

# Analysis of optical efficiency values for various reflecting surface shapes of power LED lighting sources

I. ATIK<sup>\*</sup>, O. FARUK FARSAKOGLU, N. WATSUJI<sup>a</sup>

*Kilis 7 Aralik University, Faculty of Engineering Architecture, Department of Electrical Electronics Engineering, Kilis, 079000, TURKEY*

<sup>a</sup>*Gaziantep University, Faculty of Engineering, Department of Electrical and Electronics Engineering, Gaziantep, 27000, TURKEY*

Power LED lighting technology is improving rapidly. Because of its advantages, conventional lighting components are currently being replaced with LEDs. Obtaining and controlling characteristics of reflector surfaces, such as luminaire optical efficiency, luminous intensity and luminance distribution, are very important in reflector design for these systems. Reflecting surface forms were computed for power LED systems to give optimum luminaire optical efficiency to provide uniform luminosities. Different power LEDs were considered. The effects of variations of reflector surfaces and materials on luminaire optical efficiency values in reflectors were determined. Luminaire optical efficiencies and illuminance distributions of reflector surfaces were simulated using computer software programs. The purpose of the present study is to provide the required background data involving production of reflector prototypes.

(Received April 7, 2015; accepted May 7, 2015)

*Keywords:* Power LED, Luminaire design, Luminaire optical efficiency, Luminous intensity

## 1. Introduction

Reflector designs are performed for the purpose of acquiring maximum benefits from sources of light, and reflecting the light towards the desired direction. When it comes to power efficiency; the most widely recognized technology of our time is LEDs. Due to the advantages of LEDs, various other lighting sources are being replaced with them. Low energy consumption, high lifecycle, high lumen efficiency levels and ease of integration are only a few of the advantages of LED lighting sources [1]. Additionally; LEDs do not involve any environmentally harmful elements such as other conventional lighting sources including mercury lamps, gas-electric arc lamps, halogen lamps, and compact fluorescent lamps (CFL) [2].

LED reflector design is also appropriate for benefiting advantages of LED technology thoroughly. Therefore; our study involves design of reflecting surface shapes for power LEDs. Materials with different reflection coefficients have been used for reflector surface designs. The purpose of these design works have been designated as acquiring a uniform optimum light dispersion.

Although there are many databases in the literature involving other conventional lighting technologies and reflecting materials, LED's reflecting surface technologies have not been studied sufficiently. In our case, we have only considered LED lighting technology and reflecting materials. Then, we have obtained data using the computer software program, Photopia Version 2014. Since LED lighting is a major emerging technology, the present study is considered to be important in terms of both design and manufacturing.

## 2. Methods

Although computers have greatly simplified modeling processes, the basic concepts used remain the same. As the first step of designing reflectors, the researchers used the point source model. Then, the researchers simulated whole flux quantities of reflectors. The general equation used in the present study determined luminous flux values by integrating the total radiant power (in watts) over the visible spectrum, while weighting each wavelength according to its ability to stimulate the human visual system. The luminous flux,  $\Phi_{lum}$  may be given the equation as follows [3];

$$\Phi_{lum} = 683 \int_{\lambda} V(\lambda)P(\lambda)d\lambda \quad (1)$$

where;  $P(\lambda)$  is the power spectral density, the light power emitted per unit wavelength, and the prefactor 683 lm/W is the normalization factor.  $V(\lambda)$  is the photometric luminous efficiency function. This is a normalized function that represents the human eye's relative sensitivity to each wavelength over the visible spectrum.

The luminous efficiency of a light source, also measured in units of lm/W, is the luminous efficiency can be given as [4];

$$luminous\ efficiency = \Phi_{lum} / (IV) \quad (2)$$

where;  $\Phi_{lum}$  is total luminous flux, (IV) is the electrical input power of the of source. The luminous flux falling on the area  $dA$  from a source of intensity  $I$  is given by;

$$dF = I dA \frac{\cos \varphi}{r^2} \quad (3)$$

This follows directly from the definitions of  $I$  as luminous flux per unit solid angle, and of solid angle. If the source is an extended one, this must be integrated over the source area. The luminous flux per unit area falling on a surface is called the illumination ( $E$ ) of the surface, and is measured in lumen per square meter. For a point source equation is given as [5];

