

Lighting requirements for pedestrian crossings – positive contrast

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Abstract. For many years now in Poland there has been a large number of road accidents at pedestrian crossings during night periods [5, 11]. One of the technical solutions that can improve this condition is the use of proper lighting for pedestrian crossings. The designated pedestrian crossing should be visible in different weather conditions and at different times of the day. In case of night vision restrictions use artificial lighting of pedestrian crossings. At the same time, lighting of pedestrian crossings should ensure: proper conditions for the driver to recognise the traffic situation and observe the pedestrian's silhouette, and for the pedestrian to observe the surroundings, pedestrian crossings and upcoming vehicles. The article gives an opinion on the proposal of lighting requirements for dedicated luminaires, realizing positive luminance contrast, used in the area of pedestrian crossings together with the proposed measurement grids. Quantitative requirements have been formulated taking into account the gradation of lighting classes resulting from the current lighting standard.

1. Introduction

The ability of drivers to identify hazards and avoid collisions is hampered by poor road lighting. Although vehicle traffic is much lower at night than during the day, more than half of all fatalities are due to traffic accidents that occurred after dark. When lighting is installed on the road, the number of road accidents caused by drivers generally decreases on average by about 30 %, under the most favourable conditions by up to three times [6,9].

Lighting significantly improves the visibility of the road, increases the range of vision and makes obstacles more visible to road users earlier and more easily. It should be possible to see obstacles and other road users from a distance appropriate to the mobility dynamics of road users, so that behaviour (driving manoeuvres, pedestrian avoidance) can be adapted to avoid collisions [10].

Pedestrian crossings are elements of roads where there are conflicts between pedestrians and drivers [5, 11]. A safe pedestrian crossing requires a clear field of vision, which is particularly important at night. Every year, almost 1700 road users (12 % of the total) die or are seriously injured at pedestrian crossings, more than 50 % of them during night time [10,11].

In this respect, it is necessary to ensure adequate visibility at pedestrian crossings, especially at night-time reduced visibility. The use of artificial lighting for pedestrian crossings provides opportunities to improve pedestrian comfort and safety for pedestrians.

The primary functional requirement for pedestrian lighting is to provide pedestrian visibility at the gangway and in the waiting or access area. It should be noted that the object distinguished from its surroundings and well perceived by the driver must be pedestrian and not pedestrian crossing infrastructure [10,14,24].

Pedestrian lighting contributes to: reducing the risk of road accidents during periods of reduced visibility as a positive effect; on the other hand, increasing electricity consumption and lighting costs, as well as negative environmental impacts through increased CO₂ emissions, light pollution, interference with human [15] and animal life, etc. as negative impacts [23].

2. Pedestrian crossing lighting

In many countries, there are laws and formal regulations in place that indicate the requirements for pedestrian lighting. Some of them result directly from the recommendations of the International Commission on Illumination of the CIE [6], which is a non-governmental, self-financing organization of international cooperation and exchange of information on all matters related to light and lighting. In its publications (technical reports) it presents recommendations and guidelines concerning the rules and levels of lighting, as well as calculation procedures and methods of measurement.

Based on the CIE guidelines [6], reports are prepared by the European Committee for Standardization (CEN), including on road lighting (e.g. CEN/TR 13201-1 [3,15,18,19]). CEN members are the national standards

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bodies of the following countries: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom. As a result of the standardization process, uniform nomination provisions for road lighting are applied in these countries. Also in Poland, on the basis of the analyses presented in the report, formal requirements included in the standard of road lighting were developed [18,19]. By 2017, the International Commission on Illumination (IIC) of the CIE had not made explicit quantitative recommendations on the level of pedestrian lighting. Existing quality records are indirectly discussed in publications concerning road lighting [4,22,23,24]. The guidelines contained in CIE Publication 115 of 2010 [6], which is an update of the 1995 report, set out the most important recommendations concerning road lighting. The above publication [6] distinguishes three basic lighting categories, which influence the choice of lighting used for areas where pedestrian traffic may occur. These provisions are reflected in Polish standards [15,16].

