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doi:10.15199/48.2019.02.33

Visual and photometric consequences of using semi-spherical LEDs in diffuser shades

***Abstract**. The article presents and analyzes the observed phenomenon of optical deformation of a cylindrical dispersing diffuser as the effect of a classical replacement a light source by LED retrofit. A cylindrical diffuser equipped with such a light source presents a luminance distribution that significantly deviates from the actual view of the unshielded lampshade. This is a feature which disqualifies such an application of these sources for aesthetic reasons, the more so because the accompanying effect is also a noticeable deformation of the cylindrical shape. In the article, apart from the analysis of the phenomenon, the equation of the diffuser profile was presented, which using the discussed type of LED source could realize an even distribution of luminance on the surface.*

***Streszczenie.** Artykuł przedstawia i analizuje zaobserwowane zjawisko deformacji optycznej klosza cylindrycznego, rozpraszającego jako efektu zastąpienia klasycznego, źródła światła przez retrofit LED. Cylindryczny klosz rozpraszający wyposażony w takie źródło światła prezentuje rozkład luminancji, który znacząco odbiega od rzeczywistego widoku niezaświeconego klosza. Jest to cecha dyskwalifikująca taką aplikację tych źródeł z powodów estetycznych, tym bardziej, że efektem towarzyszącym jest również zauważalna deformacja kształtu cylindrycznego. W artykule, poza analizą zjawiska przedstawiono równanie profilu klosza, który przy zastosowaniu omawianego rodzaju źródła LED realizował by równomierny rozkład luminancji na powierzchni (**Konsekwencje wizualne i fotometryczne stosowania półsferycznych ledówek w kloszach rozpraszających**).*

Keywords: lighting technology, luminaires, luminance distributions, LED retrofits
Słowa kluczowe: technika świetlna, oprawy oświetleniowe, rozkłady luminancji, retrofity LED

Introduction

The current development of light sources, especially those intended for use in flats, is carried out through various implementations of the so-called LED's, or electroluminescent light sources, which are supposed to be a replacement for traditional light bulbs [1 - 4]. Careful analysis of this development process allows us to expect that the LEDs of semi-spherical shape of a glowing body (semi-capsule) will soon become the main source of light in homes. The source dimensions resemble the shape of the main bulb of the series. In terms of installation options, they can be screwed into a traditional E27 or E14 handle. The characteristic feature of this source, in terms of the structure of the luminous body, is the radiation of the luminous flux from the semi-spherical surface. This fact should be combined with a specific, photometric body, which is already far away from the regular light distribution. Comparability of luminous flux values, installation adequacy and size similarity are not enough to fully accept this source as a full replacement for a traditional bulb [5, 6]. The following considerations aim to show the aesthetic and photometric implications of the use of this innovative light source in diffuser shades.

Photometric characteristics of a semi-spherical LED

It can be assumed that the semi-spherical LED belongs to the average luminance sources of light (luminance about 20-30 thousand cd/m^2). Its distinctive feature in relation to popular sources used in flats is the shape of a glowing body. It is usually a semi-spherical diffuse dome with a diameter of about 40 mm. The interior of this dome is filled with LED chips emitting white light, so the role of the semi-dome comes down only to a good mixing of light and its diffusion, approximately in accordance with Lambert's law (from each surface element). After lighting, the outer surface has a fairly even luminance. This source, due to the shaping of the luminous body, is a novelty in the area of previously used light sources. All previous solutions of compact fluorescent bulbs and lamps were characterized by a fairly uniform light distribution, almost omni-directional in the entire space, with a slight limitation towards the shaft. The semi-spherical LED, in terms of light distribution significantly deviates from the known curves of light sources of incandescent light and those with a transparent bulb, as well as those without a bubble and those with a spherical or elliptical distracting bubble.

The light distribution of the spherical half-sphere can be described with great accuracy by analytical dependence:

(1) $$I(\gamma) = \frac{I_m}{2}(1 + cos\gamma)$$

where:
I_m – means the maximum luminous intensity directed along the axis of the LED, γ- the plane angle that defines any direction in relation to the axis of the LED.