$$E = \frac{dF}{da} = \frac{I \cos \varphi}{r^2} \quad (4)$$

Optical efficiency was calculated for all designed reflectors. Luminaire Optical Efficiency design is as follows. This ratio can show how well the luminaire is

designed and how much light is lost in its optical systems. The light output ratio of luminaire (LOR) takes into account the loss of light energy, both inside and by transmission through light reflectors, and is given by [6];

$$LOR = \frac{\Phi_{luminaire}}{\sum_{i=1}^n \Phi_{source}} .100 [\%] \quad (5)$$

where;  $\Phi_{Luminaire}$  is luminaire luminous flux and  $\sum \Phi_{source}$  is the sum of luminous fluxes of all light sources within the luminaire.

### 3. Analysis and discussion

The present study involves LEDs with different light dispersion angles. Light dispersion angles, colors, efficiency values and driving currents of LEDs are given in Table 1.

Table 1. Data of power LEDs used.

Lamp Type	LED XR-E XLamp	LED XR-C	LED XP-C XLamp	LED XP-E XLamp
Degree	75	90	110	115
Color	white	white	white	white
Lumen/W	69.3	49.0	60.3	84.0
Drive current (mA)	350	350	350	350
Manufacturer	Cree	Cree	Cree	Cree

Different reflector surfaces with different collection angles were defined for each LED. Light collection angles of surfaces were derived from 20° to 45° with 5° increments. Different surface alternatives with 70%, 80%, 86%, 92%, 95% and 99% reflection coefficients were used. All surface alternatives were selected from Generic Company's specular surface series. Different designs were provided with various reflector collection angle values, ranging from 20° to 45°. The reflective materials with 70% reflection coefficient were used. Depth, width,

minimum and maximum luminance values ( $E_{min}$ ,  $E_{max}$ ) of target surface, and luminaire optical efficiency data are given in Table 2-7.

Table 2 provides the data for the design with the collection angle 20°, likewise Table 3 provides the data for the collection angle 25°, Table 4 for the collection angle 30°, Table 5 the collection angle 35°, Table 6 for the collection angle 40° and Table 7 provides the data for the collection angle 45°.

Table 2. Parameters for the design involving the collection angle 20° and the material coefficient 70%.

Lamp Type	The width of Reflector (mm)	The depth of Reflector (mm)	$E_{min}$ (lm/m <sup>2</sup> )	$E_{max}$ (lm/m <sup>2</sup> )	Optical Efficiency (%)
XR-E XLamp 75°	11.05	1.83	58,220	109,419	99.60
XR-C 90°	13.00	2.25	38,626	74,256	99.30
XP-C XLamp 110°	5.38	1.03	38,563	76,222	97.20
XP-E XLamp 115°	5.20	1.00	54,349	107,885	97.50

Table 3. Parameters for the design involving the collection angle 25° and the material coefficient 70%.

Lamp Type	The width of Reflector (mm)	The depth of Reflector (mm)	$E_{\min}$ (lm/m <sup>2</sup> )	$E_{\max}$ (lm/m <sup>2</sup> )	Optical Efficiency (%)
XR-E XLamp 75°	13.00	2.46	52,761	105,750	99.00
XR-C 90°	15.00	3.20	36,787	66,074	98.90
XP-C XLamp 110°	6.40	1.50	37,736	81,726	95.50
XP-E XLamp 115°	6.00	1.50	59,280	144,637	95.80

Table 4. Parameters for the design involving the collection angle 30° and the material coefficient 70%.

Lamp Type	The width of Reflector (mm)	The depth of Reflector (mm)	$E_{\min}$ (lm/m <sup>2</sup> )	$E_{\max}$ (lm/m <sup>2</sup> )	Optical Efficiency (%)
XR-E XLamp 75°	15.00	3.85	46,208	85,340	98.70
XR-C 90°	18.00	4.80	28,624	50,842	98.50
XP-C XLamp 110°	8.00	2.18	34,857	90,080	93.50
XP-E XLamp 115°	7.50	2.11	58,801	117,205	93.80

Table 5. Parameters for the design involving the collection angle 35° and the material coefficient 70%.