Over the years, various standards have been in place in Poland [17,18,19], defining the principles and conditions of using road lighting and lighting used in the area of pedestrian crossings. These regulations defined general rules for the use of lighting solutions applied in conflict areas, which are considered to be pedestrian crossings. Currently, the issue of road lighting is regulated by the five-sheet European standard PN-EN 13201:2016 Road lighting [19]. The standard for the pedestrian crossing area does not specify lighting requirements, but only provides general guidance on the solutions to be used.

The current standard [19] indicates that there are two main lighting solutions for pedestrian crossings:

- the pedestrian's silhouette is observed by the driver in negative contrast (Fig. 1). Such a lighting situation is achieved by means of street lighting fixtures set in a standard configuration along the street line. This solution must produce a high level of illumination behind the pedestrian crossing in such a way that the pedestrian has a significantly lower luminance value than the illuminated roadway behind the pedestrian. The illuminated section of the road must therefore be long enough, but the standard does not indicate this.



Fig. 1. Negative contrast of pedestrian figure luminance.

- the pedestrian's silhouette is observed by the driver in positive contrast (Fig. 2). This lighting situation can be achieved by installing additional luminaires with asymmetrical light beam distribution dedicated to illuminate the pedestrian crossing area.



Fig. 2. Positive contrast of pedestrian figure luminance.

Some countries apply additional lighting requirements for pedestrian crossings, which operate in parallel with road lighting requirements and lighting standards. Separate regulations are applied by such countries as: Belgium [16], including Flanders [25], the Czech Republic [21], Norway [26], Germany [7,8], Sweden [12], Switzerland [20], Italy [13], the United Kingdom [3], the USA [1,4], Australia and New Zealand [2]. These regulations apply a differentiated approach in terms of detail and scope of requirements.

According to the available literature, the method of appropriate pedestrian crossing lighting has not been harmonised to date. Existing regulations generally point to an approach requiring a high level of contrast - positive or negative [10] (Fig. 3), with no contrast being the worst case. It is emphasized that pedestrians should be distinguished, mainly by the level of light intensity or the colour of light.

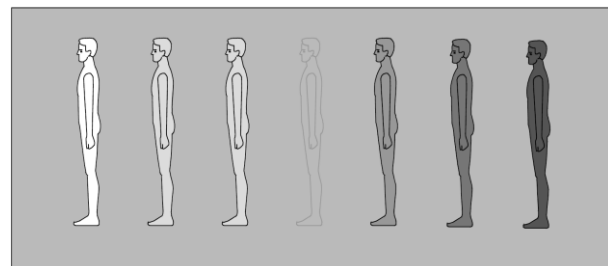


Fig. 3. Contrast of pedestrian figure luminance (positive on the left and negative on the right).

Positive contrast solutions are preferred, where pedestrian crossings are illuminated by dedicated luminaires with asymmetric light distribution. These luminaires have appropriate light distribution geometries, adapted to the location of the luminaire on the right (Fig. 4), left (Fig. 5) side of the road and directions of traffic.

Countries such as Germany [7,8], the Czech Republic [21], Australia and New Zealand [2] have introduced detailed requirements for dedicated solutions described

by the lighting intensity values (luminance of the road before and after the passage [7,8]).

