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Spectral characterization of a Philips LED lamp

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Abstract
A luminaire of LED type has been studied at Laboratorio de Investigación Científica Avanzada (LICA) of Universidad Complutense de Madrid to determine its spectrum, color temperature, and other optical properties. The results for this lamp is compared with previous observations of luminaires found in Madrid streets.

1. INTRODUCTION

A luminaire has been provided by "Departamento de alumbrado público e Instalaciones especiales" of the Ayuntamiento de Madrid to be tested in LICA. The main goal was to obtain the color temperature from the spectrum. The transmission of the glass window and the angular response of the luminaire have also been measured. The luminaire is one of the lamps that Ayuntamiento de Madrid is installing around Madrid city streets.

Figure 1. Label on the luminaire tested at LICA.

2. INSTRUMENTS

The spectrograph used for acquiring the lamp spectrum was an Ocean Optics JAZ EL200-XR1. This is the same portable device employed to build the lamps spectral database from data gathered on the streets of Comunidad de Madrid pointing to the luminaries used for urban lighting. The main optical characteristics of the spectrograph are: spectral resolution of 1.7 nm and reciprocal dispersion of 0.3 nm/pixel. The detector is a Sony ILX511B optimized to UV output and the spectrograph has a uniform response from 200 to 1025 nm. The light is feed into the spectrograph by an optical fiber of 400 microns. The raw spectrum is corrected by the system from spectral response and linearity to yield a fully corrected spectrum that is also calibrated in wavelength.

Figure 2. Upper Left: Setup to obtain the spectra at different angles and for testing the angular response. The luminaire was mounted on a goniometer to rotate the head. Upper Right: Setup for testing transmission of the window on the LICA optical workbench. Lower Left: PCE-174 portable lux meter. Lower Right: Ocean Optics JAZ EL200-XR1 spectrometer.

Additionally, to double check the results, a spectrum was obtained with the LICA optical workbench. This workbench used a monochromator –Oriel Cornerstone 260– with improved output in the blue range, two filters wheels to prevent the superposition of different orders and a calibrated photodiode by NPL –Hamamatsu S2281-04–. For the spectral response a stabilized incandescent lamp with quartz cover was used. This optical workbench has been also used to measure the transmission of the glass window.

The angular response was measured with a PCE-174, a standard portable lux meter that measure illuminance (lux, footcandle) with a precision of 5% and reproducibility of 3%. The spectral response is CIE Photopic (CIE human eye response curve) with a spectral accuracy: CIE Vλ function 6%.

3. RESULTS

Two spectra were obtained in a frontal view and from a side view at 75 degrees from the optical axis. The spectra, displayed in Figure 3, show a decrease in the blue part of the spectrum for the side view, as expected.