The luminous flux can be expressed with the help of the maximum luminous intensity I_m in the following way:

(2) $$\Phi_0 = 2\pi I_m$$

Thus, having the value of the luminous flux, it is easy to determine from the dependence (3) the luminous intensity in the individual directions of space.

(3) $$I(\gamma) = \frac{\Phi_0}{4\pi}(1 + cos\gamma)$$

The analytical equation of luminous intensity distribution allows, as a result of simple transformations, to calculate the luminous flux emitted into the area of a spatial angle defined by a cone with an apical angle γ:

(4) $$\Phi_\gamma = 4\pi I_m(5 - 4cos\gamma - cos2\gamma)$$

The luminous intensity distribution of the spherical half-sphere, calculated on the basis of dependence 1, is shown in Figure 1.

The curve shown in Figure 1 refers to luminous intensity. Distribution of luminous flux into individual areas of the spatial angle associated with 10-degree angular intervals of plane angle is shown in Table 1 and the graph shown in Figure 2.

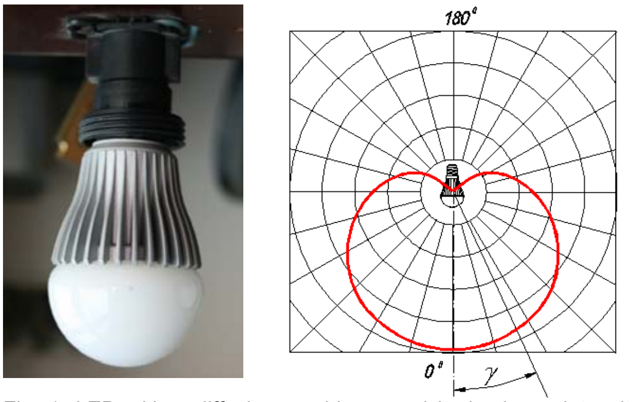

Fig. 1. LED with a diffusing semidome and its luminous intensity distribution.

Table 1. Calculations of the partial luminous flux emitted from the semidome into ten-degree intervals of the flat angle Δγ.

γ [deg]	I(γ)/φo	$\Delta\omega_{\Delta\gamma}$ [sr]	$\Delta\phi_{\Delta\gamma}/\phi o$ [%]	ϕ_Λ, ϕ_V
5	0,169	0,095	0,2	
15	0,156	0,28	4,3	
25	0,151	0,46	7,0	
35	0,145	0,63	9,1	
45	0,136	0,77	10,5	ϕ_V=75%φ
55	0,125	0,90	11,3	
65	0,113	0,99	11,2	
75	0,100	1,06	10,6	
85	0,086	1,09	9,4	
95	0,073	1,09	8,0	
105	0,059	1,06	6,0	
115	0,046	0,99	4,6	
125	0,034	0,90	3,1	
135	0,023	0,77	1,8	ϕ_Λ=25%φ
145	0,014	0,63	1,0	
155	0,007	0,46	0,3	
165	0,003	0,28	0	
175	0,0003	0,095	0	

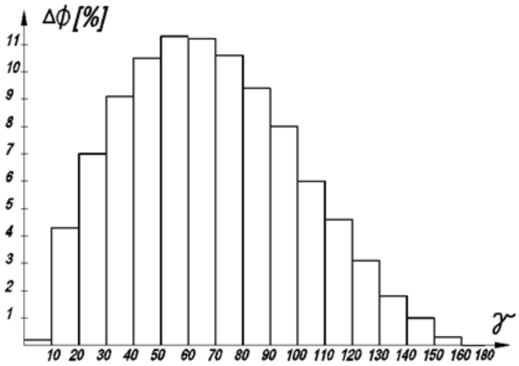

Fig. 2. Distribution of the luminous flux of the LED, with a semidome shaped luminous block, in equal, 10-degree compartments of the flat angle Δγ.