Lamp Type	The width of Reflector (mm)	The depth of Reflector (mm)	$E_{\min}$ (lm/m <sup>2</sup> )	$E_{\max}$ (lm/m <sup>2</sup> )	Optical Efficiency (%)
XR-E XLamp 75°	19.00	5.50	36,188	66,595	97.30
XR-C 90°	22.00	7.00	22,918	43,600	95.20
XP-C XLamp 110°	9.50	3.20	36,862	92,178	91.10
XP-E XLamp 115°	9.20	3.10	52,987	118,320	91.30

Table 6. Parameters for the design involving the collection angle 40° and the material coefficient 70%.

Lamp Type	The width of Reflector (mm)	The depth of Reflector (mm)	$E_{\min}$ (lm/m <sup>2</sup> )	$E_{\max}$ (lm/m <sup>2</sup> )	Optical Efficiency (%)
XR-E XLamp 75°	23.00	8.00	29,572	59,932	91.70
XR-C 90°	28.00	10.50	15,565	38,641	87.90
XP-C XLamp 110°	12.00	4.73	29,798	81,439	88.30
XP-E XLamp 115°	11.60	4.65	43,428	112,670	88.40

Table 7. Parameters for the design involving the collection angle 45° and the material coefficient 70%.

Lamp Type	The width of Reflector (mm)	The depth of Reflector (mm)	$E_{\min}$ (lm/m <sup>2</sup> )	$E_{\max}$ (lm/m <sup>2</sup> )	Optical Efficiency (%)
XR-E XLamp 75°	28.00	11.70	20,937	53,944	83.80
XR-C 90°	34.00	16.00	10,891	34,626	78.30
XP-C XLamp 110°	15.00	7.16	25,932	77,770	85.00
XP-E XLamp 115°	15.00	7.17	38,785	110,040	84.30

According to the data, XR-C 90° power LED provides the most depth with the largest size, even though the collection angle is the same. Therefore, this design required the most materials. When luminous dispersion is taken into consideration, maximum luminance values were

observed with the LED design XP-E XLamp 115° having the largest light dispersion. On the other hand, when luminaire optical efficiency is considered, the best efficiency values was observed with the low-angle XR-E XLamp 75°. Additionally; when the all tables are taken

into account; it can be seen that the first LED XR-E XLamp 75°, has the collection angle 20°, yet it provides a maximum luminance value of 58,220 lux; while when the collection angle is increased to 45°, luminance level decreases to 20,937 lux. In terms of maximum luminance level; the second LED, XR-C 90° provides 66,074 lux illumination with 25° of the collection angle, while its illumination is measured to be 38,641 lux with a collection

angle of 40°. As a brief result, it can be said that, the luminaire optical efficiency level decreases when collection level is increased. Figure 1 below shows the analysis of optical efficiency levels that were acquired by means of various reflecting materials with different reflection coefficients; 70 %, 80 %, 86 %, 92 %, 95 % and 99 % for each reflector design data given in tables.

