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doi:10.15199/48.2015.04.41

The concept of the uplight luminaire optical system

***Abstract**. The article presents the design of the uplight luminaire optical system whose aim is to produce a homogeneous luminance distribution on the illuminated surface when its location in asymmetric. Proposed optical system was compared with two competitors currently available on the market. Evaluation of the proposed design takes into account the resulting area of homogeneous values of luminance, the luminaire efficiency and utilization factor.*

***Streszczenie.** Artykuł prezentuje układ optyczny oprawy oświetleniowej doziemnej, która ma na celu wytworzenie wyrównanego rozkładu luminancji na powierzchni obiektu zlokalizowanego asymetrycznie. Zaproponowany układ optyczny został porównany z dwoma oprawami oświetleniowymi obecnie dostępnymi na rynku. Ocena przedstawionej konstrukcji uwzględnia uzyskany obszar o wyrównanych wartościach luminancji, sprawność oprawy oświetleniowej i sprawność oświetlenia. (**Koncepcja układu optycznego oprawy oświetleniowej doziemnej**).*

Keywords: floodlighting, luminaires, luminaires design
Słowa kluczowe: iluminacja, oprawy oświetleniowe, projektowanie opraw oświetleniowych

Introducton

Floodlighting (illumination of objects) is a procedure that is designed to allow observation of architectural objects in the nighttime. This is done with the use of the lighting equipment (luminaires), which are properly located around the object and emit luminous flux into individual parts of the object [1]. The task of selecting the appropriate lighting equipment, as well as its installation and aiming have a key influence on the resulting lighting effect, which can be defined as the formation of corresponding luminance distributions on each surface of the object. Perception of architecture is always associated with daylight view with its significant uniform scatter illumination coming from the clouds cover or from the sky or, with optional directional illumination directly from the sun. In addition, the architecture of the buildings are formed for its perception in the daytime. As a result of above mentioned, during the nighttime, the task of illumination is to keep daily view of the object, of course, to a degree associated with existing technical capabilities. Intended generation of uneven luminance should be considered only for short-lasting, incidental activities [2].

The author aims to improve the situation described above by means of a design of a luminaire which can be mounted at the bottom of vertical surface (wall) in close distance. It should also allows production of homogeneous luminance distribution. This particular type of luminaire is important, because in point method of floodlighting is the hardest to obtain homogeneous luminance distributions [1]. In the prior art, we can hardly find a luminaire which can generate homogeneous illumination in asymmetric and close location to the object. The author wants to improve the situation and propose his design of a luminaire optical system that can create even illumination. The task, as it turns out, is very complex and requires an individual approach to each part of the optical system, as well as finding solutions to many design problems. Evaluation of the proposed design takes into account the resulting area of homogeneous values of luminance, the luminaire efficiency and utilization factor. In addition, evaluation of the luminance distributions obtained as a shaded plots or graphs is ambiguous, because we still do not know how it will be perceived by human and this further complicates the situation.

Current product offering of lighting equipment

On the market of illumination lighting equipment, we are now dealing with the second period of the Renaissance. After entering metal halide lamps with high luminous flux that allow the generation of white light, now it's time for the widespread use of LED luminaires. LED luminaires initiated an era of dynamic lighting, both white and colored light, and with the largest savings on power consumption. Unfortunately, currently there is no adaptation of luminaires luminous intensity distributions to the specific conditions prevailing in illumination, especially if we are dealing with a close and asymmetric positioning of the luminaire with respect to the illuminated plane. The introduction of new technology in the form of LEDs, giving the potential for innovative designs of optical systems and thus new forms of luminous intensity distributions. Unfortunately, this potential has not been exploited yet and the only novelty encountered in terms of shaping the luminous intensity distributions of LEDs luminaires is replacement the reflectors by the lens, caused by using the method of replication in place of the previously used method of complementation in designing of LED matrices [3]. Furthermore, most of the luminaires (including LED) still have rotational symmetry of luminous intensity distributions, which is best suited to illuminating the subject from a distance, preferably perpendicular. The reason for the lack of innovative lighting illumination optics (especially LED) is probably the lack of regulatory requirements in terms of derived lighting parameters, in contrast to e.g. automotive lighting technology. Therefore, there is no "driving force" to improve the photometric performance of luminaires.