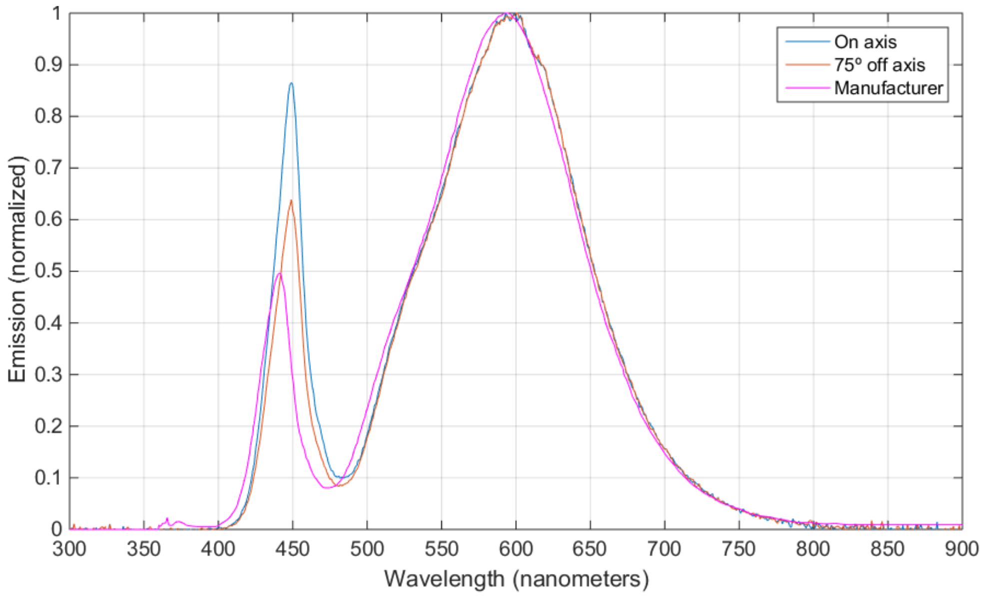

Figure 3. Spectra of the LED luminaire obtained with the JAZ spectrograph. On axis spectrum (blue) and 75 degrees off-axis (red). The pink line shows the spectrum from the Philips datasheet for LUXEON-R Warm White 3000K (Cálido) [2].

For comparison the spectrum taken from the Philips datasheet for LUXEON-R Warm White 3000K [2] has been plotted on the same graph. This spectrum shows displaced peaks and an extended redder wing. The 450 nm feature appears at around 440 nm.

3.1 XYZ, RGB and CCT

Once we have the spectrum it is easy calculate their correspondence to a RGB working space. For this work we selected one of the most used color space, sRGB. We have used gamma 1 with the reference white point D65. To match a color with the power distribution of our lamp *P*, the XYZ coordinates follows:

$$X = k\int P(\lambda)\ \bar{x}\ \ d\lambda$$
$$Y = k\int P(\lambda)\ \bar{y}\ \ d\lambda$$
$$Z = k\int P(\lambda)\ \bar{z}\ \ d\lambda$$

where *k* is 680 lumens per watt for self-luminous bodies and $\bar{x}$ $\bar{y}$ $\bar{z}$ the color matching functions (CMFs). For this work we have used the CMFs transformed from CIE 1931 for 2 degrees LMS cone fundamental primaries that cover all trichromatic color matches [3].

Convoluting the spectral response of the lamp with the response of the eye (the CMFs) we obtain the XYZ coordinates. And using the matrix transform between spaces we have the RGB.

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 3.2404542 & -1,5371385 & -0.4985314 \\ -0.9692660 & 1.8760108 & 0.0415560 \\ 0.0556434 & -0.2040259 & 1.0572252 \end{bmatrix} \bullet \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

For calculating the correlated color temperature (CCT) of the lamp we prefer to use the calculator offered by Bruce Lindbloom [4], for simplicity. If the color space, white reference and XYZ (or RGB) coordinates are known the color temperature of the lamp tested with a precision of less than a degree can be calculated.

After the analysis and the reduction of the data from the spectrograph we obtain the data listed in Table 1 for the two orientations. For comparison we show in Table 2 the results for LED lamps whose spectra was obtained on the streets of Madrid and villages of Comunidad de Madrid. The lamps have been arranged from lower to higher color temperature.

Lamp	**CCT (K)**	**XYZ**
LED on axis	3107	0.8060; 0.7209; 0.4103
LED 75^{o} of axis	2973	0.7866; 0.7148; 0.3125
LED Philips datasheet	3029	0.7783; 0.7319; 0.2597

Table 1. Test result of LED luminaire

Lamp	**CCT (K)**	**XYZ**
LED Travesía Andrés Mellado	2961	0.7904; 0.7027; 0.3563
LED Moncloa	3045	0.7978; 0.7191; 0.3654
LED Espoz y Mina	3140	0.8006; 0.7304; 0.3794
LED Faro de Moncloa	6770	0.3868; 0.3945; 0.4660
LED Facultad Farmacia (UCM)	6801	0.4123; 0.3879; 0.5152

Table 2. Comparison with other LED lamps tested

4. ADDITIONAL INFORMATION

We have also tested the ULOR (Upper Light Output Ratio) using a goniometer with resolution of 0.2^{o} and a lux meter PCE-174 in a fixed position. We tested this angular response (CIE photopic spectral response, i.e. human eye response curve) in the directions parallel and perpendicular to the post.

