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An attempt at controlling the utilisation factor and light pollution within the context of floodlighting

Abstract. *An observer of a floodlit object is able to reflect, contemplate upon and observe the beauty of their environment. However, one has to remember that floodlighting is also associated with some threats to the environment. Firstly, with regard to the low energy efficiency of floodlighting, and secondly with regard to the phenomenon of light pollution. This work is concerned with a preliminary consideration of the assessment of these two threats at a design level. Some new and useful parameters are also discussed and calculated.*

Streszczenie. *Nocne oświetlenie obiektów architektonicznych skłania odbiorcę do refleksji, przeżywania i dostrzegania piękna swojego otoczenia. Należy jednak pamiętać, że luminacja obiektów jest również związana z pewnymi zagrożeniami. Po pierwsze kwestią niskiej efektywności energetycznej oświetlenia, po drugie zjawiskiem zanieczyszczenia światłem środowiska. Referat przedstawia wstępne rozważania na temat sposobu oceny tych dwóch zagrożeń, na poziomie projektowym, odbywającej się za pomocą nowych parametrów.* ***(Próba kontroli efektywności energetycznej i zanieczyszczenia światłem w iluminacji obiektów).***

Słowa kluczowe: technika świetlna, iluminacja obiektów, efektywność energetyczna oświetlenia, zanieczyszczenie światłem
Keywords: lighting technology, floodlighting, energy efficiency, light pollution

Introduction

Nowadays, the floodlighting of objects has become widespread all over the world [1]. This has mainly been caused by the rapid development of new light sources, and the fact that light emitting diodes (LED's) have become increasingly popular in recent years. Monuments, modern buildings, temples, bridges and shopping malls are all now being illuminated more and more frequently. Additionally, the issue of the energy efficiency of lighting [2] and the phenomenon of light pollution needs to be considered; the latter is a new, photobiological threat and an intriguing topic in contemporary lighting technology [3,4]. New restrictions and normative requirements have been developed in connection with these issues [5]. Additionally, a few unified systems for the evaluation of the energy efficiency of lighting have already been created [2]. It is important to realise that these systems are connected with interior lighting and road lighting only [6,7]. The problem of the optimization of floodlighting design with regard to energy efficiency and light pollution has not yet been considered. However, it is important to realize how significant this is. Most floodlighting starts at the bottom of the object [1]. This means that the major part of the luminous flux is directed upwards towards the sky and much of it can miss the object, especially if the project was designed in an inappropriate way or if bad- quality luminaires were used, which is quite common [8]. This causes two main environmental threats. The first of them is a loss of energy and, indirectly, an increase in carbon dioxide production. The second, as already mentioned, is the phenomenon of light pollution. It is well known that both humans and animals feel the influence of electromagnetic radiation. This light is of a specific form, as defined by a certain spectrum [9]. If the level of luminance of the surroundings is too high, and there is inadequate spectral distribution of light, this can result in disorders of the circadian rhythm [10]. Moreover, light scattering in the atmosphere increases the luminance of the sky during night time. This has a negative impact on the observation of stars [3,4,10]. Natural night darkness is needed for living organisms to exist in a proper way. The phenomenon of light pollution is now considered to be a real environmental threat and an issue that has to be controlled [11,12]. In addition, it is important to remember about the possibility of glare, and methods of reducing it, as this is also a most important safety issue [13, 14]. When talking about the floodlighting of objects, one should be aware of these potential threats and problems. When enhancing the beauty of architecture and the surrounding area, we should not let it be harmful to human health or hinder any activities, and in general floodlighting ought to be environmentally-friendly.

The floodlighting utilisation factor (FUF)

With regard to floodlighting, there is a need to define what proportion of luminous flux emitted from the sources used in the design is aimed at the surfaces of the object. The floodlighting utilisation factor is required to achieve this (1). This parameter is related to the classic definition of lighting efficiency [8], but the application of it is quite different. The floodlighting utilisation factor can be defined as the proportion of useful luminous flux which is aimed at the surface of a floodlit object and causes a certain visual effect (such as the luminance of illuminated surfaces), and the total luminous flux which comes from all the light sources used in that lighting solution.

(1) $$FUF = \frac{\phi_u}{\phi_t} \cdot 100\,[\%]$$

(2) $$\phi_t = \sum_{i=1}^{n} \phi_{0_i}\ [lm]$$

where: FUF – floodlighting utilisation factor, ϕ_u - useful luminous flux , ϕ_t - total luminous flux, ϕ_0 - rated luminous flux (of a light source)

Considering the following assumption: that floodlighting consists of one luminaire only and the light output ratio (LOR) is known, then there is a dependence (3).