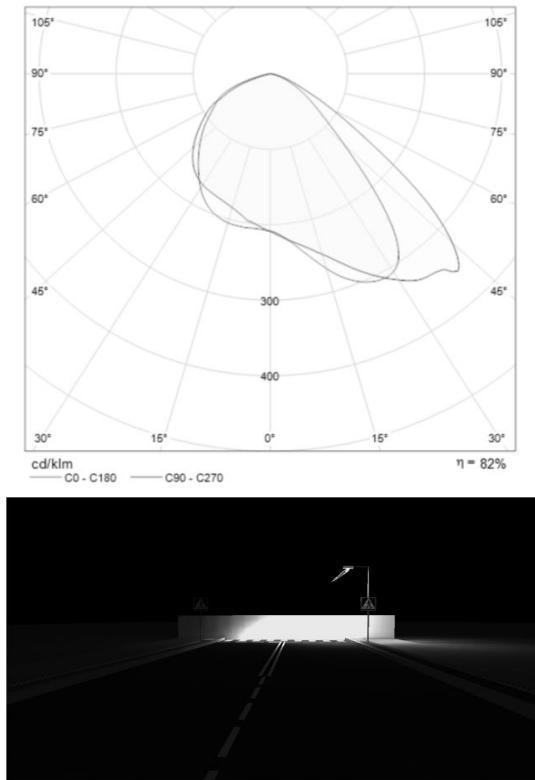


Fig. 4. Light body and visual effect obtained for asymmetrical luminaires with right optics.

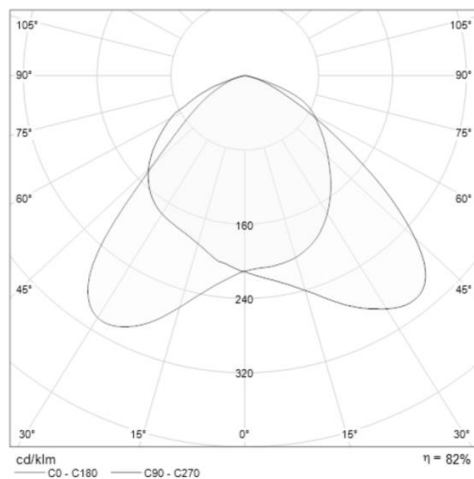


Fig. 5. Light body and visual effect obtained for asymmetrical luminaire with left optics.

And the precisely defined dimensions of the measurement grid ensure that the pedestrian crossing area is illuminated with the right lighting geometry. The introduction and maintenance of appropriate measurement grids at all stages of the investment project allows for the verification of the designed lighting solution at the stage of investment acceptance and for the systematic control of the installation at the stage of operation [10,24].

3. Determination of the class of road and pedestrian crossing lighting

To select a lighting solution and determine the lighting classes to be used in the pedestrian crossing area, an assessment of the lighting conditions in front of, behind and in the pedestrian crossing area should be made. The determination of the class of pedestrian crossing lighting includes: determining the class of lighting by means of analysis of the available design documentation and/or performing the necessary lighting measurements (luminance and/or luminous intensity) (Figure 6).

Dedicated pedestrian lighting is provided by luminaires with asymmetrical beam distribution.

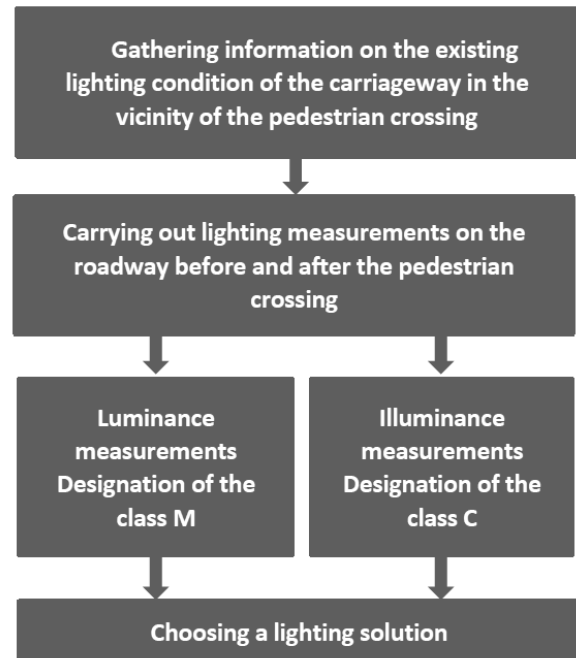


Fig. 6. The procedure for choosing a lighting solution.

