MODEL FOR ILLUMINANCE PRODUCED BY LEDS AS A FUNCTION OF DISTANCE

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Abstract

The lighting industry has experienced a revolution with the arrival of novel lighting technologies in particular Light Emitting Diodes. LEDs have clear advantages in energy efficiency over conventional lighting technologies, and since 19 % of electricity worldwide is used for lighting, this can contribute significantly to saving energy problems worldwide and contributing to Europe’s 2020 strategy. In order to validate performance claims and stimulate user confidence, as well as facilitate efficient development of this kind of products, dedicated metrology is needed. The objective of this work was to study goniometrical aspects of LEDs, and their dependence with distance to find a model to predict the illuminance at any distance. A modified inverse-square law model, considering only the offset of the LED virtual source with respect to their front tip is proposed. The applicability of the method was tested for 18 LED’s types, with different angular and spectral distributions.

Keywords: Solid State Lighting, Light Emitting Diodes, Photometry, Inverse Square Law

1 Introduction

The raising awareness on energy saving has led to the development of more efficient light sources such as solid state *Light Emitting Diodes* (LEDs)- based sources. In recent years, the utilization of these illumination devices has exponentially increased, creating the need to photometrically characterize them. New methods of measurement are required (CIE, 2007), because these sources have different emission characteristics than traditional lighting sources.

LED manufacturers generally specify one single luminous intensity value in the specification of LEDs. However, LEDs cannot necessarily be considered as point sources. As a consequence, the specified luminous intensity value does not necessarily describe the photometric behaviour of the LED at varying distances. Calculating illuminance levels from the specified luminous intensity values may lead to errors up to tens of per cent in, e.g., luminaire design.

The objective of this work was to study goniometrical aspects of LEDs, and their dependence with distance to develop a model for the illuminance produced by LEDs. Comparison of results with other published models (Manninen, 2007) has been also done.

2 Methodology

Eighteen high-power LEDs from different manufacturers: Philips Lumileds LUXEON Rebel®, Osram Golden Dragon® and Cree Xlamp®, with different angular and spectral distributions (polar white, white, warm white, neutral white, blue, red and green) were chosen for this study. Illuminance measurements as a function of distance were performed on a 2-m optical bench. Measurements were made at 19 distances in the range 10 cm to 190 cm at 10 cm intervals. The photometer was mounted on a rail carrier and the tested LEDs were placed, one by one, at the end of the optical bench. Following CIE recommendations, the mechanical axis of the LED was aligned perpendicular to the receiving aperture of the photometer.

A commercial standard photometer, temperature stabilized, manufactured by LMT Lichtmesstechnik GmbH, was used. The photometer has a circular entrance aperture with a 100 mm^2 area. The photometer has got a planar diffuser behind the aperture to improve its angular responsivity. The illuminance responsivity of the photometer has been previously calibrated by direct comparison with a standard photometer of CSIC. For the determination of the spectral mismatch correction factor, the relative spectral responsivity of the photometer was measured at the CSIC's reference spectral comparator system.

To obtain angular distributions at different distances, the LEDs were mounted in a goniophotometer (Figure 1) designed and developed at IO-CSIC (Velazquez, 2013). Angular measurements were taken from 0 degrees to 90 degrees with a 5 degrees step, where 0 degrees is the normal to LED. The system is provided also with a CCD camera with a 50 mm lens, orthogonally located, for alignment purposes. The alignment of the LED respect to the centre of rotation of the reference system is accomplished with an iterative process in which the LED is observed alternately from two orthogonal directions by the CCD camera. The alignment ends up when no shift of the LED tip is observed in the image while varying the azimuth angle.

