

Floodlighting luminaire for homogeneous illumination

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The main subject of the research is a proposition of a luminaire optical system which allows us to illuminate building facades in a more uniform way than it is today in the case when luminaire location is close and asymmetric to the illuminated object. Firstly, the paper introduces and explains the term of floodlighting and presents luminaires that are used in floodlighting. The author casts doubt on floodlighting luminaires quality especially related to luminous intensity distributions. Certain problems arising from illuminating objects by using improper luminaires are presented and discussed. As an attempt to improve the situation, the author shows his innovative concept of the luminaire optical system. Finally, to verify the proposed luminaire optics, the author has made a comparison of his conception with two other luminaires.

Keywords: lighting technology, illumination, floodlighting, luminaires, luminaire design

Introduction

„Floodlighting is the effect of actions that use artificial lighting and other means of expression to exhibit buildings at night, mostly visually.”, this definition of floodlighting is presented in the book of Professor Wojciech Żagan, Warsaw University of Technology [1]. In the scope of the paper we will refer to the main objective of floodlighting as to enable viewing object architecture at nighttime by illuminating a solid of the object using electric lighting equipment.

Floodlighting is currently undergoing its second renaissance. The first was associated with the emergence on the market and the development of gas-discharge light sources with high intensity white light, while the second is based on light-emitting diodes (LED) technology. LEDs are commonly known for their dynamic colorful light and low power consumption. Unfortunately, so far we have not observed the renaissance in shaping the luminous intensity distributions of lighting equipment (luminaires). In spite of the use of the innovative technology, LED luminaires generate typical luminous intensity distributions. When we want to illuminate the building surfaces with the luminaires placed in the vicinity of the building, we cannot find appropriate luminous intensity distributions of either conventional or LED luminaires. The illuminated surfaces uniformity exists during the day, in daylight. In the case of artificial lighting on the same wall different luminance distributions will rise radically. This causes adulteration of the perceived surfaces, as it takes another form, such as a concave surface instead of flat. This leads to ambiguity in the perception of illuminated objects. The issue justifies the

fact that mankind noticed the night images subconsciously through the experience gained in daylight.

Figure 1 presents an example of unsuitable illumination. The picture on the left shows the image of illuminated object, where an inadequate luminous intensity distribution of luminaires was chosen. Here we can see a set of spot luminaires with quite narrow luminous intensity distributions. Therefore, it causes huge luminance gradients which split one flat surface (actually rounded in one direction) into a set of pieces. However, the picture on the right presents a better luminance distribution and also linear luminaires and, therefore, is appropriate. Here in a correct way we can perceive the geometry of the illuminated surfaces as they would be during the day.

In the author's research there is an assumption that the illuminated surfaces have diffuse reflective properties, therefore, luminance distributions can be used instead of illuminance distributions thanks to their proportionality. The luminance is used in the research as the one of the photometry metrics that is the closest to the human sense of brightness.

To obtain satisfactory night building appearance we need luminaires which can generate homogeneous illumination on individual surfaces. The author's research is related to this issue.

'State of the art luminaires'

The luminaires currently available on the market and used in the floodlighting, as a rule, do not differ from the luminaires applied in outdoor areas such as squares, parks, play-

grounds. The only types of luminaires specially adapted to their mounting conditions in floodlighting are ground-mounted luminaires. However, this adaptation mainly applies to the mounting aspects not with lighting performance. They are not like the rest mounted on masts, but directly near the object in the ground (exit aperture of a luminaire is flush with the level of the ground) (Fig. 2). In this case, the luminaire is close and asymmetrical with respect to the object, e.g. at the bottom of a high wall. This reveals certain problems that are not known from the other locations of luminaires. As a consequence, when the luminaires are ground-mounted near the facades, or even on the facades, an adverse visual impression appears – the excessive lighting (in some cases we have an impression of overexposed light around the luminaire) and uneven luminance on the rest of the surface. Therefore, we achieve a highly uneven distribution of luminance when we illuminate the surfaces of objects from close distances in an asymmetrical manner. This leads to a distortion of the object image. The visualization in Figure 2 shows a clear example of the aforementioned issues – the overexposed light at the bottom of illuminated area and the uneven illumination of the rest of the area.