(3) $$FUF \le LOR$$

In this case, the light output ratio is the maximum possible floodlighting utilisation factor required to achieve the effect. However, usually, many different types of luminaire are used in a design. Therefore, the maximum value of the floodlighting utilisation factor can be calculated based on the formula (4).

(4) $$FUF_{MAX} = \frac{\sum_{i=1}^{n} LOR_i \cdot \phi_{0_i}}{\sum_{i=1}^{n} \phi_{0_i}} \cdot 100\,[\%]$$

Useful luminous flux is defined within the definition of the floodlighting utilisation factor (1). It is the part of the luminous flux which is aimed at the object. Therefore, the part which is not aimed at the object can be called the loss of luminous flux. This parameter can be defined by this formula (5). Basically, it is the difference between the sum of luminous fluxes from all luminaires and the useful luminous flux.

(5) $$\phi_{loss} = \sum_{i=1}^{n} LOR_i \cdot \phi_{0_i} - \phi_u\ [lm]$$

The loss of luminous flux can be also presented in relative form (6). This describes the percentage amount of luminous flux emitted from all luminaires not aimed at a certain illuminated surface

(6) $$\phi_{loss}^{'} = \frac{\phi_{loss}}{\sum_{i=1}^{n} LOR_i \cdot \phi_{0_i}} \cdot 100\,[\%]$$

It is worth noting that intrusive luminous flux (luminous flux emitted directly to the upper hemisphere), when related to floodlighting, is part of the loss of luminous flux. However, this issue will be not discussed in this work.

The specification of calculations

The computer simulations presented below are based on a floodlighting design for a building which belongs to Warsaw University of Technology – „The Old Boiler Room". A virtual model has been created using 3dS MAX 2016. It contains a special calculation plane – LightMeter (fig.1) which is set just in front of the main illuminated surface. The main dimensions of this location are 23 m x 14 m (This represents the main dimensions of the building as well). The dimensions of the calculations grid are 0,1 m x 0,1 m.

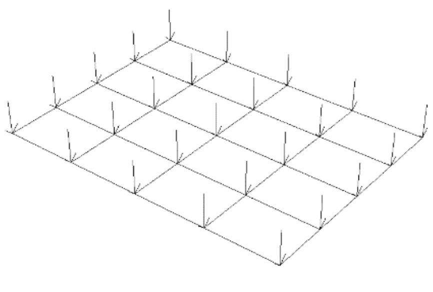

Fig. 1. A view of the calculation plane – LightMeter (3dS MAX).

The received illuminance distribution on that plan is exported to a spreadsheet and then, using a simple mathematical transformation, the average direct illuminance and useful luminous flux are able to be calculated. Knowledge of the lighting and electrical parameters (table 1) allows for the calculation of the floodlighting utilisation factor and relative loss of luminous flux. Firstly, the calculation was prepared for a basic location and angle of direction of lighting equipment (angle 0°), which was defined during the process of designing the floodlighting of the building. Next, calculations were made for different angles (ranging from -5° to 10°) of direction of the luminaires. A negative value of the angle means that the luminaires were pivoted in the opposite direction to the surface of the building and the converse is true when the value of the angle is positive. For every 1° change, the parameters of the floodlighting utilisation factor and loss of luminous flux were calculated using the spreadsheet.

Concept of floodlighting of the top part of the Old Boiler Room Building

A summary of the lighting equipment used is shown in table 1. The bottom part of the Old Boiler Room building is illuminated by four ground-recessed rotationally symmetrical luminaires with a metal halide light source, of power 35W (type A). The main aim of this is to highlight the pilasters of that elevation. Two luminaires (of type B) are located a little further from the illuminated surface. By means of this setup, the illumination of the small tympanum located above the entrance is possible. The uniform illumination of the top part of the building (above the door) is achieved by using linear luminaires with LEDs (type C). These luminaires are located along the cornice of the elevation. The same luminaire is mounted just above the doors, with the intention of exposing the entrance in a proper way. In addition, a rotationally symmetrical luminaire (type D) is used to highlight the architectural decoration of the building. This is mounted on a lantern which is located at a distance of 9,5 m from the main surface. The average level of luminance of the elevation of the Old Boiler Room is declared to be 12 cd/m^2. This is in line with the requirements described in [15].

