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The superposition of light spots in calculations of reflectors for illumination

***Abstract**. This paper was presented the author`s method of determining a profile of the trough-shaped reflector surface generating the even luminance distribution on a flat surface at an oblique and asymmetric location. The method of this procedure is based on the usage of the surface luminance distribution measured on the screen coming from the bare light source and then converted to their corresponding partial luminance distribution of the illuminated surface. The calculation results are compared with effect of a lighting sample obtained using commercially available luminaires.*

***Streszczenie.** W artykule został zaprezentowany autorski sposób wyznaczenia profilu rynnowego odbłyśnika wytwarzającego zadany, tzn. wyrównany rozkład luminancji na płaskiej powierzchni przy jej skośnym i asymetrycznym usytuowaniu. Metoda postępowania opiera się na wykorzystaniu powierzchniowych rozkładów luminancji zarejestrowanych na ekranie pochodzących od samego źródła światła a następnie odpowiednim ich przekształceniu na cząstkowe rozkłady luminancji na oświetlanej powierzchni. Wyniki obliczeń zostały zestawione z efektem oświetleniowym uzyskanym za pomocą przykładowych, dostępnych na rynku opraw oświetleniowych. (**Superpozycja plam świetlnych w obliczeniach reflektorów iluminacyjnych**).*

Keywords: lighting technology, illumination, luminaires, luminaire design
Słowa kluczowe: technika świetlna, iluminacja, oprawy oświetleniowe, projektowanie opraw oświetleniowych

Introduction

The current rapid development of illumination leads us to a reflection on its quality [1]. Potential claims may arise both from the concept and the luminaires used. The illumination concept should be considered in the area of aesthetics, which, as we know, is the subjective value. However, the matter of lighting equipment is a typical engineering issue, which is possible to investigate, evaluate and improve.

Lighting tasks can be divided into certain groups, which are assigned to the relevant requirements and parameters of the luminaire and the whole lighting system. Thus, for road lighting purposes specifically constructed luminaires are available and also the ways of their installation, location, road surface and material selection and etc. Such situation is ruled by the lighting standard CEN/TR 13201:2007 [2].

For illumination such standard document does not exist. This is a normal condition, as it is difficult to normalize aesthetics issues such as desired shape of the light spots.

The lack of regulations causes a great deal of freedom in design and manufacturing of light spots by luminaires. These solutions are not always fully thought through.

Currently used designs of uplight luminaires, do not guarantee in any way even luminance distribution, or vertical illuminance on the illuminated surface [3]. This situation is unacceptable when it comes to the surface elevation exposion or the graphic content that is presented on it (billboard).

The surfaces of the object, which themselves carry the information such as structures (brick elevation) or as applied graphics (advertising poster) should be illuminated in a uniform manner in order not to distort the information contained in the image.

The situation is different in architectural mapping, due to deliberate introduction of non-uniform lighting, because it carries the information (graphic image) – Table 1.

Table 1. The range of illuminated surfaces due to the source of information

The source of information	Example	Desired way of illumination
Surface	Brick facade, advertising poster	Uniform
Lighting	Architectural mapping	Non-uniform

This raises the need to propose a design solution of optical system, which realizes the uniform luminance distribution on the illuminated surface.

Considerations on the choice of the method of calculation of the optical system

Among illumination applications, general and specific applications can be specified – Table 2. With respect to applications for general use there is certain freedom in usage. It means, eg. a wide range of possible mounting height above the working plane. In such solutions, the evaluation of usefulness of the luminaire is based on a luminous intensity distribution by means of luminous intensity curves. A different situation occurs in the luminaire to specific applications. The choice of installation location is limited and sometimes even imposed. Therefore, this group is beginning to have a decisive influence on obtained illuminance or luminance distribution on illuminated object. Luminaires manufacturers rarely do such distinction - for both of these groups is given only the information in the form of luminous intensity curves [3, 4].

A good example of the necessity to replace the photometric data in a form of luminous intensity curves to illuminance (luminance) distributions on an object are high beam and low beam vehicles projectors. Hardly anyone had the opportunity to see the luminous intensity distribution of such luminaire when not once seen illuminance distribution on the screen, which comprehensively quantify and qualify given design.

Thus, in certain cases, there is a need to move away from the presentation of photometric data of luminaires in the form of luminous intensity curves for the illuminance or luminance distribution on a reference surface. Going a step further we can say that if the evaluation of the usefulness of the luminaire will be made on the basis of these planar distribution of the photometric measures, the process of designing of such a device can be reduced to achieve the desired planar illuminance distribution (or luminance) on a defined plane.

