor of installations, which is 0.92 [9], [10]. In this case, it would be preferred that all the electrical equipment plugged to mains could present a greater than 0.92 power factor. According to Table II, the LED lamp can contribute for the regulation compliance of a given installation, while the fluorescent lamp does not.

The next section concerns with the photometrical evaluation of both lamps under study.

## III. PHOTOMETRIC PARAMETERS EVALUATION

The current photometrical regulation adopted in Brazil for indoor lighting requires that the illuminance, the reflectance and the glare (and visual comfort) of a given lighting project be evaluated and observe the requirements [1].

So, the photometric analysis of the fixtures under test were obtained by means of a DIGILUX OPTRONIK lux meter model 9500, equipment able to measure the illuminance of a given luminaire and a KONICA MINOLTA luminance meter model LS-100, capable of measuring the luminance of the light source.

### *A. Photometry Standard Evaluation*

To measure these parameters, it was performed experimental photometrical measurements in an corridor of lecture rooms of a typical university building, with dimensions 3m x 6.4m x 2.85m of width, length and height, respectively.

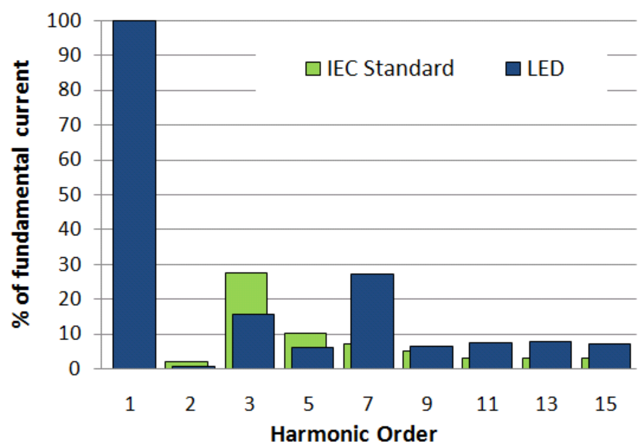


Figure 2. Harmonic levels for LED luminaire.

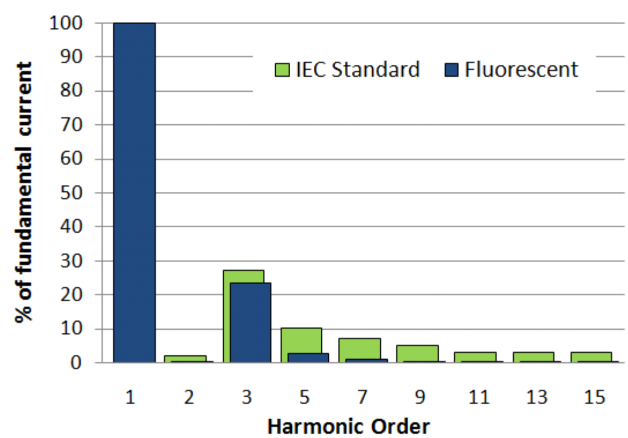


Figure 3. Harmonic levels for fluorescent luminaire.

TABLE II –LAMPS MAIN ELECTRICAL MEASURED PARAMETERS.

| Lamp | Input Current | Input Power (W) | Output Current (A) | Lamp Voltage (V) | Output Power (W) | Driver/Ballast Efficiency (%) | Power Factor | THD (%) |
|---|---|---|---|---|---|---|---|---|
| ***LED*** | 117.4mA (DC) | 23.70 | 1.087 (DC) | 18.77 (DC) | 20.38 | 86.00 | 0.92 | 36.9 |
| ***Fluorescent*** | 312.1mA (RMS) | 32.15 | 0.212 (RMS) | 138.6 (RMS) | 28.96 | 90.08 | 0.90 | 23.6 |

As already mentioned, the indoor lighting standard establishes minimum illuminance and reflectance values for certain applications, defining methods for measuring these parameters.

In the corridor case, a task area of 1 m wide by 6.4 meters long is required (see Fig. 4). Considering the higher dimension, d, equation (1) defines the grid size, p. The quotient between d and p results in the number of points (n) to be measured.

$$p = 0{,}2x5^{\log_{10} d} \tag{1}$$

Figure 4 also shows the points to be measured, represented by the circles in the task area in a specified portion of the corridor under study. In this figure, the central rectangle represents the lamp to be studied. Each lamp has two bulbs of the analyzed technology. Dimensions are given in meters. The results of the measurements are shown in Table III.