The above mentioned luminaires mounted in the ground have a suitable construction both in terms of their tightness and mechanical strength (possible car invasion), as well as thermal issues (they are easily accessible). In terms of light distribution, sometimes we can find appropriate modifications, but not always. Especially in the case of luminaires installed in the ground, the aim is to reduce the luminous flux in the direction outside the illuminated object, which can cause glare. This is done through deep optical system positioning in the luminaire housing. This, however, adversely affects the illuminated object, because it rises up the lower boundary of illuminated area. In addition, the engineers have to deal with a serious problem to obtain an asymmetric light distribution, because the light in one direction must only be emitted in order to illuminate the object. However, in the opposite direction it should not be emitted, because it will be directed toward other objects including pedestrians, which is undesirable and also introduce some luminous flux losses and light pollution. The above described modifications, apart from improving the luminous intensity distribution, decrease the efficiency of the luminaire very often, which is the ratio of the luminous flux emitted from the luminaire to the luminous flux of the light source therein. Sometimes the luminaire efficiency is close to 40%. If we consider the utilization factor which shows how much of the light source luminous flux reaches the illuminated surface, we get a level of 10-20%. Therefore, approximately 80-90% of the light source luminous flux is lost [2].

The presented information indicates a need for some innovative solutions in the field of floodlighting luminaires.

The author's idea of optical system modeling

The idea how to model optical system to reach the goal – to illuminate surface in homogeneous way, has been found in floodlighting theory. There the illuminated object image is a superposition of the individual lighting effects that are generated by means of individual luminaires. To design a luminaire reflector shape, we can assume that a final luminance distribution obtained from the whole reflector is like floodlighting. Therefore, the individual discrete parts of reflector (facets) act as luminaires in floodlighting. Finally, throughout a proper adjustment of each reflector facet, we can obtain the illuminated representation of the area (luminance distribution). The idea of the author's own method of calculation is detailed in [3,4].

The fragment of exemplary reflector has been calculated using this method.

Luminaire optical system design

The lighting task, which is shown in Figure 2, has specific properties. If we assume putting only a light source instead of the luminaire and determine the desired luminance level e.g. 12 cd/m^2 on the wall, it will turn out that in the lower parts of the wall these values will exceed the agreed value of luminance, whereas in the upper they will be below this value [5]. Therefore, during designing the optical system of the luminaire, the luminous intensity of the light source has to be strengthened in certain directions and in the others weakened, and even eliminated in the rest (in the directions outside the illuminated object). This is a special case of the luminaire, because as a rule, luminaires only strengthen or weaken the luminous intensity of a light source.

In order to design the optical system, which will transform the light source luminous intensity as described above, may be shaped as reflecting surfaces (reflectors). We can then assign appropriate materials, which can scatter the reflected luminous flux to a certain extent and thus change its luminous intensity. When converting luminous intensity with the use of reflectors cannot give sufficient results, we can enter the transparent elements with the appropriate shape of boundary surfaces (refractors) and then there will be an adequate refraction of luminous flux, and thus also a change in its luminous intensity.

To designate the reflector shape, we can consider it as a set of individual discrete components (facets) and adjust properly its dimensions and aiming to use them to light the particular areas of the illuminated surface using the methodology described in the previous section of this article [3,4].

The utilization of the described methodology led to implementing the supporting computational tools in the form of an Excel spreadsheet. However, there has been an assumption that a reflector has a trough shape, which comes

from the profile extruded along the vector perpendicular to the plane containing this profile. The computational tool allows us to transform the input data entered to luminance distribution along the axis of symmetry of the illuminated area (vertical line that can be drawn through the center of the illuminated wall in Figure 2).

The shape of the reflector has been calculated using the resultant tool. The optical system consists of a compact metal halide lamp, a reflector surface built with a set of flat mirrors and a lens [6, 7, 8]. The author made a decision to use the compact metal halide lamp instead of LED. One of many reasons for this decision was to utilize the reflectors in the optical system, which is not common in the LED luminaires.

The concept luminaire optical system geometry will not be shown in the paper because of the author's interest in patent protection.

Obtained lighting effect verification

To verify the obtained lighting effect the computer simulations of the optical system were performed. The optical system was placed inside the housing and positioned in front of a test screen which imitated the illuminated object like a facade or wall – Figure 3.

Figure 4 shows the visualization of the test screen surface luminance distribution as a shaded plot while Figure 5 (bold line) presents the luminance distributions of de-

signed optical system along the vertical line of illuminated area symmetry (as drawn on the test screen in Figure 3) and two other solutions which are competitive.