Table 2. Range of luminaires for illumination

Luminaire mounting	Photometric data presentation	Example
Free	Luminous intensity curves	Floodlight luminaire
Imposed	Luminance / illuminance distribution on the object	Uplight luminaire

A description of the author's method of determining the profile of the reflector

Author's calculation method is as follows:

1. Registering the luminance distribution with a use of a matrix luminance meter obtained on a flat screen located in the long distance which is illuminated through the bare light source – Figure 1 [5, 6]. Directions of the screen relative to the light source location should correspond to the directions in which the reflector elements may appear, as viewed from the center of the light source. The resulting set of luminance distributions are the input data for calculations.

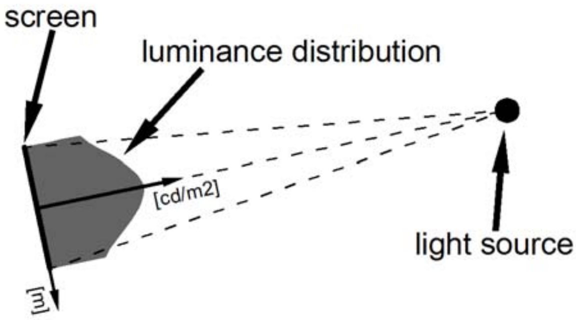

Fig.1. Scheme of registering luminance distribution on a screen

2. Assuming the use of perfectly flat mirror elements, the measured luminance distribution on the screen can be converted into the luminance distribution formed on the illuminated surface. We only need to calculate the luminance of each point on the screen to the corresponding points on the object, taking into account the change of the distance and the angle relative to the position of the light source center respectively – Figure 2.

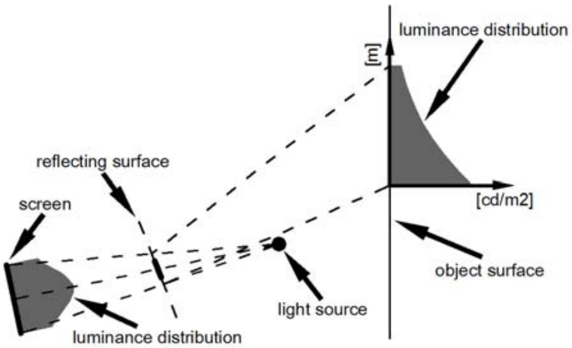

Fig.2. Scheme of transformation a luminance distribution from screen to object

3. The resulted luminance distribution on the object is based on a sufficiently large reflecting surface. The luminance distribution obtained in such way will be limited only by the size of the measurement screen. It is unreal situation – Figure 2.

4. For a flat surface of the mirror with dimensions comparable to light source we take into account the creation of transitional zones on the light spot. Transition zones contain points which are illuminated only by a part of the light source, due to the finite dimensions of the reflecting surface – Figure 3.

The proposed method of calculation is based on three very important aspects of the photometric calculations:

- the actual dimensions of the light source
- the actual luminance distribution of the light source
- short distance photometry (occurring below minimum photometric distance) [7, 8].

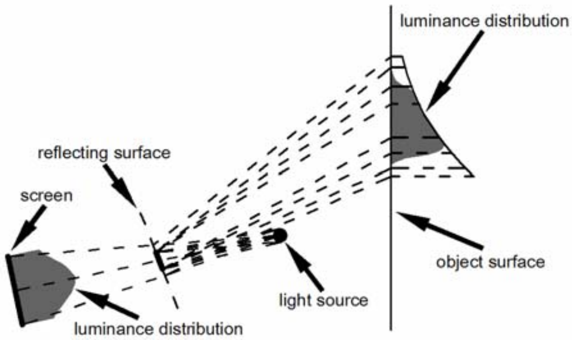

Fig.3. Scheme of a luminance distribution on object with transitional zones

Determination of the sample reflector profile

Based on the calculation method a spreadsheet was made for reflector profile calculations. The input to the sheet is a collection of luminance distributions along line registered on the screen, coming from the bare light source.

Inclusion of luminance distributions along line instead of surface luminance distributions is a result of the modeling assumption in only one plane (lateral symmetry of the trough-shaped reflector) - Figure 4 [9].

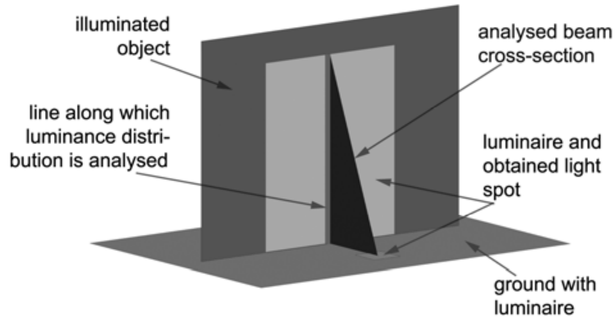

Fig.4. Scheme of calculated situations

The calculation process is based on a specifying the location, height and aiming of the reflector n'th zone surface to obtain a satisfactory luminance distribution derived from the zones up to the n'th zone included on the illuminated plane (in the line of interception of the object plane and transverse plane of symmetry of the optical system). The calculations is done in Excel form. After a sufficient number of iterations a trough-shaped reflector profile consisting of a set of flat mirror surfaces and the luminance distribution on the object formed in the position of housing in question are achieved. The luminance distribution on the illuminated object which was generated during the design phase is an evaluation of the resulting illumination, without necessity of an additional calculations based on e.g. Monte Carlo simulation method – Figure 6 [10].