Luminance measurements were performed in order to observe if the luminaires attend the same standard about the limits of reflectance for the environment under study. Equation (2) [11]-[13] shows reflectance (ρ) depending on illuminance (E) and luminance (L).

$$L = \frac{\rho E}{\pi} \tag{2}$$

The LED technology attended to the standard [1], surpassing the average minimum of 100 lux for corridors environments, while the fluorescent lamp failed to provide the minimum required illuminance level.

Concerning the reflectance, both technologies attended the standard [1], which suggests a range between 0.2 cd/m² to 0.6 cd/m² at the work plan. In the case of corridors, this means the transit floor.

An important observation to be made regarding the proposed evaluation concerns the large portion of area with unspecified illuminance. Thus, a lighting project oriented to cover the narrow range of required measurement points could comply with the standard, but could fail to illuminate other environment elements, such as the walls or any type of information supposedly exposed on the walls of the corridor. The next item aims to propose an alternative measurement methodology.

## B. *Proposed Test*

In order to propose a more complete test compared to the one proposed in the standard, it is suggested to divide the width by two to determine the main focal column position. Then, this value is divided by two again, to find the left and right columns. Thus in an analogous manner to the standard, it would have a central column of the measurement points and two lateral columns (different from the standard) with ten other measuring points each. Therefore, it covers a larger area to be analyzed. This area was studied in order to guarantee a higher level of information than required by the standard as well as a study of the distribution of illuminance and luminance along the corridor to be studied. It was used a lighting fixture with two lamps. A total of 30 points around the lamp ground projection were measured, as shown in Fig. 5. Dimensions are all given in meters.

The results of this test are presented in table IV. From those data, it can be seen that concerning the average illuminance aspect, the LED luminaire presented the best results. When comparing Tables III and IV it is observed an error inferior than 5%. However, it is possible to ensure by using the proposed method that the lateral areas receive incidence of minimum illumination as required by the standard. Once again, it was observed that the LED luminaire observed the standard, while the fluorescent fixture could not attain the minimum illuminance values. With respect to reflectance, both technologies can be considered to comply with the standard.

TABLE III. PHOTOMETRIC PARAMETERS ACCORDING TO STANDARD.

| Lamp | Average Iluminance (lux) | Average Luminance (cd/m²) | Reflectance |
|---|---|---|---|
| ***LED*** | 111.17 | 20.825 | 0.588 |
| ***Fluorescent*** | 80.601 | 11.1097 | 0.433 |

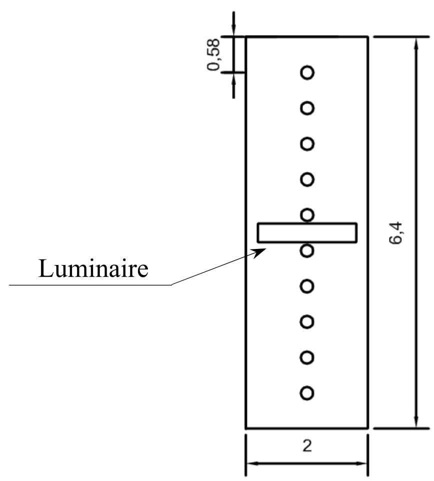


Figure 4. Standard area and definition of measurement points.

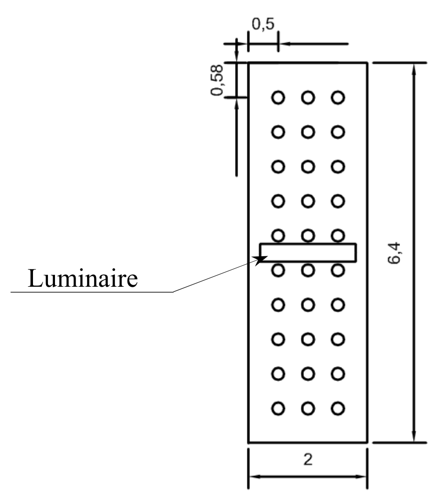


Figure 5. Measurement points of the proposed test.