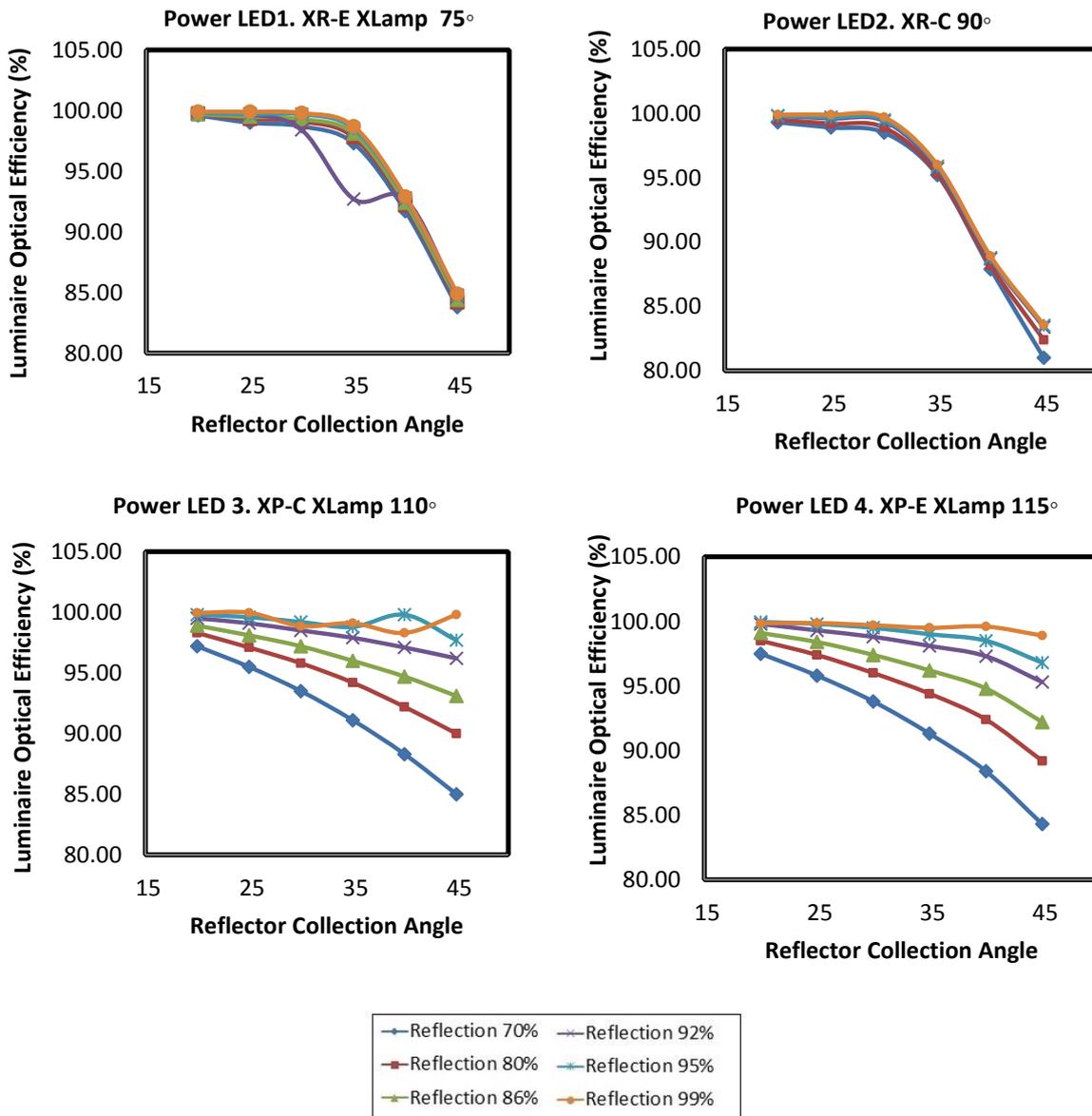


Figure 1. Optical efficiency values acquired from different reflector designs with reflective materials having 70%, 80%, 86%, 92%, 95% and 99% reflection coefficients.

As it can be seen from the graphs; when materials that provide a higher reflection coefficient with higher collection angle are used; optical efficiency tends to decrease. Light dispersion curves for different reflection

coefficients for 70 %, 80 %, 86 %, 92 %, 95 %, and 99 % and the collection angle 45° are given for the LED, XR-E XLamp 75° in Fig. 2. Contour plot curves of the same design are also seen on Fig. 3.

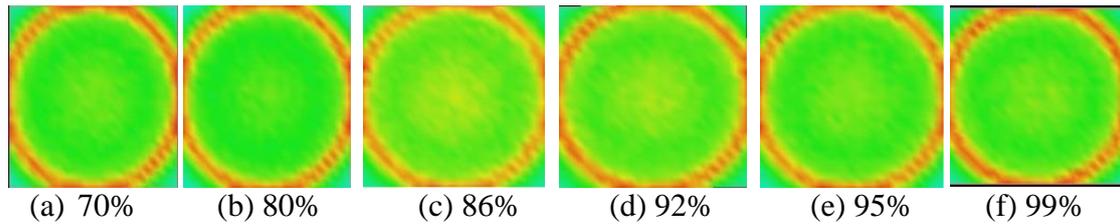


Fig. 2. Luminous dispersion curves for XR-E XLamp 75° power LED with the collection angle 45°.