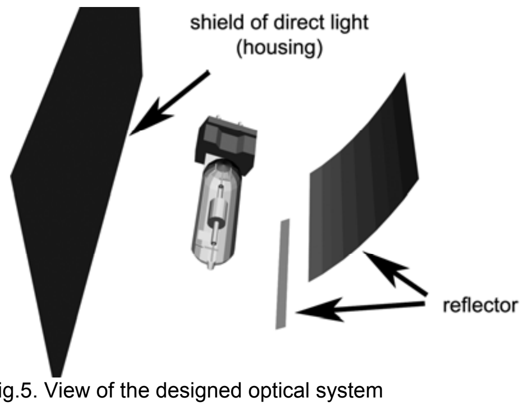

Fig.5. View of the designed optical system

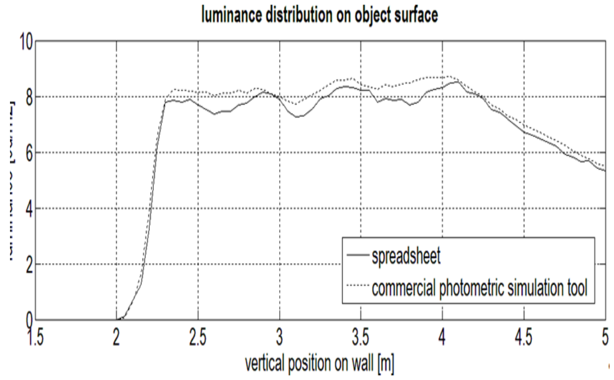

Fig.6. Presentation of the luminance distribution produced by the designed optical system

In summary, implementation of the proposed method in the Excel form allows for simultaneous constructional decisions and observing the results of their actions without the use of simulation tools in the form of programs which make the photometric calculations of previously obtained design and hence extend the design process of the optics.

In Figure 5 the designed optical system was presented. It consists of a shield which eliminates direct radiation, the light source and the reflector. The shield imitates housing side to limit the distribution of the direct luminous flux. It is important to highlight the fact that the luminance distribution shown in Figure 6 is achieved with a relatively small solid angle in which the light beam falls on the reflector (Figure 5). This situation allows application of further surfaces of the reflector to reach uniform illumination of the object in both the vertical and horizontal directions. Width of the reflector was set to be equal to the length of the light source, which guarantees a uniform illumination across the area of the object in some extend.

In Figure 6 the result of luminance distribution calculations is presented on the illuminated wall in the line of intersection of the wall and the transverse plane of symmetry of trough-shaped reflector based on Excel file. In order to verify the correctness of the luminance distribution obtained by means of author's method, its graphic comparison with the results of computer calculations based on photometric algorithm which uses the Monte Carlo method was shown (Fig. 6). The assumption of the calculations was to locate the optical system 1 m away from the illuminated surface with the aperture in the plane of the ground (Fig. 4).

The comparison of the conceptual reflector with existing solutions

Three luminaires were chosen in order to compare the lighting effects of the designed optical system with existing solutions (Fig. 7). Then their luminance distribution on the axis of symmetry of light spots were combined. The first luminaire had a standard design, which was based on a paraboloid reflecting surface used in addition to a half-ring to illuminate the object (Figure 7a). The second luminaire like the first had a paraboloid reflector, but with the following modifications: a paraboloid had a stepped circumference, the direct radiation of the light source was limited by the sides of light-absorbing cylinder and upwards by means of the lens that scatter light (Figure 7b). Last luminaire had unique, patented design of the anisotropic material reflector - parabolic trough with a special matched set of two louvres (Figure 7c).

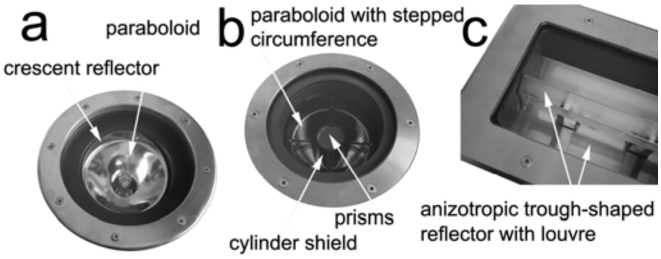

Fig.7. Photographs of luminaires used to compare with the concept one

The assumption of the comparison was to locate luminaires 1 m away from the wall and align their aperture with a plane of the ground (Fig. 4). All luminance distributions (Fig. 8) are related to the luminous flux equal to 1000 lm. The curves refer to the luminaires in Figure 7 (7a, 7b and 7c) and the designed reflector (concept). Luminaires were placed according to the assumptions and produced light spots were measured by means of a matrix luminance meter. With respect to the designed reflector – data was derived from the simulation in a commercial application (Figure 6).