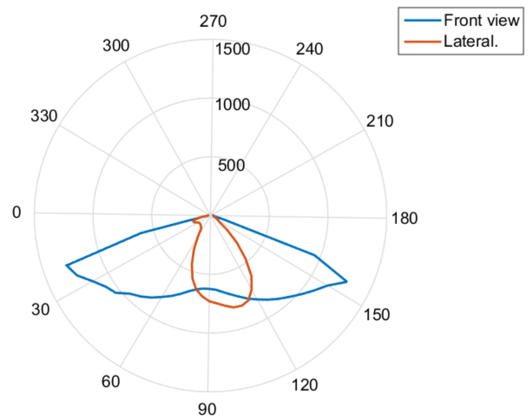

Figure 4. Angular response (ULOR) of the luminaire (front and side view). The side view with the post at the left.

We also checked the transmission response of the glass window of the luminaire. For the test we used the monochromator of the LICA optical workbench. The transmission (see Figure 5) is very constant and over 90% on the wavelength range of the LED emission and has no resonances between 350 and 370 nanometers.

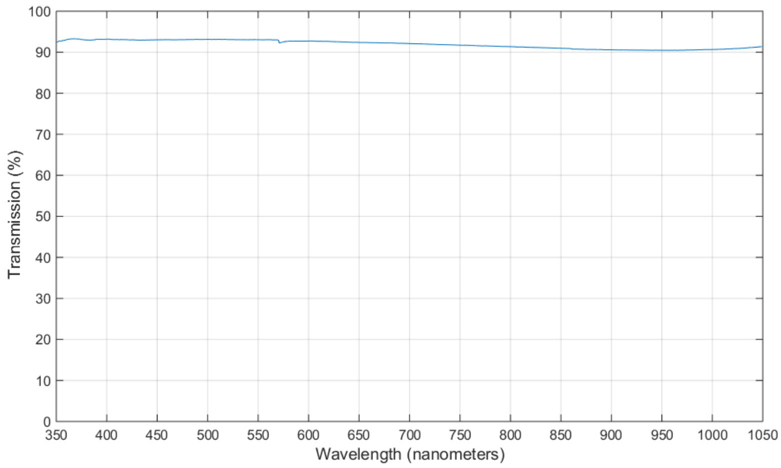

Figure 5. Transmission of the glass window of the luminaire.

The cumulative Spectral Distribution (SPD) is listed on Table 3. These values shows the energy ratio of light emitted to some wavelength with respect to the total amount of light emitted by the LED over the entire spectrum.

Lambda (nm)	**Cumulative lambda/total (%)**	
	On axis	75° off axis
440	16.0	16.3
450	18.1	18.3
500	28.3	28.3
550	38.5	38.2
600	48.7	48.2

Table 3. Cumulative amount of light under selected wavelengths.

4.1 Comparison with other LED lamps

Due to change on street illumination, now it is easy to find LEDs on streetlights and we have taken several spectra during the last months. Gathering the spectra on the streets we have detected the change in spectrum for different view angles and we have found that the 450 nm feature differs greatly with the pointing angle [5][6].

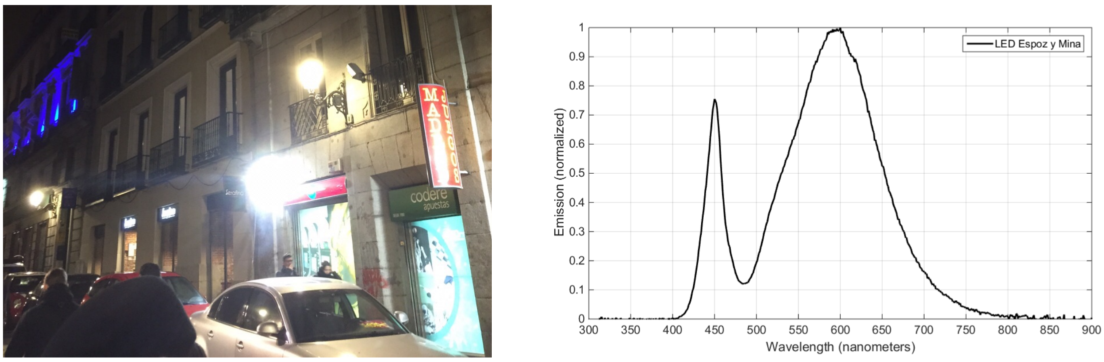

Figure 6a. Spectrum of white LEDs obtained on Madrid (Espoz y Mina street).