If we make a comparison between floodlighting luminaires (for illumination of objects architecture) with the offer of luminaires for outdoor areas, the only group specifically engineered to meet the needs of floodlighting are ground mounted uplight luminaires. Their construction is aligned to their applications conditions. We can find components such as moisture resistance for mounting in the ground, mechanical strength allows for placement in areas with the movement of vehicles or pedestrians, thermal insulation limiting high temperatures on the surface of the glass cover, which is easily accessible and ultimately design treatments in the field of the optical system. Constructors therefore introduce a deep placement of the optical system in the housing in order to increase cut-off angle to minimize glare. However, such a procedure rises the lower edge of illuminated area and creates unpleasant parabola or reversed trapezoid shape of this lower edge according to the shape of the outlet opening of the luminaire. In some designs, there is asymmetrical optical system that provides sending luminous flux mainly to illuminated object arranged asymmetrically with respect to the luminaire housing. Such modifications in the optical system, but are designed to fit luminaire to the specific conditions of use, however, adversely affects the efficiency of the luminaire which often reaches a level of about 40%. But when the term of luminaire efficiency we expand to send luminous flux to the illuminated plane, which in such cases is arranged asymmetrically relative to the housing, then utilization factor (used in interior lighting) in typical situations reach the level of 10 – 20%. The utilization factor tells how much of the light source luminous flux reach the illuminated object [4, 5].

Optical design of the luminaire

The author have found the idea of this particular luminaire design in methods of preparing conception of floodlighting. There we have to deal with the creation of the resultant image of illuminated object as a composition (superposition) of individual lighting effects, arising from the use of individual luminaires. In the same way we can look at the formation of the optical system of the luminaire. There we can also point out the individual elements of the optical system. Each of these elements illuminates a certain area of the object. The final distribution of luminance is obtained as an addition of individual element.

Implementation of the aforementioned method was described in details in previous publications by the author and is limited to the possibility of designating the profile of the trough-shaped reflector, for which the effect of lighting (luminance distribution – assuming Lambertian surface) is determined along the vertical line representing the axis of symmetry of the illuminated area [6]. By means of this method, the exemplary optical system was calculated. The optical system consists of a compact metal halide lamp, a reflector built with interconnected plain mirrors and a lens element [7, 8]. This design has not been presented in this paper due to the author's interest in patent protection. Although will be shown the results of the calculated luminaire optical system in the form of distributions of luminance on the test screen and visualizations of illuminated test screen.

The design of the optical system, according to the study, must fulfill three functions: to strengthen, to weaken and to eliminate the luminous intensity of the light source, depending on the considered direction [9]. In general, the luminaires only strengthen or weaken the light source luminous intensity. In the analyzed luminaire we have a full range of converting luminous intensity distribution of light source from its strengthening, through weakening, to the total extinction.

Designed luminaire competitors

Designed luminaire parameters are compared with two different luminaires from the market.

The first one indicated in the following part with the letter "a" is the classical system of the reflector. It has a single-ended metal halide light source placed in the focal point of the parabolic mirror reflector. The resulting optical system is placed in the cylindrical housing. The outlet opening is round and covered by a transparent glass cover. Luminous intensity distribution is rotationally symmetric and has a beam angle of 3,85º.

The second one determined in the following part with the letter "b", has a more complex structure, which prompted manufacturers to its patent protection. The description presented here is based on the description in the patent document [10] and refers to Figure 1. The light source **4** is of the same type as in luminaire “a”, but it is double-ended. The housing **1** is a cuboid elongated in the direction of the axis **A** of the light source **4**. The luminaire has two reflectors - primary U-shaped **3** located between the light source **4** and the bottom of the housing **1**, and - secondary **6** and **7** located between the light source **4** and a transparent glass cover **2**. Secondary reflector **6** and **7** consists of two parts, each of which has a triangular cross-section with concave sides. The lower surfaces of the secondary reflector **8** and **9** turn back the luminous flux from the light source **4** back to the light source **4** and the primary reflector **3**. The inner surfaces **10** and **11** direct the luminous flux toward the same direction **5**, such as the primary reflector **3**. While the outer surfaces of the secondary reflector **12** and **13** reflect the luminous flux diffusely to the both sides of the housing **1**. This construction, according to their authors, allows the emergence of asymmetrical light beam in efficient way which properly illuminates vertical planes, which are the subject of the author’s research. What can induce a negative evaluation are a bare housing surfaces in optical chamber which are not covered by reflectors and located along the housing above the primary reflector **3** on both sides and on perpendicular sides of the housing to the axis **A** of the light source **4**. Moreover, the luminous flux from the light source **4** is directed back to the light source, by the surface **8** and **9** of secondary reflector **6** and **7**.