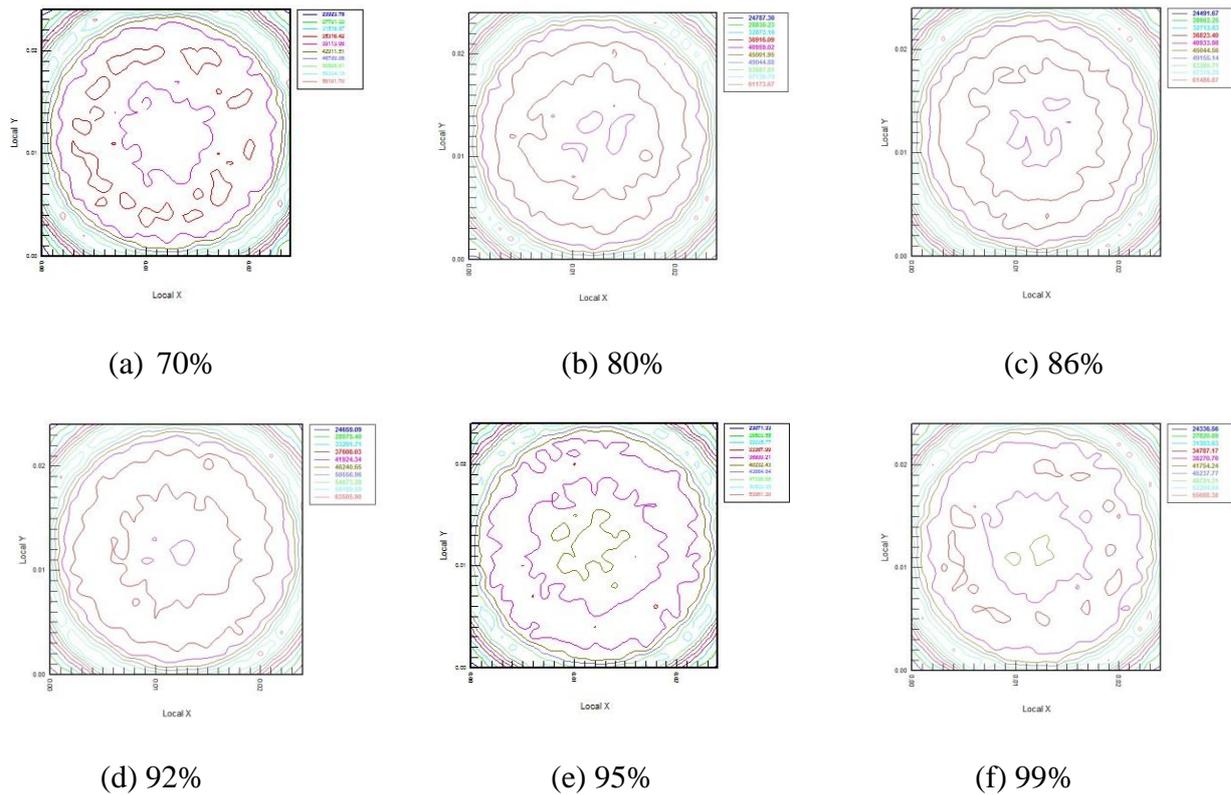


Fig. 3. Luminous dispersion contour pilot curves for different reflection coefficients for 70 %, 80 %, 86 %, 92 %, 95 % and 99 % and XR-E XLamp 75° power LED with the collection angle 45°.

Luminance contour plot curves shown in Fig. 3 were provided as the data “lux”. Each interval is accepted as 0.000001 sq. meters. In terms of luminous dispersion, the best values could be acquired with materials having the reflection coefficient 99 %. It is seen that the smoothness of the luminous dispersion tends to dissolve when the

reflection coefficient value is increased. In Fig. 4, luminance shaded plot curves are given for different materials for the different reflection coefficients 70 %, 80 %, 86 %, 92 %, 95 % and 99 % and XR-C 90° power LED with the collection angle 40°.

