Analysing the behaviour of LED module driver under variation of ambient temperature

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Abstract. Temperature variations affect the operation of electronic devices. In this article we analyze effects that temperature variation entails a LED lamp commonly used in Brazil. We simulated temperature variations through the use of an oven of 1 m³. Then obtained emission spectrum in the visible, CRI, Correlated Color Temperature, harmonic distortion on the current, supply current, and CIE Chromatic Coordinates x and y in two situations: first with the LED module and controller inside the oven and second with the controller outside. The temperature was monitored in different part of this set. Interesting correlations for specifiers and developers were found.

1. Introduction
The theoretical process of conversion of electric energy to light energy that occurs in a semiconductor diode is a well-known technology. Taking this into account the search for improvements in components and in materials leads to fast changes on the luminotechnical scenario, principally when we are talking about technological applications.

Two different factors leads to this situation: from one side there is a demand to be filled and specifiers that needs products and resources to make possible the total generation of projects, always taking into account the needs of their customers and new conceptions of lightning technique. Most of the time these customers show their needs focusing in the quality of the product for the end user. By the other side, the financial impact of lightning services is taking place as an important variable, relevant in the budget of many public and private enterprises/services. In this context, there are situations that need particular metrics to measure their needs like energetic expenditure by illuminated area or the financial performance of a lightning service in the business or at the human productivity.

Figure 1 illustrates the process responsible for the conversion between electric energy and luminous energy when analyzing a classic model of physics. The semiconductor junction p-n maintain an electrical potential difference where electrons tends to go from the valence band in order to fulfill conduction band losing energy in the form of light.
The quantum efficiency of this conversion depends on the crystal structure, its purity, the absence of imperfections in the crystal net and some other parameters. The temperature at the semiconductor junction influences the quantum efficiency inasmuch as disrupts the crystal net and changes the emission spectrum.

The emission spectrum is the key point to reproduce color of surfaces and stuff rightly. When we look at a stuff and see colors, what is actually happening is the surface of the stuff reflecting photons from a light source to our eyes, making possible its visualization. This way, if the incident light in the stuff changes, the apparent color of the object may also change. LED sources with different technologies, such as RGB LED and a PC LED is shown in figure 2. The stimulus in human vision can be calculated multiplying the energy distribution spectrum of a lamp by the reflectance spectrum of the stuff (in figure 2 we have a TCS09, a standardized lamp used to calculate the Color Reproduction Index using the 9 CIE standards – R9). Taking into account that visual stimuli is the main way that human receive information day-to-day it is relevant to understand the LED behavior when this product is being used in real situations, like lightning services.

Figure 1. Conversion of electric energy to electric light occurring on a P-N junction. [1]

Figure 2. Color perception with two different LEDs models. [2]
2. Motivation
The energy spectral distribution emitted by the LED determines the lightning efficiency of the radiation. Most white LEDs on the market shows the curve illustrated in figure 3 (continuous black line). The peak at 450nm, high intensity and thin, is due to the transition of electrons in the p-n junction whereas the second peak, at 550nm, less intense and more widespread is due to the florescence of the phosphorus inside the LED capsule. Still in figure 3 there is a green dotted curve that represents the standard photopic curve that represents the human eye sensibility to light. The combination of these two curves determines the human sensibility for colours.

A parameter that most affect on this behavior of White LED and determines its efficiency to convert electric energy into luminous energy is the ambient temperature. The ambient temperature interferes not only in the life cycle of LED and its driver, but also in the spectral emission, changing colorimetric characteristics of LED. Therefore study the behavior of the set LED and driver is important to obtain conditions that are the best to operate. So, it is fundamental to have a good knowledge about the luminaire that will be used in the set-up in a way to provide a specific light distribution and adequate heat dissipation of the heat emitted in the process of conversion of electric energy to luminous energy – about 5% of all energy is consumed and converted into heat.

![Figure 3. Energy distribution spectrum of the luminaire determines the efficacy of the lightning. [1]](image_url)

So, the intent of this article is to identify changes in colorimetric parameters – like correlated color temperature, color rendering index and chromatic coordinates – when a white LED is in an ambient with variation of temperature.

3. Experimental
To study the colorimetric behavior of the white LED luminaire and be able to differentiate which parameters depends on the driver, and which depends on the driver and the LED module together. An luminaire that represent the ordinary product that are available in stores to general public was used.

The luminaire design is a metallic box with a ribbed diffuser and a heatsink. The driver of the LED module may be installed together or not with the luminaire box. The dimension of the luminair is 360mm x 240mm x 50mm, 220Vac, rated power of 50W – with driver it consumes 74W –, total flux of 4002lm, energetic efficiency of 54lm/W at ambient temperature of 25°C. Figure 4 is a general vision of the luminaire.
We simulated variation in ambient temperature and obtained colorimetric values for each situation. A Nova Ética oven of approximately 1m³ of useful volume, a power source California Instruments 1251RP, a Yokogawa wattmeter WT210 to monitor electric parameters, and in order to monitor temperature in 5 different spots of the luminaire a Yokogawa MV100 system integrated with 5 thermocouple was used. To obtain emission spectra from the luminaire, SpectraScan PhotoResearch 705 photometer was used. These spectra data were analyzed according to CIE protocol from 1995.