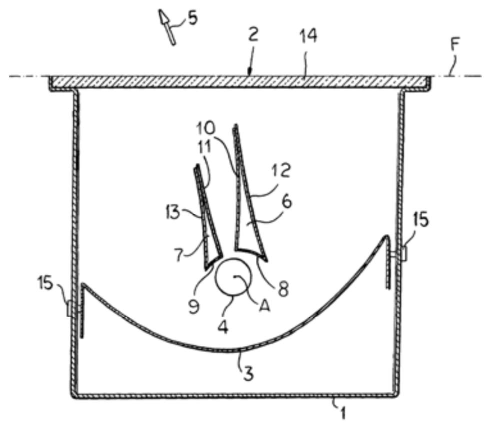

Fig.1. Cross-section drawing of luminaire “b” from patent document [10]

Discussion of the results

The resulting optical system of the luminaire (mathematical model) was subjected to computer simulations using dedicated software. The simulated model is presented on Figure 2. The lighting device consists of the designed uplight luminaire, wherein the light source center is located at a distance of 1 m from the bottom edge of the test screen. The outlet glass cover of luminaire lie on the same plane as bottom edge of said screen. The test screen is 8 meters high and 4 meters wide. The results of the simulation in the form of luminance distributions charts and visualization of luminance distributions as shaded plots on the test screen have been summarized with the results obtained from the two sample uplight luminaires from the market (depicted as "a" and "b"). In order to minimize calculation errors, for competitors luminaires, the author rather than rely solely on IES photometric files obtained from the manufacturers of these luminaires used a Monte Carlo simulation of mathematical models of optical systems. The reason of that was to minimize errors connecting with wide range of distances between optical center of the luminaire and illuminated points that are both in near and far field photometry [11]. Commercial luminaires modeled, due to their relatively non complex structure, should not introduce significant errors associated with the precision of the modeling especially to luminaire “a”.

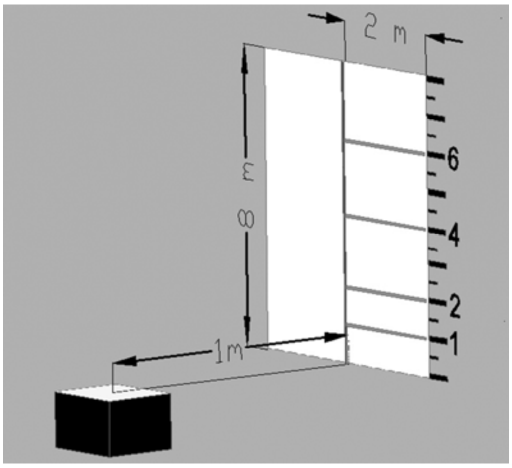

Fig.2. Lighting device geometry for simulations with indicated lines on the white test screen along which luminance distributions will be presented

Firstly, will be shown the results along vertical line of illuminated area symmetry, after that the results along a few horizontal half lines as drawn on a plane on Figure 2.

Figure 3 shows the resulting distributions of luminance along the vertical line representing the axis of symmetry of the illuminated area. As follows from the Figure 3 analysis, only for proposed luminaire we can talk about homogeneous luminance distribution. This indicates a region of constant luminance in the range of 1 m to 5 m, and higher than 5 m is a mild decrease in luminance. Furthermore, in the lower part of the object (less than 1 m height) the maximum luminance is lower in comparison with the luminaire "a". Luminance values for concept luminaire oscillate around 15 cd per square meter, which is a correct level according to standards [12]. What should be added is the fact that all luminaires on Figure 3 have the same luminous flux of the light source, so different levels of luminance are caused by different luminaires efficiency and different luminous intensity distributions.