TABLE IV. PHOTOMETRIC PARAMETERS ACCORDING TO THE PROPOSED TEST.

| Luminaire | Average Illuminance (lux) | Average Luminance (cd/m²) | Reflectance |
|---|---|---|---|
| ***LED*** | 109.114 | 20.666 | 0.595 |
| ***Fluorescent*** | 79.407 | 12.063 | 0.477 |

Figure 6 shows the distribution of the illuminance for the evaluated LED technology, while Fig. 7 shows the same parameter for the fluorescent luminaire. The plane is arranged by measurement points, width and length, whereas the height represents the illuminance for each combination of tested points.

In these figures it can be seen that the LED luminaire offers higher illuminance at all point of measurement and a smoother variation along the length of the corridor, providing a better lighting distribution when compared to the fluorescent luminaire. The fluorescent fixture favors the line immediately below it, offering lower illuminance levels along the corridor what contribute to the shadow phenomena between fixtures.

Thus, by analyzing the results described in sections II and III, one can conclude that the LED luminaire has some important advantages in comparison to the fluorescent luminaire. The first one drives less power and yet achieves the best photometric results. An interesting fact to be noted regards the luminous flux as indicated by the manufacturers. As seen in Table II, the fluorescent lamp has the higher value of this parameter. However, it is known that this type of luminaire provides light directed to all directions, i.e., a diffuse lighting [14], which is not a so important feature, since the lighting directed to the top of the fixture is partly lost or absorbed. Figure 8 shows the behavior of luminous beams for both technologies, revealing that the LED luminaire can provided a more objective lighting distribution. In other words, the LED fixture, when compared to its equivalent fluorescent, features a better photometric performance in the studied case.

## IV. EFFECTS OF TEMPERATURE

In order to observe the temperature behavior for both luminaires, two pictures were taken at a distance of 2.6 m from the luminaires LED and fluorescent, respectively, with the assistance of a FLUKE thermal camera model Ti 125. Figures 9 and 10 depicts those images.

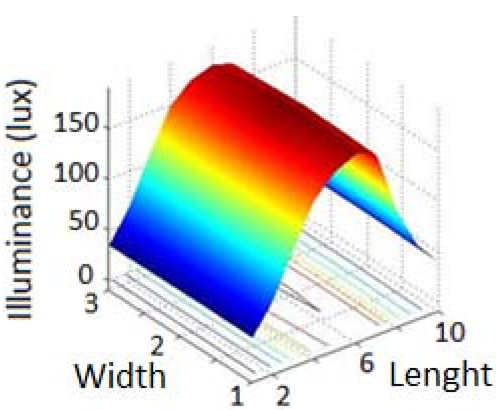


Figure 6. Illuminance distribution for LED luminaire.

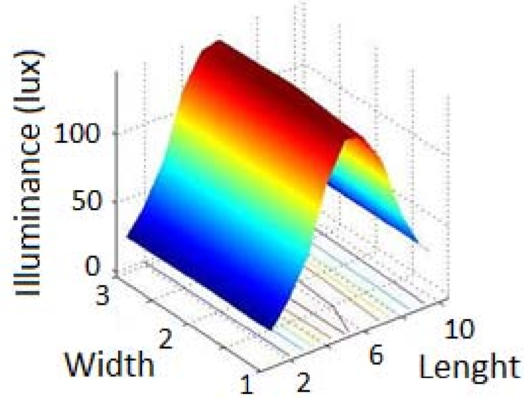


Figure 7. Illuminance distribution for fluorescent luminaire.

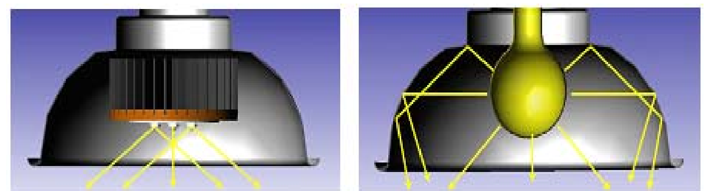

Figure 8. Luminous flux for LED (left) and other technologies (right) [12].