Analyzing Figure 8 we should take into account the rotational symmetry of luminaires 7a and 7b and asymmetry of luminaire 7c and the concept one. This has a significant impact on the delivered luminous flux to a plane which is placed asymetric and near. For this reason, the rotationally symmetrical luminous intensity distribution, most of the luminous flux does not reach the illuminated object [3]. The differences in luminance levels show the degree of matching of the luminous intensity distribution to the lighting task and the size of the lumen loss in the optical system. It is worth highlighting that the low level of luminance of the conceptual design is dictated by the low angle of collection of the light source by the reflector (Fig. 5). This situation gives the potential for further expansion of the optical system.

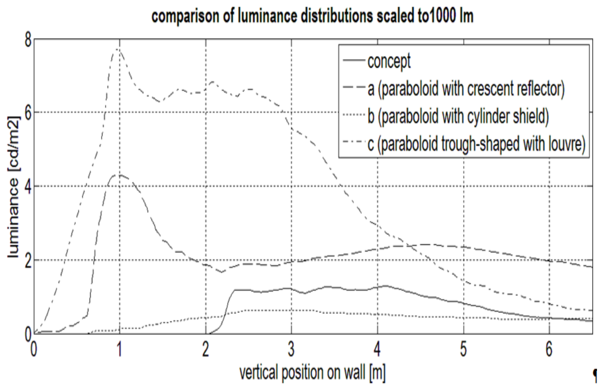

Fig.8. The summary of the luminance distribution of light spot in the axis of symmetry obtained by the testing (Fig. 7) and conceptual lighting system (Fig. 5). All data related to 1000 lm.

In Figure 8 the greatest effect of "overlit" can be noticed in the lower part of the wall for luminaire 7a, and to a lesser extent to 7c. Unlike 7a, luminaire 7b has no "overlit", but this is the effect of blocking the source light in a way which unfortunately, greatly increases losses in the optical system [3]. Luminance uniformity can be observed in the conceptual solution and in luminaires 7b and 7c. However, out of the three uniform distributions the most desirable situation is for the conceptual design. Although the luminaire 7b is characterized by a relatively even distribution of luminance in the present vertical line on the object unfortunately due to the rotational symmetry of luminous intensity distribution, the horizontal distribution will be negative.

Figure 9 as Figure 8 showed luminance distribution on the wall, but related to the maximum value of the luminous flux of each source. Bold square corresponds to 20% range of the luminance changes, which is considered as indistinguishable by the human eye. Only the results for 7c and the conceptual design, the even luminance range is located in the selected area.

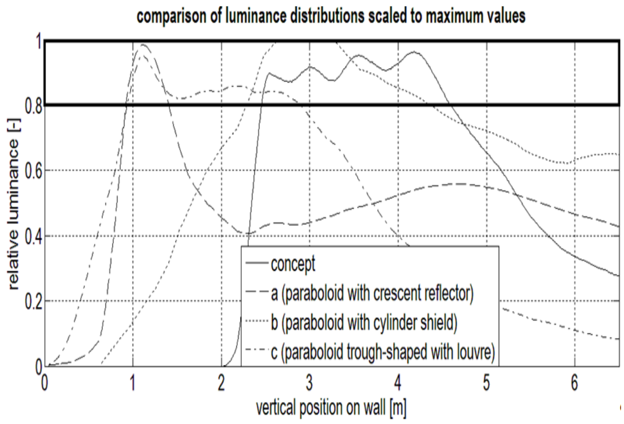

Fig.9. The summary of the luminance distribution of light spot in the axis of symmetry obtained by the testing (Fig. 7) and conceptual lighting system (Fig. 5). All data related to maximum values.

Conclusions

The article presents the results hitherto in the design of the optical system of luminaire. Its purpose is to obtain even luminance distribution on the illuminated surface, which is located close and asymmetrical with respect to the housing. The results are satisfactory and show improvement of the luminance distribution produced in relation to the existing solutions. The use of a flat, reflective surface of the reflector enabled to fulfil the task - to produce even luminance distribution in the axis of symmetry of the light spot. In order to expand the area of even luminance, according to the author, there is a necessity to use non-flat surfaces of the mirror. It is a subject of further research on the designed optical system of luminaire.

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