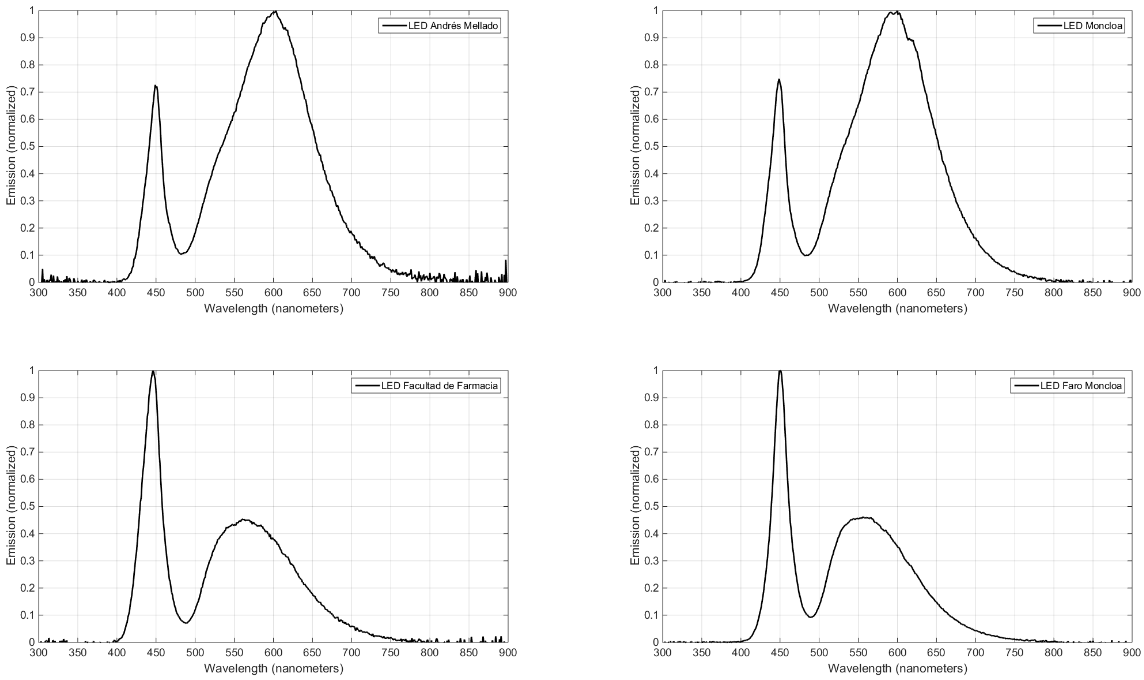

Figure 6b. Spectra of white LEDs obtained on Madrid streets.