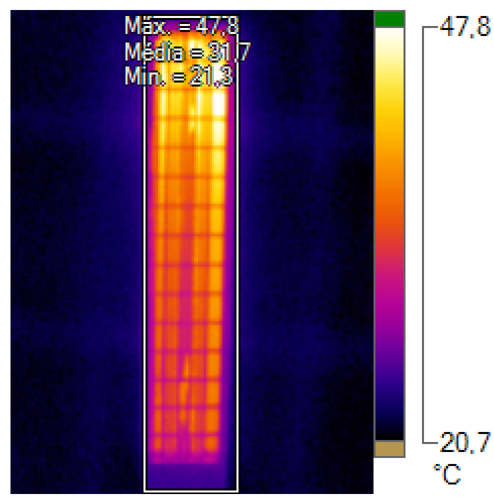


Figure 9. Thermal photo of LED luminaire

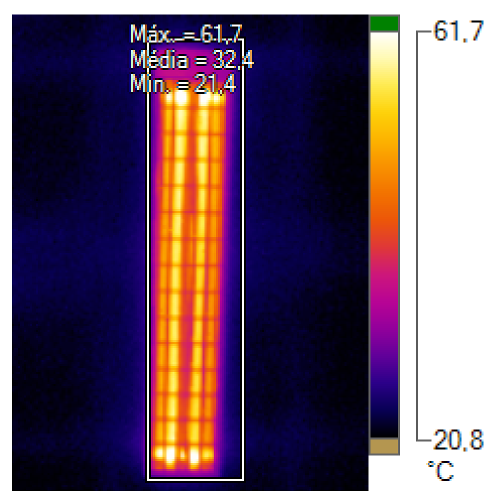


Figure 10. Thermal photo of fluorescent luminaire.

For Fig. 9, it is observed that the LED fixture surface temperature rises as the measure gets close to the position of the electronic circuit that drives the lamp, which could impair the performance of some LEDs, which are exposed to higher temperatures, than the ones placed at the opposite extreme. However, it could be inferred that those temperature levels are not high enough to affect the junction temperature. In contrast, Fig. 10 shows a better heat distribution over the fluorescent lamp. In this case, higher temperatures have been observed around the region of the electrodes.

For a more precise analysis of the temperature along the luminaires, it was used a GUBINTEC thermometer model ICEL TD800D to measure thirteen points across the tubes, as shown in Fig.11. Dimensions are given in centimeters and the ambient temperature was recorded at 21ºC.

Table V presents the results of such measurement. In this table it is possible to observe the temperature distribution along the lamp. Figure 12 shows the measurement regions that have been considered here.

It is worth mentioning here the importance of a well-designed heatsink. It can be seen that the temperatures measured along the heatsink from the LED luminaire are higher than that of the diffuser surface. As demonstrated in Fig.9, it was observed here a high temperature zone near the region where the driver is located, thereby decreasing along the luminaire. For the fluorescent lamp, it should be noted that closer to the contacts of the electrodes the temperature increases drastically, almost reaching the temperature of the heatsink in the LED luminaire. However, apparently the fluorescent lamp has a temperature distribution more symmetrical than its counterpart, although none of technologies could be blamed to harm the ambient temperature as some halogen lamps do.

## V. SIMULATION RESULTS

To compare the photometrical results obtained by on-site measurements with a digital simulation study, it was used the DIALUX software able to simulate the working environment and the lamps analyzed. Throughout this, it can be create the scene and insert the objects present in it, such as doors, windows and luminaires in the study, with their respective characteristics. Figure 13 shows an overview of the simulated plant. Two tubular LED lamps have been inserted in order to represent faithfully the study environment, since each luminaire has two light sources. The environment presents five doors and a power distribution board. The corridor reproduced featured 3 meters wide by 10 meters long and 2.8 meters of height. However, the simulated area for data acquisition was reproduced in the same area as in the assay described in section III.

Table VI presents the simulated photometric parameters. Through a comparative analysis of this regarding the results obtained in section III, it is observed that the proposed method in this paper in Section III-B is closer compared to those obtained by the test proposed by the applicable standard [1]. Hence, it could be said that the proposed method represents a more accurate alternative to this type of analysis.

It is worth mentioning the existence of possible errors from various factors, such as the choice of floors, walls, ceiling and doors that have specific values of reflectance as well as the depreciation factor of each luminaire.