The luminaires are installed before the pedestrian crossing, separately for each direction of traffic (Fig. 7).

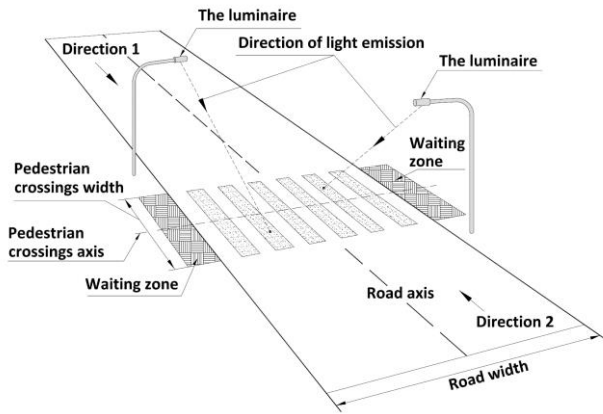


Fig. 7. Main directions of emission of dedicated luminaires.

The task of h luminaires is to create high luminous intensities on the pedestrian silhouette - a horizontal plane passing through the axis of the pedestrian crossing.

In order to determine the required level of illumination, the level (value) of luminance of the background at which it is observed from the driver's perspective should be determined on the pedestrian's silhouette passing through the pedestrian crossing (Figure 8).

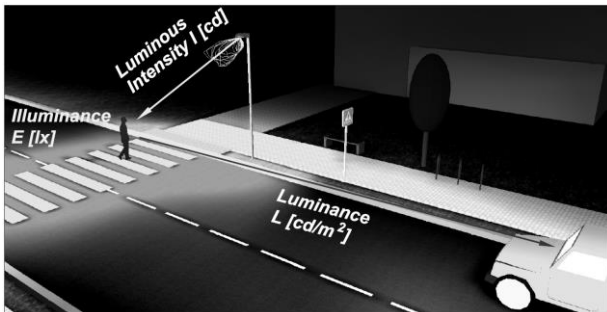


Fig. 8. Pedestrian observation from a driver's perspective.

The contrast between the luminance of a pedestrian's figure and the background (road) can be described by equation (1):

$$C = \frac{L_O - L_T}{L_T} \quad (1)$$

where :

- C – luminance contrast,
- L_O - luminance of an object (pedestrian silhouettes) [cd/m²],
- L_T – background (road) variation [cd/m²].

Taking into account the reflectance of the material in which pedestrians are dressed, the luminance of the pedestrian's silhouette L_O shall be given by the formula (2) :

$$L_O = \frac{\rho \cdot E_V}{\pi} \quad (2)$$

where:

E_V – vertical component of illumination - value of illumination at the pedestrian figure [lx],
 ρ – reflectance pedestrians clothing ($\rho = 0,2$ [1,4,22,23]).

One of the most important issues related to the possibility of pedestrian access by the driver is the parameter of the reflection coefficient of the matriculation in which the pedestrian is dressed. The value of $\rho = 0,2$, considered in the literature as representative, was assumed for the calculations [1,4,22,23] (Fig. 9).

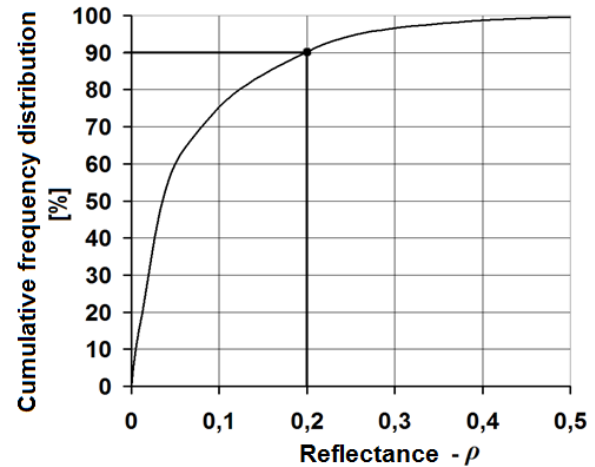


Fig. 9. The cumulative frequency of the reflectance of pedestrians clothing [4].