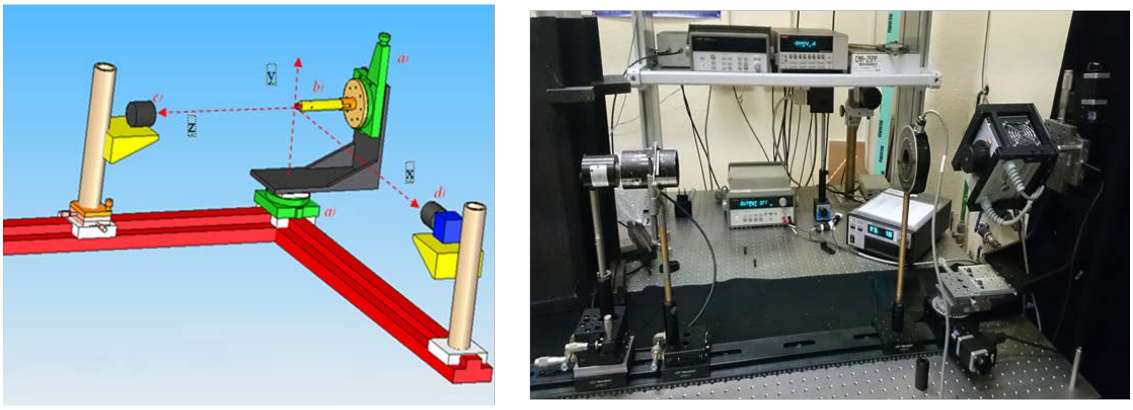

Figure 1 – Scheme and picture of the goniophotometer developed at IO-CSIC for LED characterization

High-power LEDs have been fed with a 350 mA constant electrical current, keeping their temperature at 25 ºC. An LED-850 Test Adapter from Instrument Systems and a TEC Source 5300 from Arroyo Instruments were used as temperature controllers.

3 Measurement Results

The measured angular illuminance distribution of three different LEDs (from different manufacturers) at four distances are presented in Fig. 2.

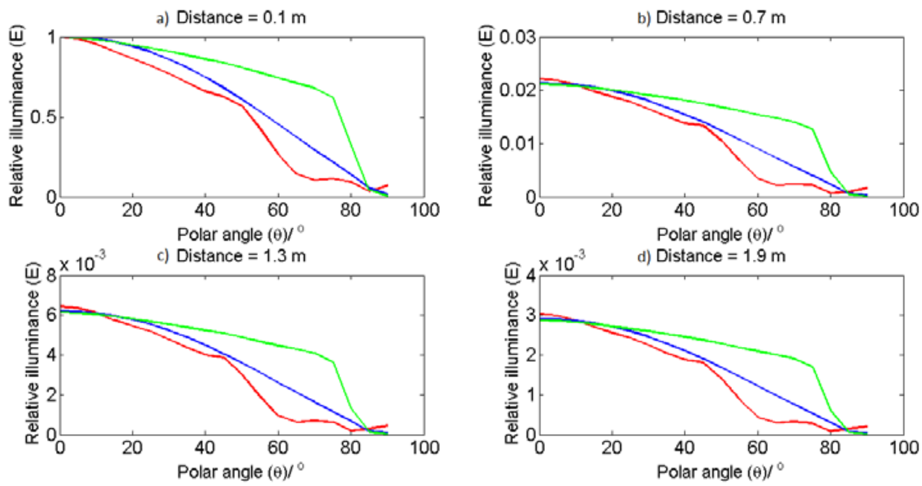

Figure 2 – Angular illuminance distribution of LEDs at four distances. Data on green correspond to a LED from OSRAM, blue to a LED from LUXEON and red to a LED from CREE.

The measured illuminance as a function of distance for different polar angles θ of the neutral white LED from CREE is presented in Fig. 3. As it can be seen dependence on distance is similar for all angles. The same behaviour was obtained for all the measured LEDs.