Figure 14 shows the distribution of illuminance along the corridor as provided by the LED luminaire. It may be noticed a large portion of the ground being lit about at least 80 lux, reaching the most distant regions of the lamp values on the order of 30 lux. The outer portions in blue and purple shades are areas that are not related to the luminaire under study and were simulated only for reasons of symmetry.

## VI. PAYBACK CALCULATION

For the calculation of payback considering replacing fluorescent lamps by LED technology, it was taken into account a floor of a building of the school of engineering in the university where the lighting laboratory is located.

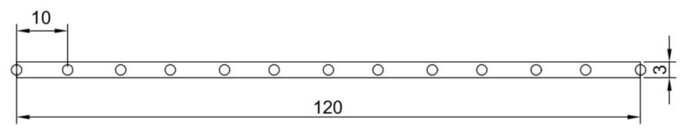


Figure 11. Proposed temperature measurement points.

TABLE V. TEMPERATURE ALONG THE LUMINAIRES.

| Measurement location (cm) | Temperature in surface of LED luminaire (ºC) | Heatsink temperature for LED luminaire (ºC) | Temperature in surface of fluorescent luminaire (ºC) |
|---|---|---|---|
| ***0*** | 30 | 48 | 42 |
| ***10*** | 32 | 48 | 37 |
| ***20*** | 30 | 48 | 38 |
| ***30*** | 30 | 44 | 36 |
| ***40*** | 31 | 42 | 37 |
| ***50*** | 30 | 41 | 38 |
| ***60*** | 30 | 40 | 39 |
| ***70*** | 29 | 39 | 38 |
| ***80*** | 29 | 38 | 37 |
| ***90*** | 28 | 37 | 38 |
| ***100*** | 29 | 36 | 38 |
| ***110*** | 29 | 36 | 39 |
| ***120*** | 26 | 35 | 44 |

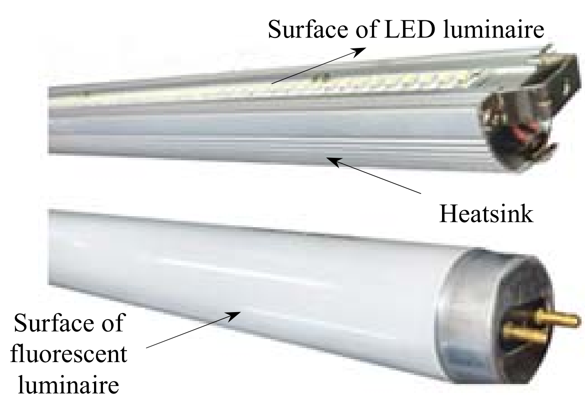


Figure 12. Measurement regions of both lamps.

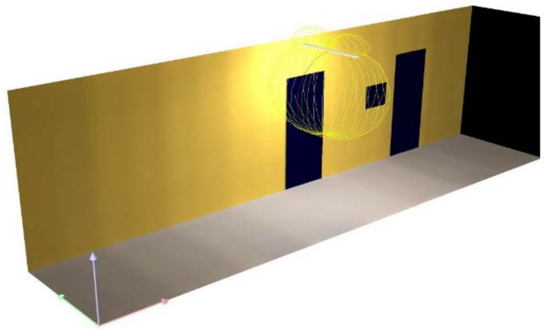

Figure 13. Overview of the simulated corridor.

TABLE VI. SIMULATED PHOTOMETRIC PARAMETERS.

| Luminaire | Average Iluminance (lux) | Luminance (cd/m²) |
|---|---|---|
| *LED* | 100 | 16 |

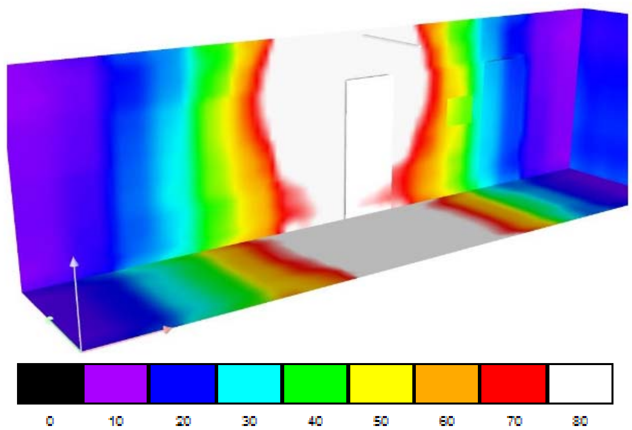


Figure 14. Illuminance distribution along the corridor.