Therefore, the required value of E_V intensity on a pedestrian's figure will result from the relation:

$$E_V = \frac{((C \cdot L_T) + L_T) \cdot \pi}{\rho} \quad (3)$$

Background luminance L_T is the luminance of the road behind the pedestrian crossing, where the driver observes the figure of a pedestrian. Assuming a minimum contrast of luminance $C = 2$ [4, 22, 23], which meets the requirement to distinguish an object from the roadway, the required luminous intensity value on the pedestrian silhouette (in the vertical plane of the pedestrian crossing) for the individual levels in the road lighting classes can be calculated. It is justified to link the values of the luminous intensity in the vertical plane of a pedestrian crossing to the road lighting classes (Table 1). A higher level of light intensity should be distinguished for the pedestrian silhouette and the pedestrian crossing area. This draws the driver's attention.

Table 1. Required and accepted values of pedestrian luminous intensity - vertical plane.

Road lighting			Lighting in the vertical plane of the pedestrian crossing			
Values before and after pedestrian crossings			Required luminance of the object (pedestrian) on the road	Required pedestrian lighting intensity (vertical plane)	Accepted pedestrian lighting intensity (vertical plane)	
Class M	L_{AV}	Class C	$E_{AV}^{(1)}$	$L_{OV}^{(2)}$	$E_{VAV}^{(3)}$	E_{VAV}
	[cd/m^2] min		[lx] min	[cd/m^2] min	[lx]	[lx]
M1	2,00	C0	50	6,0	94,2	-
M2	1,50	C1	30	4,5	70,7	75
M3	1,00	C2	20	3,0	47,1	50
M4	0,75	C3	15	2,2	35,3	35
M5	0,50	C4	10	1,5	23,6	25
M6	0,30	C5	7,5	0,9	14,1	15

Assuming:

1. Class R4 road surface with parameters: $Q_0 \leq 0,05$ [$cdm^{-2}lx^{-1}$].
2. Luminance contrast $C = 2$.
3. Reflecting index of pedestrian clothing $\rho = 0,2$.

Therefore, it is possible to introduce new, dedicated only for pedestrian crossings, lighting classes (PCs) at pedestrian crossings. On the basis of international experience [2, 8, 21] and own research [14, 22, 23, 24], it was proposed to introduce new lighting classes described by lighting intensity parameters. It is recommended to use new lighting classes (Table 2) for each newly designed and modernized pedestrian crossing equipped with dedicated luminaires characterized by asymmetrical light distribution [10].

Table 2. PC lighting classes (for dedicated solutions) at pedestrian crossings.

Class PC	Pedestrian crossings lighting				
	Planes				Points A, B, C, D, E, F
	Vertical E_v		Horizontal E_h		
	E_{vAV}	U_{ov}	E_{hAV}	U_{oh}	E_{vmin} (A, B..)
[lx] (min)	[-] (min)	[lx] (min)	[-] (min)	[lx] (min)	
-	No need to use dedicated solutions				
PC1	75	0,35	75	0,4	5,0
PC2	50	0,35	50	0,4	4,0
PC3	35	0,35	35	0,4	4,0
PC4	25	0,35	25	0,4	3,0
PC5	15	0,35	15	0,4	2,0

The illumination values corresponding to the requirements of Table 2 refer to the measurement points located at the pedestrian crossing in the following planes: vertical (Figure 10) and horizontal (Figure 11) and control points (A, B, C, D, E, F).