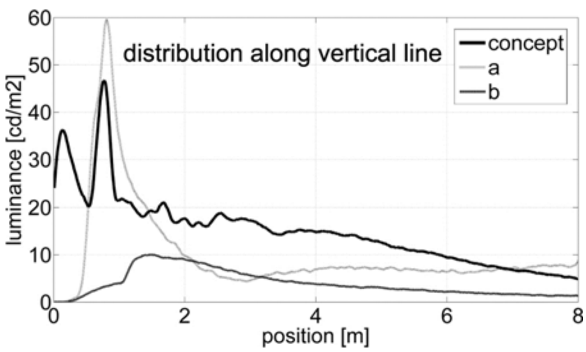

Fig.3. Luminance distributions along vertical line of symmetry

On presented on Figure 4c and 4d horizontal distributions for concept one, in higher parts of the wall (4 and 6 m above the ground) is wider area of homogeneous distribution with higher values of luminance comparing to other distributions. While in lower areas on Figure 4a and 4b (1 and 2 m above the ground) distributions have comparable width. It forces some further improvements in the design to make the concept distributions wider with smoother edges in comparison to other luminaires distributions.

The luminance distributions obtained during the simulations are also presented as a shaded plots for each cases. All plots show different shape of illuminated area and also different luminance distributions within. Moreover, shaded plots shows different level of flat surface deformation (Fig. 5).

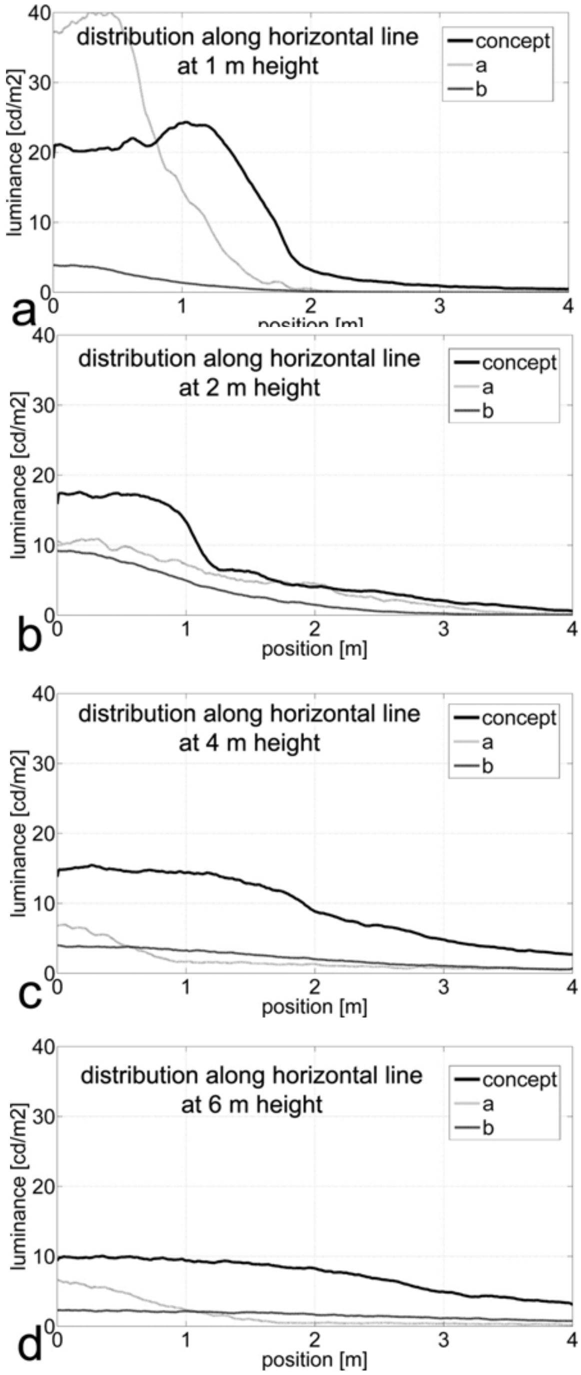

Fig.4. Luminance distributions along horizontal half lines

On Figure 5a we can see a luminaire “a” from Figures 3 and 4. Here we have inadequate distributions mainly because of rotational symmetry of luminous intensity distributions that is not aligned to asymmetrical conditions in such lighting device. It causes visible parabola contour that lead to unpleasant perception. Rotational symmetry also waste energy because of directing luminous flux outside the illuminated plane and what is more the range of the highest luminous intensity are directed to the sky, which induce light pollution. Directing luminous flux outside the illuminated object which is observed here cause glare effect on pedestrians. Only about 24 % of luminaire luminous flux reach this plane.