Table VII shows the relation of rooms and the number of lamps per room. This made it possible to analyze the total expense of lighting for a period of one month in this building. In order to simplify the study, the bathrooms and the kitchen of the analyzed building were disregarded. Thus, the calculation gives the estimated time to get the return on investment in LED light lamps.

Equation (3) shows the calculation of the monthly consumption (C) of luminaire to the building under study, considering a sixteen hours period of operation a day (H), for twenty two days in the month. In this equation, N is the consumption for each luminaire (24 W for LED bulb and 32 W for fluorescent bulb) and L is the total number of lamps of a floor of the building studied. In this case it was obtained a monthly consumption of 1,182.72 KWh for LED luminaires ($C_L$) and 1,576.96 KWh for its equivalent lamp ($C_F$).

Equation (4) presents the financial calculation ($G_{month}$) (referring to 12/06/2013 and obtained from the weighted average of the tariff) [15]. In this equation, $T_{ph}$ is the tariff due to the peak hour (1,479.00 R$/MWh), $T_{oph}$ is the tariff charged out of the peak hour (182.56 R$/MWh), $T_D$ is the demanded tariff (16,346.00 R$/MWh) and P is the total power, in MW, regarding all the fixtures (L x W). C is given in MWh. The financial monthly consume of the LED system ($G_{month\ L}$) obtained was R$558.34 and for the fluorescent system ($G_{month\ F}$) was R$744.45.

Equation (5) shows the calculation for the amount of annual savings. Thus, the annual savings achieved is R$ 2,233.32 for one floor of the building.

Equation (6) [16] represents the calculation of the payback of the system. It is necessary to first define the cost of investment in the LED lamps to the building in question. Table VIII presents the cost of three different tube LEDs with power consumption around the 24W provided by different manufacturers as well as the average cost, which value will be used as the basis for the calculation of the payback. Thus, the result is a return on investment in the LED luminaires at 5.5 years.

$$C = H.22.W.L \tag{3}$$

$$G_{month} = C.\left(\frac{3}{16}.T_{ph} + \frac{13}{16}.T_{oph}\right) + (T_D.P) \tag{4}$$

$$Ec_{Anual} = 12.(G_{month\ F} - C_{month\ L}) \tag{5}$$

$$Payback(years) = \frac{Implantation\ cost}{Ec_{Anual}} \tag{6}$$

TABLE VII. RELATION BETWEEN ROOMS AND NUMBER OF LAMPS.

| Room | Number of lamps |
|---|---|
| *Laboratories* | 116 |
| *Corridors* | 8 |
| *Administration Office* | 16 |
| *Total* | 140 |

TABLE VIII. LED TUBE FIXTURE COSTS.

| Manufacturers | Cost (Brazilian Currency) |
|---|---|
| *F1* | 78.98 |
| *F2* | 89.90 |
| *F3* | 96.00 |
| *Average* | 88.29 |

## VII. CONCLUSIONS

The study presented a comparative analysis of linear fluorescent lamps and their LED equivalent. Measurements of electrical parameters were presented as well as photometric. Moreover, analysis of temperature effects, simulations and calculation of the economy considering the replacement of new equipment. The paper also presented a new test methodology for measuring photometric parameters that proved more efficient than the current method proposed by [1].

It was observed that in certain parameters such as total harmonic distortion and initial cost, fluorescent luminaires will have advantage over the new technology. However, in general, regarding the increased cost effectiveness presented by the LEDs due to low consumption and higher photometric parameters, it can be concluded that the technology of light emitting diodes has great advantage against the fluorescent lamps. Besides, its agreement with the standard related to photometry proved to overcome the fluorescent technology. In contrast, it is need to emphasize the use of well projected driver for the LED luminaires, since the one used was not able to meet good levels regarding the last five odd harmonics analyzed.

In means of conclusion, it is observed that both technologies are not equivalent. Each one has its own characteristics. However, recent researches shows that have been notable performance gains, with the efficacy, color quality and power quality of the LED lamps [6] which points the new technology as a best choice.

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