Table 1. Summary of lighting equipment used in the concept of floodlighting

Symbol	Light source	No.	ϕ_0 [lm]	P [W]	LOR [%]	$\delta_{1/2}$ [°]
A	MH	4	3300	35	67	C0-180: 16 C90-270: 16
B	MH	2	1600	20	57	C0-180: 8 C90-270: 8
C	LED	35	591	15	100	C0-180: 11 C90-270: 63
D	MH	1	3200	35	58	C0-180: 7 C90-270: 7

Results

The calculated values of the following new parameters are presented in table 2. This shows that the floodlighting of objects is characterised by quite low levels of lighting efficiency. The value of the floodlighting utilisation factor is 31% and the loss of luminous flus is 62% for an angle of 0°. This means that the vast majority of luminous flux emitted from the luminaires does not fall on the illuminated surfaces. What is more, this causes an unnecessary loss of electrical energy and increases the phenomenon of light pollution. There are many reasons for this occurrence. Primarily, it is connected with the inadequate selection of luminous intensity distribution for the planned illumination task. However, the inappropriate mounting of lighting equipment also has an impact on this.

These calculations highlight the importance of the proper location and angle of direction of the lighting equipment. Even small changes (of a few degrees) in the angle of direction can cause either a big improvement or a large deterioration in the parameters analyzed. The proportion of these parameters as a function of the angle of direction of the luminaires is shown in figure 7. At an angle of -5°(luminaires pivoted away from the elevation), the values of the parameters are extremely adverse; the floodlighting utilisation factor is only 22% and the loss of luminous flux is 74%. This means that the lighting equipment must be located precisely according to the design outlines. When considering the values calculated at the angles of 5° and 10°, these are definitely more advantageous, with regard to both the energy efficiency of lighting in floodlighting and to the phenomenon of light pollution. In the best case scenario, the parameters were 65% and 21%, respectively. Despite increasing the floodlighting utilisation factor by a factor of 2, the maximum result was not achieved. The maximum value of the floodlighting utilisation factor for this project was about 82%. This was calculated by proportion (6). In the best case scenario, the floodlighting utilisation factor was only about 80% of the maximum possible value of this parameter.

Table 2. Results of calculations of floodlighting utilisation factor and relative loss of luminous flux for each angle of direction of the equipment.

$\alpha[°]$	$FUF[\%]$	$\phi'_{loss}[\%]$
-5	22	74
-4	23	72
-3	25	70
-2	27	68
-1	29	65
0	31	62
1	34	59
2	37	55
3	41	51
4	44	46
5	48	41
6	52	37
7	56	32
8	59	28
9	63	24
10	65	21

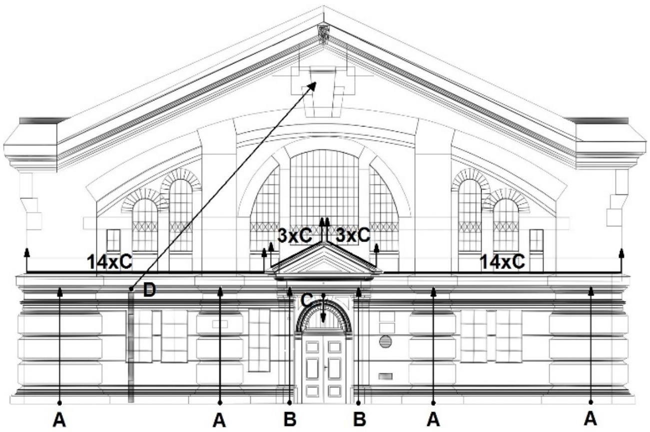

Fig. 2. Scheme of location and angle of direction of the lighting equipment.

Fig. 3. Computer visualisation of concept of floodlighting of the Old Boiler Room Building (angle 0°).

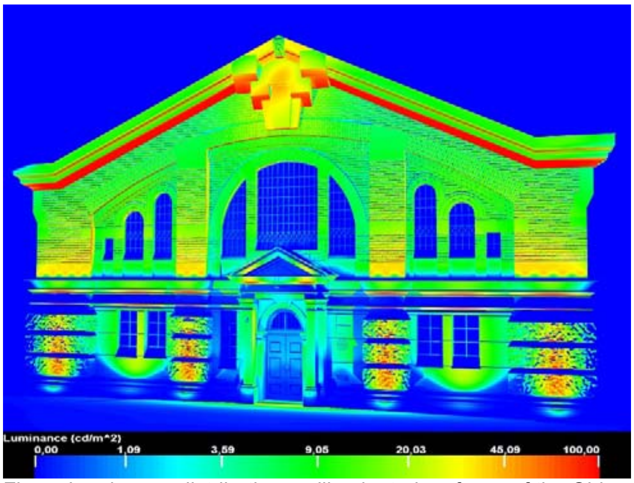

Fig. 4. Luminance distribution on illuminated surfaces of the Old Boiler Room Building (angle 0°).