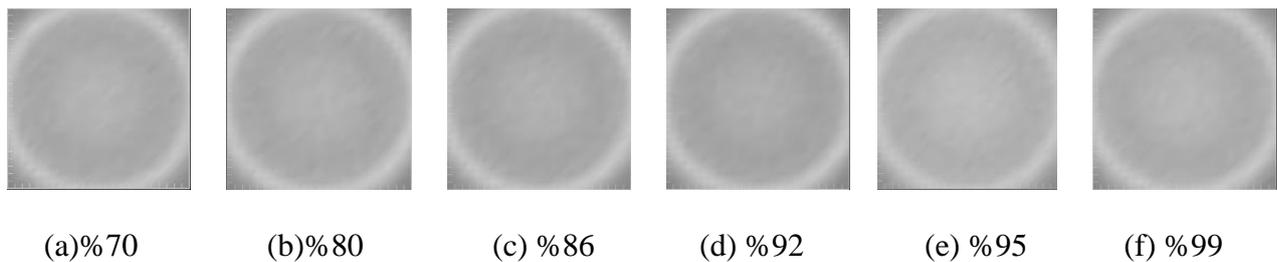


Fig. 4. Luminance shaded plot values acquired with changing LED reflection coefficients for XR-C 90° power LED with the collection angle 40° are denoted in the correct order.

As seen in Fig. 4, reflective materials with lower reflection coefficients provide a more uniform luminous dispersion. Therefore, smoothness and uniform nature of the luminous dispersion tend to increase with lower reflection coefficient values.

#### 4. Conclusion

As the power LED technology improves, the need of reflector design becomes important. From this perspective, prescribed results can only be acquired by means of correct designs.

In the scope of the present study, several assessments were performed with the purpose of evaluating reflector design parameters for power LEDs. Different results were obtained by comparing different reflector materials and reflector collection angles for power LEDs with different reflection angles.

In the present study, reflector collection angle values starting from 20° up to 45° were analyzed. These designs were made for LEDs with different light emitting angles.

Some of the results obtained from the analyses are as follows;

- As commonly examined, when the reflector collection angle values increase, amount of the used material also increases. The maximum material consumptions were defined as the power LED XR-C 90°.
- As the LEDs light emitting angle increases, fluctuations are observed in luminaire optical efficiency values. As an example, it is seen in the data; under the same circumstances, when the reflector collection angle is 25°, the reflectance material coefficient is 80 %; the luminaire optical efficiency values for XLamp XR-E 75 °, C XLamp 110°, and XP-E XLamp 115° become 99.30 %, 97.10 %, and 97.40 % respectively.
- Commonly, while each LEDs collection angles increase, the luminaire optical efficiency values decrease. For instance, when collection angle value starts from 20° with 5° steps to 45°, the luminaire optical efficiency values become 99.60%, 99.40%, 99.10%, 99.50% , 88.50%, 78.90% respectively.

- As concluded from the analyses; there are fewer optical efficiency degradation in lower reflection coefficient materials. There is not much fluctuation between the maximum and minimum limits of obtained optical efficiency. It is clearly seen that there are more fluctuation as the material with the reflection coefficient 99 % is used.

Luminaire optical efficiency as well as minimum and maximum luminance distribution values were obtained for proposed reflector designs. A detailed assessment was performed on changing luminance distribution and optical efficiency values, especially in terms of the influence of reflection coefficients. Additionally, visual illustrations were provided for reflector luminance distribution. Additionally, the relationship between luminance distribution angles of LEDs and reflector design parameters were assessed. Besides, all related parameters were evaluated and analyzed for acquiring a uniform illumination surfaces. Results of the analysis were processed by using appropriate computer softwares. Therefore, wasting the time, the budget, and the labor for manufacturing prototypes can be prevented by using these softwares.

#### References

- [1] Schubert E. F. (2014). Light emitting diodes, 2nd edition. New York: Cambridge University Press.
- [2] S. Lim, D. Kang, O. Ogunseitani, J. Schoenung, *Environmental Science & Technology*, 45, 320 (2011).
- [3] L. Jeanne, B. L. McHale *Handbook of Luminescent Semiconductor Materials*, CRC Press, (2011)
- [4] A. V. Arecchi, T. Messadi, R. J. Koshel *Field Guide to Illumination*, SPIE Press, USA 000, (2012).
- [5] T. Acharya, A. K. Ray, *Image Formation and Representation*, in *Image Processing: Principles and Applications*, John Wiley & Sons, Inc., Hoboken, NJ, USA. (2005).
- [6] OMS Lighting (2015), LED Academy, <http://www.ledacademy.net> (accessed 10.04.2015)

\*Corresponding author: ipekinal@kilis.edu.tr