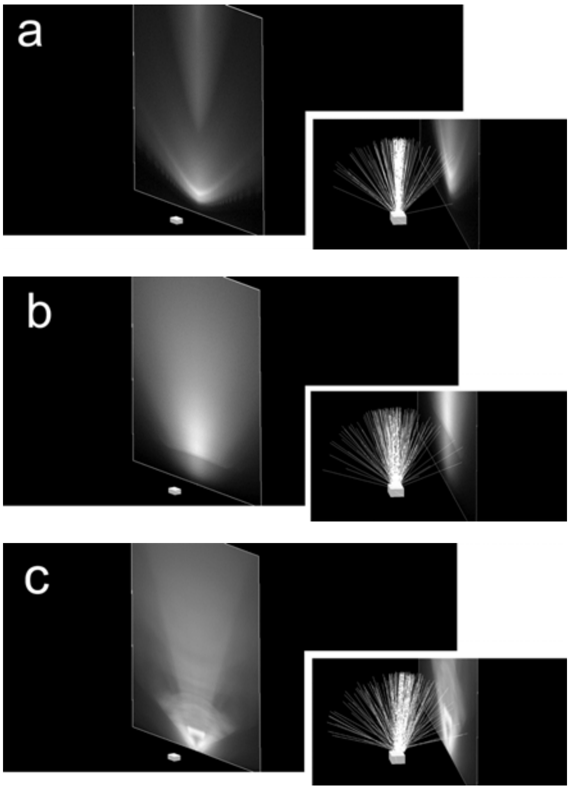

Fig.5. Visualizations of luminance distributions as a shaded plots (larger images) and rays emission visualizations (smaller images)

On Figure 5b for luminaire "b" we have better situation, distribution is quite asymmetric so luminous flux is directed mainly toward illuminated surface limiting light pollution and glare effect. Luminance distribution is smoother, but has lower level of luminance. Here about 15 % of luminaire luminous flux reach this plane. Less light directing to the plane for luminaire "b" compared to luminaire "a" is an effect of more scatter light emission of the luminaire "b".

For concept luminaire (Fig. 5c) only distinguish trapezoid shape is a drawback which need some improvements. And also distribution in lower part of the plane has some striations which need to be limited. Distribution and luminance level is mostly acceptable. Moreover luminous flux is rather emitting toward desired directions limiting energy wastage, light pollution and glare effect. Here about 56 % of luminaire luminous flux reach this plane which is a good result indeed. The drawback at the moment is a trapezoidal shape of a cut-off contour and the luminance striations occurring in the lower part of the area, as shown in the illuminated screen visualization in Figure 5c. Should be noted that Figure 5 shows only the visualization, so it is not identical with the impressions, that arise in reality after applying the conceptual luminaire.

Further research outline

Further research will involve reduction of trapezoid shape and striations of illuminated area to make it smoother in lower part on illuminated area. Furthermore there is a need to compare distributions in order to its validation. Now this valuation is unclear because of its ambiguity. We see striations on distribution, but we don't know if they will be visible in real conditions.

Conclusions

The floodlighting is now becoming more and more popular. Its purpose is to allow at nighttime admiring the objects architecture. Therefore, there may not be formed on the illuminated objects excessive uneven illumination, because they cause erroneous perception of the geometry and texture of the surfaces of the object. To preserve daylight image of the buildings is essential to use luminaires with properly adjusted luminous intensity distributions, especially in the case of uplight luminaires. Although, we can see certain constructions of optical systems, they are not sufficient and we need new solutions and structures.

The author presents the current results of the design of the uplight luminaire which allows creation of uniform illumination of the object. The obtained results are better than competitors in terms of overage luminance level, luminance uniformity, limitation of luminance peak and better utilization factor. Some drawbacks of concept solutions still remain, but the author will deal with them in next researches.

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