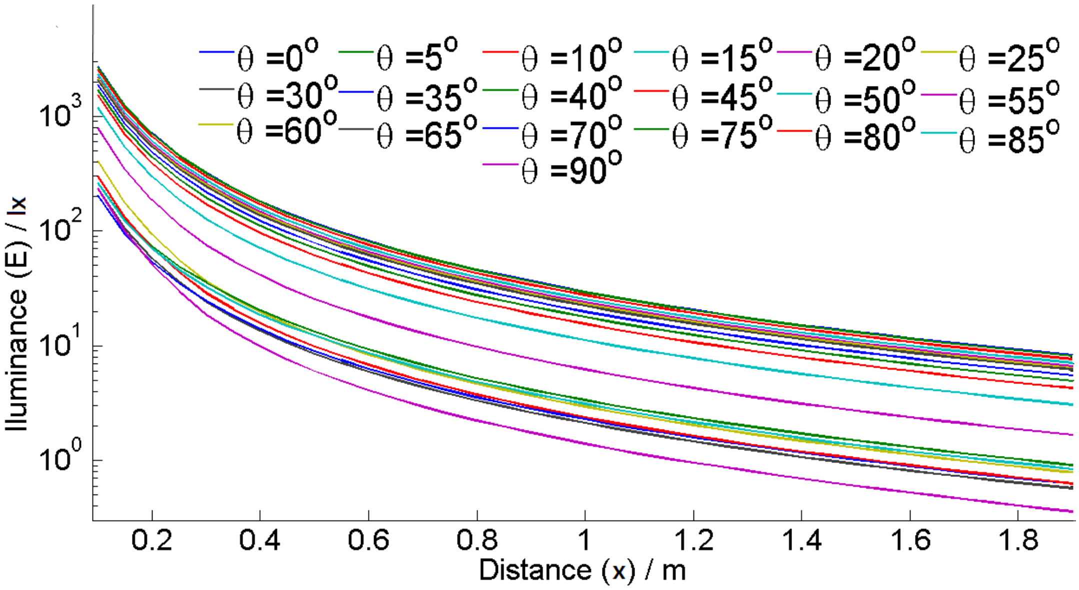

Figure 3 – An example of illuminance as a function of distance for different polar angles.

In order to fit the data, two different models have been tested: a general modified inverse-square model (eq. 1, Manninen, 2007) and a simplification of it (eq. 2, Pons, 2013), in the form:

$$E_v = \frac{I_v}{(x-d)^2+r^2} \tag{1}$$

$$E_v = \frac{I_v}{(x-d)^2} \tag{2}$$

being I_v the luminous intensity of the LED in the observation direction, E_v the illuminance measured in that direction, x the distance between the photometer reference plane and the LED tip, r a factor that combines the radii of the photometer aperture and the effective radii of virtual source and d the offset of the LED virtual source with respect to the front tip of the LED.

Based on the general and simplified model, the values of the effective luminous intensity and parameters *d* and *r* were obtained by two different procedures. The first procedure is to obtain these values with a least squares fit of the illuminance measured as a function of distance. The second procedure is to solve the equation for a number of distance values: two for Eq. 2 and three for Eq. 1.

For the solution with two distances, different couples were tested, although one value of the couple was always the corresponding to the farthest position (190 cm). For the other value, we have tested all measured positions. The best results were obtained when choosing the shortest distance; then we have chosen the initial position (10 cm) that represents CIE B condition (CIE, 2007).

For the solution with three distances, the experimental value obtained in an intermediate position was added to the shortest and the longest distances.

Relative differences (in %) between the measured illuminance and the calculated illuminance with both models and both methods have been obtained for all the selected LEDs. An example of the results obtained (similar results were obtained for all the selected LEDs), at normal incidence (θ = 0º) as a function of distance for the green LED from LUXEON is presented in Fig. 4.

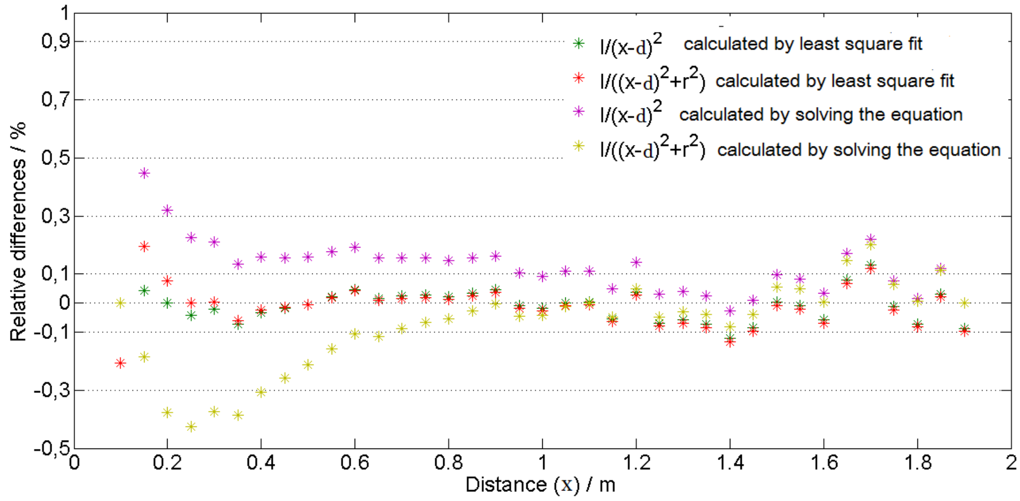

Figure 4 – Relative differences between measured and calculated illuminance values as a function of distance at θ = 0º, for the green LED from LUXEON.

To analyze the dependence on polar angles, we have calculated the average of the relative differences obtained for all the distances and we have represented this value as a function of the polar angle. Fig. 5 shows this representation for the green LED from LUXEON, and Fig. 6 shows the average for all the distances and all the polar angles for all the selected LEDs. In some of the selected LEDs, in particular those from CREE, that present a lower beam angle, we have found unusually high values for polar angles, greater than 55º. Then we have limited the evaluation to 50º.