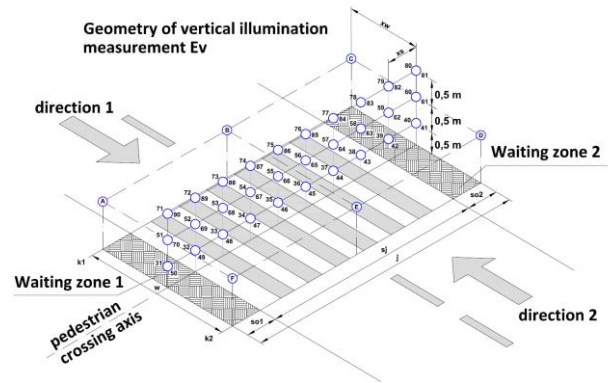


Fig. 10. Example of a grid for measuring vertical luminous intensities (E_v) at a pedestrian crossing [10].

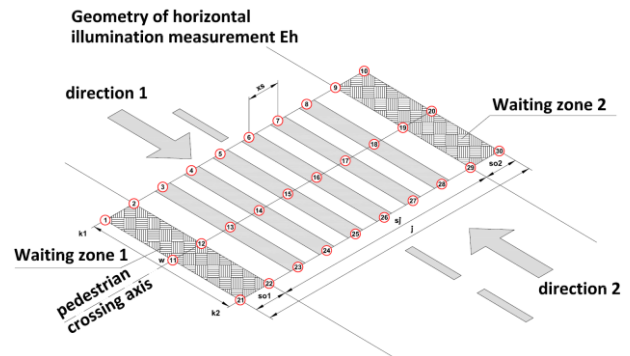


Fig. 11. Example of a grid for measuring the horizontal luminous intensity (E_h) at a pedestrian crossing [10].

Summary

Each of the applied solutions should perform the assumed lighting functions. This involves defining and applying formal requirements, rules for pedestrian lighting and the rational use of available solutions. Currently, there are a number of technical possibilities to illuminate the pedestrian crossing area (e.g. by means of street lighting luminaires) or to illuminate the pedestrian crossing area by means of dedicated solutions (luminaires with special lighting features - asymmetrical light beam distribution).

The proposed new lighting classes (PC) for dedicated lighting solutions at pedestrian crossings allow to ensure correct lighting conditions for the implementation of high contrast positive pedestrian silhouette observed from the driver's perspective. This is due to the consideration of the quantitative luminance requirements assumed in the road lighting class [19] and the reflectance of the pedestrian's clothing material [4,21,22,23].

The introduction of lighting requirements in the area of pedestrian crossings, in particular for dedicated solutions, requires the validation of the results of the designed installation at the stage of investment acceptance. On the other hand, at the stage of operation it is possible to carry out systematic supervision over the condition of the lighting system and, on this basis, to carry out the necessary maintenance measures necessary

to maintain the lighting parameters at the pedestrian crossing.