Visual consequences of using LEDs with semi-spherical dome

Each light source is characterized by a smaller or greater suitability for use in various optical systems of luminaires. LED with a diffusing diaphragm, is supposed to replace the main row bulb. The question arises, therefore, whether with its characteristic luminous intensity distribution of LED, a lamp can be used wherever the main row bulbs were used. What will be the consequences of its use (in the form of lighting effect of the interior and the view of the luminaire) in the arrangement of a lampshade, reflector, in a multi-point chandelier, being the equipment of our apartments. Narrowed beam angle, rapid decay of luminous intensity distribution above 90 deg indicate that the diffuser equipped with such a light source should loose its previous undeniable advantage in the form of even distribution of luminance of the entire lampshade. A clear division into a brighter and darker part must appear in the image of the lighting lampshade. Multiple reflections of the luminous flux inside the lampshade can somewhat mitigate the situation, but knowing the scale of the effect of this phenomenon on increasing the final luminance [7] one can expect only a slight improvement. To make these doubts check, simulation calculations were performed. Models of cylindrical, conical and spherical open diffuser have been made, in which the source of light is a LED semiconductor with a luminance of 20.000 cd/m^2. Following the simulation calculations, an image of a shining lampshade was generated, which clearly shows two brightness zones: with greater luminance at the bottom and a smaller one at the top of the lampshade, respectively to the surface direction of the luminous semiconductor in relation to the lower and upper halfspace (Fig. 3).

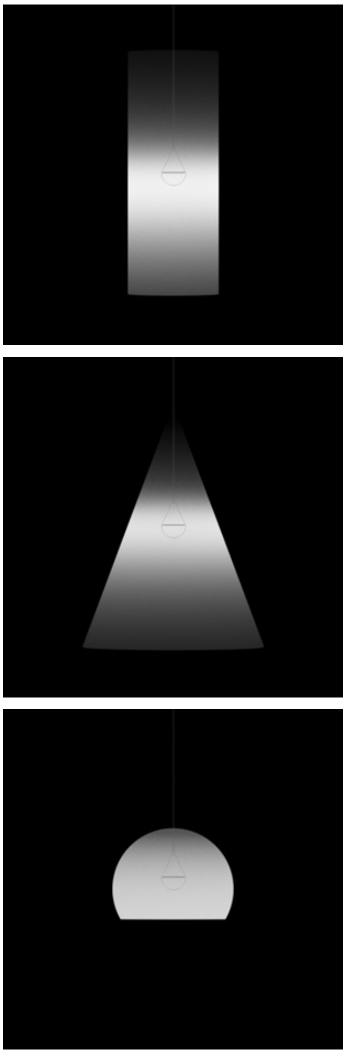

Fig. 3. Calculated distribution of luminance on the surface of milk shades, with scattering LED with semi-spherical dome application.

As can be seen from Figure 3, the consequence of using a LED with semi-spherical dome is the specific distribution of luminance on the surface of the lampshade with relatively small bright area of the lampshade. It extends in a range from the light output opening, more or less to the height of the source attachment. Going up, this area continues to rapidly disappear. An unattractive border of the glowing and dark areas is created on the lampshade. Shown simulation images of the luminance distribution on the surface of the lampshade do not reflect one important feature that can be seen only with the "naked eye". With the cylindrical lampshade, the lightest area of its surface appears slightly below the mounting height of the light source. It corresponds more or less to the direction specified by the angle range γ = 50°-70°. Characteristic for this direction areas of the lampshade show luminance so large, and their gradient changes rapidly, that it causes the observable phenomenon of deformation of the real image of the lampshade (Fig. 4) in the form of a characteristic thickening. This is an unsightly effect that destroys the planned image of the lampshade, probably designed for incandescent or fluorescent light sources.

Fig. 4. The apparent widening of the diameter of the lampshade in the area of the source installation is a consequence of the use of a LED with semi-spherical dome.