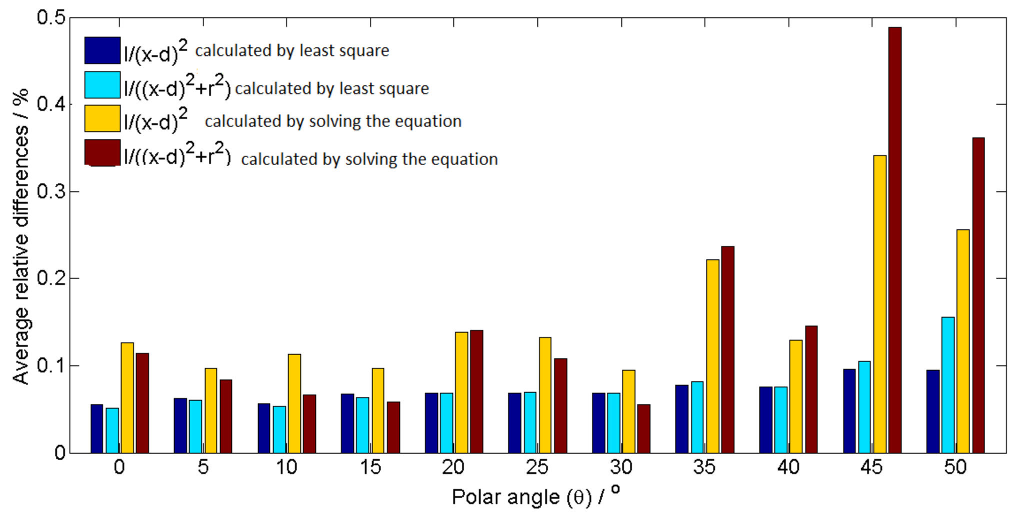

Figure 5 – Average relative difference between measured and calculated illuminance values, as a function of polar angle, for the green LED from LUXEON.

It must be mentioned that in some of the selected LEDs no solution to the calculation has been reached for the approximation of three distances.

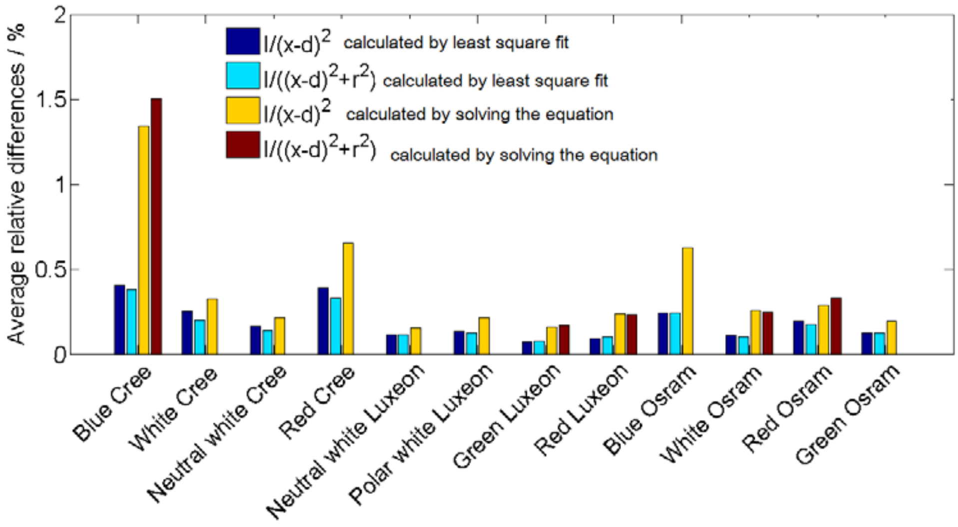

Figure 6 –Relative difference, averaged for all distances and all polar angles, between measured and calculated illuminance values, for all the studied LEDs.

4 Discussion and conclusions

Looking at the results, the following considerations can be established:

- In relation to illuminance dependence on distance, a simplified model (Eq. 2) considering only the offset, *d,* of the LED virtual source with respect to the front tip of the LED can be used for all the LEDs. No significant improvement is obtained when using a more complete model (Eq. 1).
- In the determination of values of all the parameters involved in the tested models, the best results (relative differences lower than 0,2 % at all distances) are always obtained with the least square fit method.
- It is possible to predict illuminance at any distance with an error lower than 1% respect to the experimental values, with measurements taken at only two distances. One of the measurements can be that corresponding to CIE B condition and the second one done at a sufficiently large distance.

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