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References

1. ANSI-IESNA RP-8-00 (R2005) Roadway Lighting, USA (2005).
2. AS/NZS 1158.4:2009 Lighting for roads and public spaces. Lighting of pedestrian crossings, Australia (2009).
3. BS EN 13201-2 2003 Road Lighting Part 2 Annex B, UK (2003).
4. Boyce P. R., Lighting for Driving. Roads, Vehicles, Signs, and Signals, *Taylor & Francis Group*, USA, (2009).
5. Budzynski M., Jamroz K., Mackun T., Pedestrian Safety in Road Traffic in Poland, *IOP Conference Series-Materials Science and Engineering*, Volume: **245**, Article Number: UNSP 042064 DOI: 10.1088/1757-899X/245/4/042064, (2017).
6. CIE Technical Report, no. 115–2010, Recommendations for the Lighting of Roads for Motor and Pedestrian Traffic, (2010).
7. DIN 67523-2 1988-04 Beleuchtung von Fußgängerüberwegen (Zeichen 293 StVO) mit Zusatzbeleuchtung, Germany (1988).
8. DIN 67523-2 2010-06 Beleuchtung von Fußgängerüberwegen (Zeichen 293 StVO) mit Zusatzbeleuchtung, Germany (2010).
9. Fors C., Carlson A.: Revision of criteria for selection of road lighting class. A pre-study. VTI rapport 882A/2013.
10. Jamroz K., Tomczuk P., Mackun T., Kornalewski L., Chrzanowicz M. i inni: Wytyczne organizacji bezpiecznego ruchu pieszych. Wytyczne prawidłowego oświetlenia przejść dla pieszych. FRIL, PWWT, PG, IBDiM, Gdańsk (2017) <https://www.gov.pl/web/infrastruktura/wytyczne-organizacji-bezpiecznego-ruchu-pieszch-wytyczne-prawidlowego-oswietlenia-przejsc-dla-pieszch>
11. Jamroz K., Żukowska J., Michalski L.: Wyzwania i kierunki działań na rzecz bezpieczeństwa ruchu drogowego w Polsce w nadchodzącej dekadzie. XII Międzynarodowa Konferencja Bezpieczeństwa Ruchu Drogowego GAMBIT 2018, Gdańsk.
12. Krav for Vägars och gators utformning - Requirements for road and street design, Sweden (2012).
13. Linee guida per la progettazione degli attraversamenti pedonali, Automobile Club D'Italia, Italia (2011).
14. Mackun T., Tomczuk P., Artur R., Risk assessment methodologies for pedestrian crossings without traffic lights – Warsaw case study – pedestrian safety assessment, *MATEC Web of Conferences*, nr **122**, 2017, ss. 1-6, DOI:10.1051/mateconf/201712201004 (2017).
15. Niemierzycka A., Tomczuk K., Mikicin M., Adrodowska A., Orzechowski G., Kowalczyk M., Examinations of the methods used to power supply of different light sources and their effect on bioelectrical brain activity, *Neurologia i Neurochirurgia Polska*, DOI: 10.1016/j.pjnns.2018.02.007, (2018).
16. NBN L 18-002, Recommendations for special cases of public lighting, Belgium (1988).
17. PN-76/E-02032: Oświetlenie dróg publicznych. Poland (1976).
18. PN-EN 13201:2007, Oświetlenie dróg.
19. PN-EN 13201:2016 Oświetlenie dróg Część 1-5, CEN/TR, 1.Wytyczne dotyczące wyboru klas oświetlenia, 2.Wymagania eksploatacyjne, 3.Obliczenia parametrów oświetleniowych, 4.Metody pomiaru efektywności oświetlenia, 5.Wskaźniki efektywności energetycznej, (2016).
20. SLG Guideline (Schweizer Licht Gesellschaft) SLG 202-2016, Switzerland (2016).
21. Technické Kvalitativní podmínky stavěb pozemních komunikací, Kapitola 15.2: Osvetlení pozemních komunikací, *Ministerstvo dopravy Odbor pozemních komunikací*, pp. 1–24, Czech (2015).
22. Tomczuk P., Assessment model of luminance contrast of pedestrian figure against background on pedestrian crossing, *Przegląd Elektrotechniczny*, R. **88**, nr 3a pp. 104–107 (2012).
23. Tomczuk P., Modelowanie, badania eksperymentalne i ocena jakości oświetlenia sylwetki pieszego na przejściu dla pieszych, *Z. 91 Oficyna Wydawnicza Politechniki Warszawskiej*, Prace Naukowe PW, (2013).
24. Tomczuk P., Chrzanowicz M., Mackun T., Methodology for assessing the lighting of pedestrian crossings based on light intensity parameters, *MATEC Web of Conferences*, nr **122**, 2017, ss. 1-6, DOI:10.1051/mateconf/201712201008, (2017).
25. Vademecum voetgangersvoorzieningen. Ontwerprichtlijnen voor voetgangersvoorzieningen, *Ministerie van de Vlaamse Gemeenschap*, Flandria (2002).
26. Veg-og gateutforming Håndbok N100, Vegdirektoratet. p. 179, Norway (2014).