As for the bold line in Figure 5 the optical system allows us to create the constant luminance of a wall in the range of from about 1.8 to 5.5 meters from the ground level. Above 5.5 m there is a mild decrease in luminance. Although in the lower areas there are some unevenness of luminance distribution and too low luminance level, their

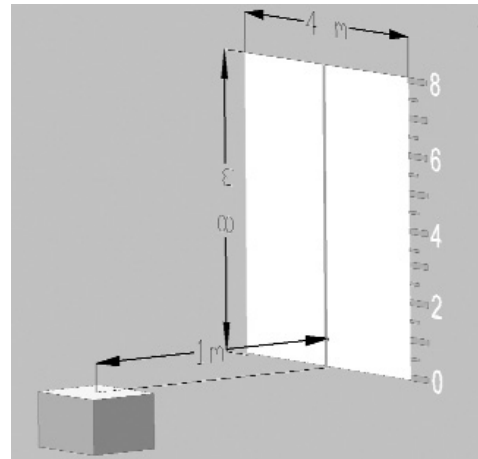


Fig. 3. Lighting device geometry for simulations



Fig. 1. Different appearance of a wall as a result of different luminance distributions [photo W. Żagan]

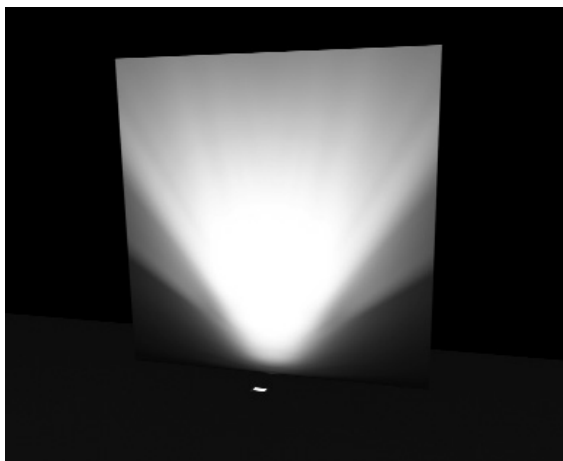


Fig. 2. Exemplary lighting effect of ground-mounted luminaire as computer visualization – Does this surface appear flat?