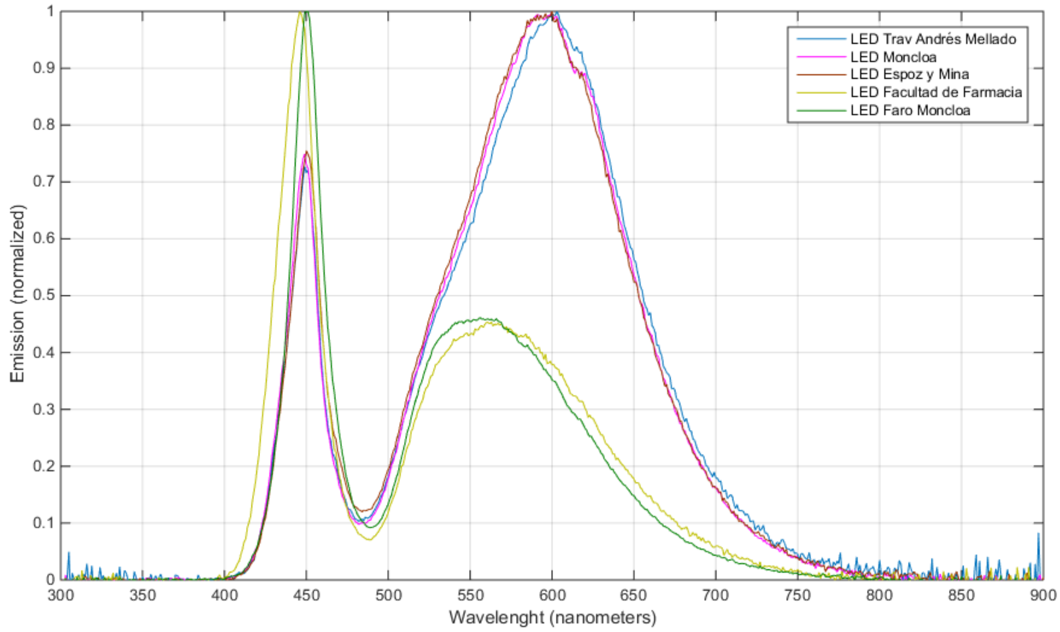

Figure 7. All the spectra of Figure 6 plotted on the same graph.

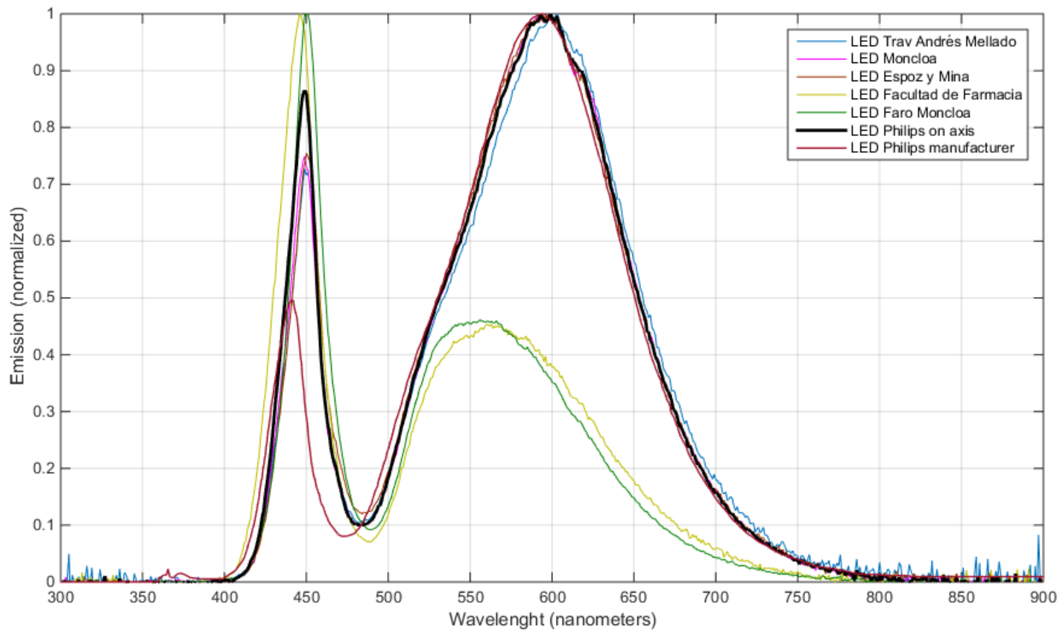

Figure 8. All the spectra of Figure 6, the one obtained in LICA test (red line), and the spectrum of Philips data sheet (yellow line).

5. CONCLUSIONS

We have obtained for the luminaire tested a color temperature CCT of 3107 K (on axis) and 2973K (75 degrees from optical axis). The color dependence is expected since the LEDs are covered with some optics. The CCT values differ from the Philips datasheet for LUXEON-R Warm White 3000K (we obtain 3029K from the spectrum plotted on the datasheet) but we are not sure that this is the same model. In fact the spectrum is different with displaced peaks and an extended redder wing that could explain the cooler color temperature claimed on the datasheet. The transmission of the glass window has no color effect.

References

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Acknowledgements

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