The experimental arrangement is illustrated in figure 5. The oven has only one hole on its top so an polytetrafluoroethylene (PTFE) target was placed in a way that PTFE target reflect the light directly from the luminaire to the PhotoResearch photometer.

Therefore, the target was in a constant temperature during all the experiment. The data were obtained in a rise of temperature starting in 25°C and rising near to 75°C. Each measurement was performed after a stabilization period of 30 minutes. To avoid background radiation the room was kept dark.

The measurements were done in two steps: one with the set LED module and driver inside the oven and the second one with only the LED module inside and the driver at constant temperature. The first step was labeled as M+C while the second one was labeled as M-C.

The reflectance of PTFE target was taken into account in the measurement process, although it shows a linearity relation in visible range as we can see in figure 6.
4. Results and Discussion

The graphs shown in figure 7 to 15 expose the results of the measurements as a function of ambient temperature (oven temperature). The label M+C refers to the data obtained with the set driver and LED module inside the oven represented by red circular spots, while the label M-C refers to the situation that only the LED module was inside the oven while the driver was in constant temperature outside the oven. M-C is represented by black dots.

In figure 7 we can observe different behaviors of temperature in each spot of the set in test according to the variation of ambient temperature, inside the oven.

Figure 6. Coefficient of reflectivity of Avian PTFE target in the visible range.

Figure 7. Temperature at different spots of the luminaire versus the ambient temperature inside the oven.
Figure 8. Effect of the variation of the temperature over the IRC.

In figure 9 and 10 we observe the effect of the elevation of the ambient temperature over the chromatic coordinate.

Figure 9. Effect of the variation of the ambient temperature over the chromatic coordinate X.
Figure 10. Effect of the variation of the ambient temperature over the chromatic coordinate Y.

In figure 11 the behaviour of the correlated color temperature is shown:

Figure 11. Effect of the variation of ambient temperature over the correlated color temperature.
In figure 12 we can note the relation between the ratio peak1/peak2 of a LED spectrum with the ambient temperature.

![Figure 12. Effect of the variation of ambient temperature over the ratio peak1/peak2.](image)

In figure 13 we have two spectra emitted by the luminaire. Both were obtained with the driver outside the oven. However the black dots represents the data obtained at 34.5ºC and the red dots the data obtained at 85.7ºC.

![Figure 13. Emission spectrum of the luminaire during the M-C procedure under 34.5ºC and 85.7ºC.](image)

In figure 14 we observe the effect of the increased temperature on total harmonic distortion.
In figure 15 we observe the effect of the ambient temperature on electric current.

![Figure 15. Effect of the variation of ambient temperature over the electric current.](image)

From figure 7 we can notice the increase of the temperature in several points of the luminaire. For both situations we can note that the inner part of the luminaire shows the maximum value of temperature. An interesting fact since the LED module is installed inside this part the luminaire. At this compartment the temperature is about 30ºC higher than in the other spots.

In figure 8 we can notice that for both situations, M+C and M-C, a rise in color rendering index occurs. However, analyzing the graph, for the set M-C, we notice a larger variation comparing to M+C, 0.045(4)/ºC and 0.032(2)/ºC, respectively. It indicated that the driver has a relatively sensibility for the variation of ambient temperature.
Talking about the chromatic coordinates, shown in figures 9 and 10 we notice that we have similar behaviors in both situations. When analyzing M+C we notice a tendency of decrease in X and Y, indicating the contribution of wavelengths corresponding to shades of purple. In M-C we notice an increase in values of X and Y, indicating the contribution of wavelengths corresponding to yellow.

The color correlated temperature, in figure 11, also shows two distinct behaviors for each case. When analyzing M+C, its linear fit shows a negative slope, whilst in M-C the opposite occurs. A curious fact is that M+C has a less variation than the M-C data. Maybe it happens because the driver compensates the effect of the temperature on the LED module and vice-versa.

Analyzing the spectra in figures 12 and 13 we can notice that the ratio between the radiance in peak 1 and in peak 2 decrease more sharply to M-C situation, indicating that the compensation occurs again. In figure 13 the variation in spectrum can be noted.

In figure 14 we can observe the behavior of total harmonic distortion – THD – under the variation of temperature. We note a wide increase of THD in the case of M+C, while a constant value represents the case M-C.

In the case of current, figure 15, the effect of the elevation of ambient temperature modifies mainly M-C data.

5. Conclusions

We can note a sharply influence of the variation of the temperature in distinct components that makes up a luminaire project. These components most of the time are sold as separated items and when these items are put together sometimes the compability between these items and the final product is not took into account.

This experiment may be improved by analyzing others colorimetric and electrical parameters that are part of the project of the luminaire. Also analyze different types of luminaires, such as those used for public lightning. The new parameters to study could be life cycle and the luminaire`s degradation suiting the boundary conditions to a Brazilian reality.

References

[1] National Research Council 2013 *Assessment of Advanced Solid State Lightning* 500 Fifth Street NW Washington The National Academies Press

[2] U.S. Department of Energy 2012 Building Technologies Program Solid-State Lightning Fact Sheet