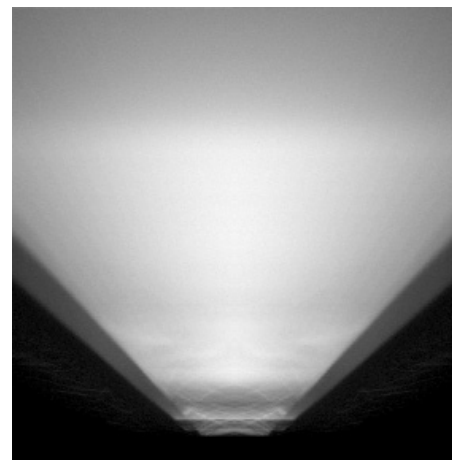


Fig. 4. Visualization of illuminated plane

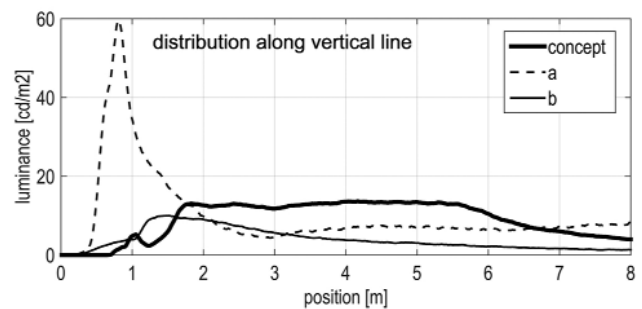


Fig. 5. Luminance distributions along vertical line of symmetry

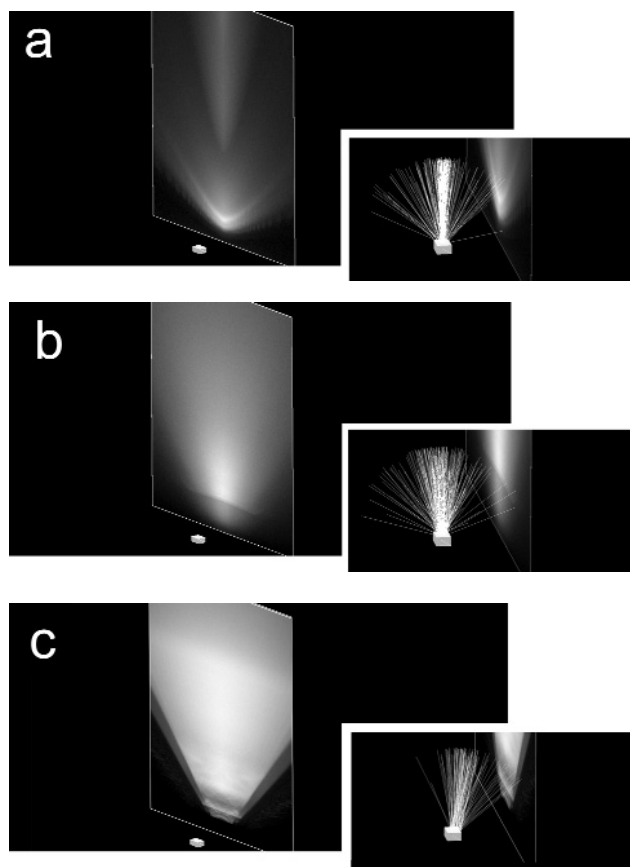


Fig. 6. Visualizations of luminance distributions as shaded plots

adjustments is a matter of further research (Fig. 4 and 5).

Moreover, in Figure 5 there is a comparison of the author's conception (bold line) with two commercially available luminaires depicted as a and b. Taking into account the vertical distributions along the symmetry line of illuminated area, we obtain an even luminance distribution along the analyzed line only in concept one. As we can see the concept luminaire has no luminance spike at the bottom of illuminated wall like luminaire a, and quite even, homogeneous distribution at the rest of the wall which oscillates around 12 cd per square meter, which is a correct level according to the standards [9]. What should be added is the fact that all the luminaires in Figure 5 have the same luminous flux of the light source, so therefore a different level of luminance is caused by the different luminaire efficiency and different luminous intensity distributions.

The simulations results of three aforementioned luminaires (concept one and two available on the market) were also shown as the visualizations of lighting effects. The visualizations present the luminance distributions as shaded plots for each luminaire. All plots show a different shape of the illuminated area and also different luminance distributions within. Additionally, the shaded plots show a different level of flat surface deformation (Fig. 6).

In Figure 6a there is a luminaire “a” from Figure 5. Here we have inadequate luminance distributions mainly because of the rotational symmetry of luminous intensity distributions. It causes a visible parabola contour of the lower boundary of illuminated area that leads to unpleasant perception. The rotational symmetry also wastes the energy owing to directing the luminous flux outside the illuminated plane and what is more the range of the highest luminous intensity is directed to the sky, which induces the light pollution. Directing the luminous flux outside the illuminated object, which is observed here, causes a glare effect on the pedestrians. Only about 24 % of the luminaire luminous flux reaches this plane.

In Figure 6b as for luminaire “b”, we have a better situation; the distribution is quite asymmetric so the luminous flux is directed mainly towards the illuminated surface limiting the light pollution and glare effect. The luminance distribution is smoother, but has a lower level of luminance. Here about 15 % of the luminaire luminous flux reaches this plane. As for luminaire “b” compared to luminaire “a”, directing less light to the plane is an effect of more scattered luminous intensity distribution of the luminaire.

As far as the concept luminaire (Fig. 6c) is concerned, the only distinguished trapezoid shape of lower boundary is a drawback which needs some improvements. And also distribution in the lower part of the plane has some unevenness which needs to be limited. The distribution and luminance level are mostly acceptable. Moreover, the light is largely emitted towards the desired directions limiting the energy wastage, light pollution and glare effect. Here about 68 % of the luminaire luminous flux reaches this plane which is a good result indeed.

Further research will involve the reduction of trapezoid shape and unevenness on the illuminated area. Furthermore, there is a need to introduce the remaining parts of the reflector. It will increase the efficiency of the luminaire and illuminate the additional areas such as lower corners of the illuminated area.

Conclusion

Floodlighting is becoming more and more popular. Its aim is to enable us to admire the architecture at nighttime. Therefore, there may not be formed excessive uneven illumination on the illuminated objects, because it causes the erroneous perception of the geometry and texture of the surfaces of the objects. The author presents the current results of the luminaire design which allows creating a uniform illumination of the object. The results have given better parameters compared to the currently used solutions shown in the paper. Some drawbacks of concept solutions remain, but they are a subject for further research.

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