Fig. 5. Computer visualisation of concept of floodlighting of the Old Boiler Room Building (angle10°).

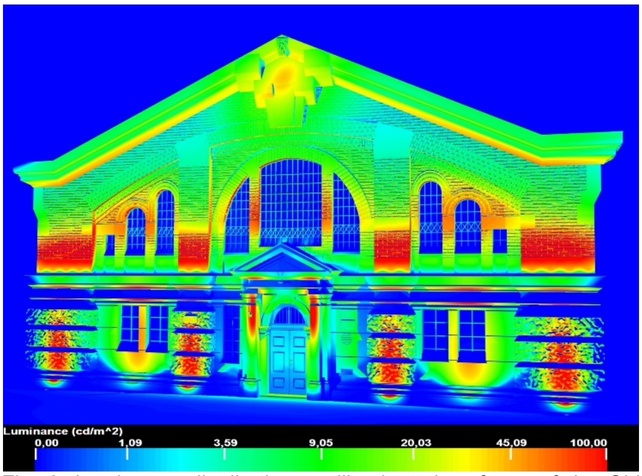

Fig. 6. Luminance distribution on illuminated surfaces of the Old Boiler Room Building (angle 10°).

The diagram in figure 7 shows the relationship between the floodlighting utilisation factor and the relative loss of luminous flux due to the angle of direction. It highlights that it is possible to find a particular angle of direction of the lighting equipment that enables these parameters to be optimised. In the case of the floodlighting of the Old Boiler Room, this angle is 4°. However, it must be borne in mind that any change in the angle of direction of the luminaires has a big impact on the final visual effect. As can be observed from the luminance distribution (fig. 4 and 5), changing the angle of direction can change the initial concept of the floodlighting. In the first figure, the top part of the building looks very calm – the illumination is very uniform. When the angle of direction is changed to 10°, much higher values of luminance on the characteristic vertical elements are achieved. A floodlighting concept of uniform illumination and general uniformity of luminance distribution is transformed instead into a concept of accented lighting.

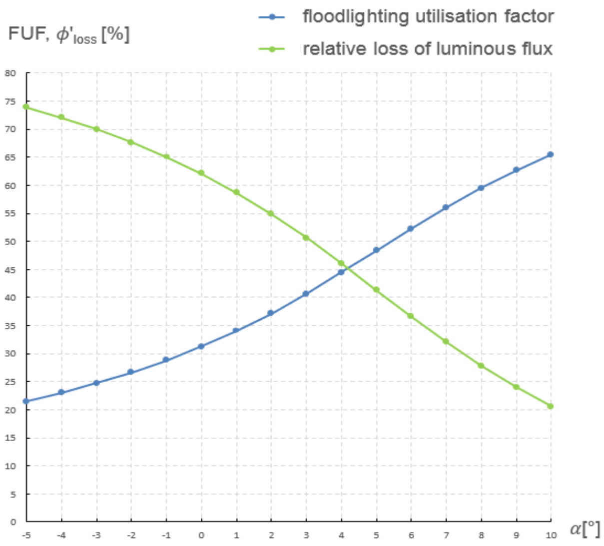

Fig. 7. Relation of floodlighting utilisation factor and relative loss of luminous flux due to angle of direction.

When designing a floodlighting scheme and optimizing it with regard to the issues of the energy efficiency of lighting and light pollution, we have to remember not to change the initial floodlighting concept. The visual perception of the effect of illumination is very individual and subjective. There are none of the normative requirements which can usually be used to decide whether a project is good or bad. Contemporary literature and technical reports present general recommendations only. The matter of assessment should be obligatory and should always be in the mind of the lighting designer. In the opinion of the author of this work, changing the angle of direction to 5° or even 10° for the concept of floodlighting of the Old Boiler Room is permissible and indicated. The floodlighting utilisation factor is twice that which was achieved in the basic case and the visual effect achieved is more interesting.

Conclusion

This work presents a first attempt at controlling the utilization factor and light pollution in the context of the floodlighting of objects. The new parameters of floodlighting utilisation factor and relative loss of luminous flux are defined and described precisely. It has been useful to make a preliminary assessment of these problems at the level of floodlighting design. Additionally, a new concept of the illumination of the Old Boiler Room building is shown. Accurate design information is also presented. This building is used as the subject of research and calculation. New parameters are calculated for different angles of direction of luminaries. Then, the results are carefully discussed. The work highlights that there is the possibility, as well as a strong need, to prepare some official, normative requirements in order to assess the design of floodlighting with regard to the energy efficiency of lighting and the phenomenon of light pollution.

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