The resulting luminance distribution divides the diffuser optically into two parts - light below the light source and dark one above. In this way, there is noticeable shortening of the height of the lampshade, change of its appearance and dimensions observed in relation to the view in the unlighted state. Of course, the luminance distribution depends very much on the shape of the lampshade, due to the distance of the light source from the walls, however, as shown in Figure 3, the problem of fast disappearance of luminance remains the same within the basic shapes (cylinder, cone, sphere). The spherical lampshade is the least sensitive to the use of this light source. It seems that for the purpose of using this shape of the luminous body, it would be necessary to design a suitable shape of the lampshade, which would guarantee an even distribution of luminance on its external surface (Fig. 5). The equation of the contour line that realizes constant luminance L on the surface of the diffuser, with the light source in the shape of a semi-scattering dome and luminous intensity distribution as in formula 1 determines the dependence 5,

(5) $$d(\gamma) = \sqrt{\frac{\rho I_m}{2\pi L}}\ (1 + cos\gamma)$$

where d(γ) is the linear dimension of the center distance of the light source from the profile of the lampshade as a function of the angular position of the current point.

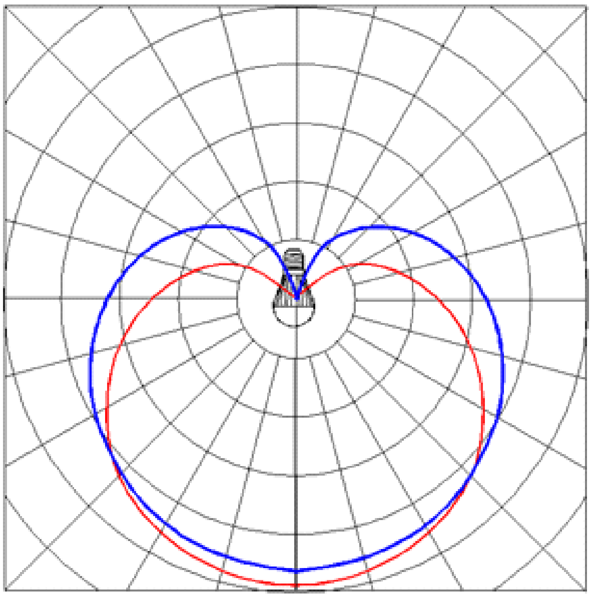

Fig. 5. Surface profile with constant luminance (blue curve) against the luminous intensity distribution of the LED with a diffusing semicolon (red curve).

Conclusions

LED with a glowing body in the shape of a semi-scattering dome is, due to its structure, and above all the luminous intensity distribution of LED, a specific source of light. The nature of this distribution represents a typical cardioid and this fact consequently qualifies this light source for light distribution with almost half-spaced distribution of light. Despite the shape of the entire source, matched with its dimensions to the dimensions of a traditional light bulb, the diode with a diffuse semidome differs from the characteristics of a traditional bulb with photometric features. This is of particular importance when used in the arrangement of diffuser lampshades. The use of this innovative light source worsens the visual effects (distribution of luminance on the lampshade) and photometric features (luminous intensity distribution curve), especially in the case of lampshades with a geometry much different from the sphere. In the image of a shining lamp there appears a significant luminance gradient in the form of a clear border between the light and dark parts, which is a negative feature of a well-designed lampshade arrangement. At the same time, the layout of the lampshade and light source as a luminaire is not able to realize higher lighting classes (III, IV and V) due to the dominant direction of distribution of the luminous flux rather downwards. In principle, a LED with a diffusing semidome should be mounted as deep as possible in the shade (near the top of the profile), which can prevent the characteristic disappearance of luminance on its surface, which is created when placing this source near the geometric center. The authors pay attention to the mismatch of the structure of many currently used lampshades, chandeliers and other lighting fixtures with a diffuser for using this light source. The interchangeable use of LEDs with a diffusing semidome in interior, especially residential, fixtures leads to a deterioration of lighting aesthetics and a change in the luminance distribution on the main interior surfaces.

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