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Analysis of the impact of road luminaire installation accuracy on lighting conditions

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Abstract. The article presents selected results of research on the accuracy of positioning road lighting luminaires at the assembly stage, in terms of inclination angles relative to the road. In recent years, there has been a massive modernization of existing street lighting installations, involving the replacement of discharge luminaires with modern LED luminaires. Often, the work is limited to replacing the luminaires on existing lighting poles. Based on the obtained results, an analysis was conducted of the variability of lighting parameters, such as luminance and uniformity. Luminaires with various characteristic light distribution types used for road lighting were analyzed. Based on the obtained results, the significance of deviations from the required lighting parameter values and their impact on road lighting conditions was assessed.

1 Introduction

Road lighting should ensure safe traffic conditions at night by, among other things, increasing drivers' ability to quickly notice pedestrians moving on the sidewalk within the road or crossing pedestrian crossings, which depends on many factors (luminance contrast, object color, vehicle and pedestrian speed, individual visual characteristics) [1-5].

In recent years, there has been a massive modernization of existing street lighting installations, involving the replacement of discharge luminaires with modern LED luminaires. Often, especially in less urbanized areas, work is limited to replacing luminaires on existing lighting poles, where street lighting luminaires can serve as simple illumination or disrupt the operation of such installations. [6-7]. This is closely linked to reducing investment costs, especially important for smaller local governments. When planning street lighting modernization and its potential use for illumination, many factors must be considered [8-9].

In many cases, overhead power line poles are used for road lighting (Figure 1), which are often located at a greater distance from the road being illuminated, and this distance is often not constant. In such a situation, replacing luminaires can pose certain problems related to the improper adjustment of the luminaire's distribution to its location relative to the road being illuminated. Another aspect may be inaccurate installation of the luminaires, involving an accidental change of the luminaire inclination angle or its adjustment "by eye" in order to compensate for the effect of different distances of the luminaire from the road, resulting, for example, from the use of booms of different lengths, despite the same distance of the pole from the edge of the road, as shown in Figure 2.

Fig. 1. Example of installing street lighting luminaires on power line poles.

(a) (b)

Fig. 2. Example of installing street lighting luminaires on power line poles – use of different booms and inclination angles for the same pole–road distance.

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The article presents selected research results related to the influence of the accuracy of positioning road lighting luminaires, with particular emphasis on the plane transverse to the road axis (distance, height and angle of inclination), on selected lighting parameters. [10].

2 Research methodology

The analysis of selected lighting parameters was performed using Dialux software [11], using the model presented in Figure 3.

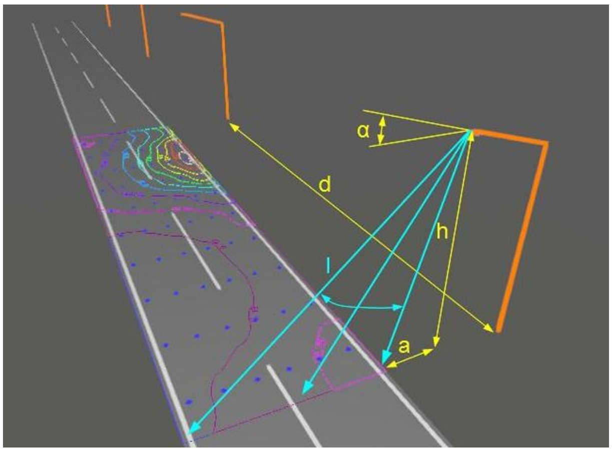
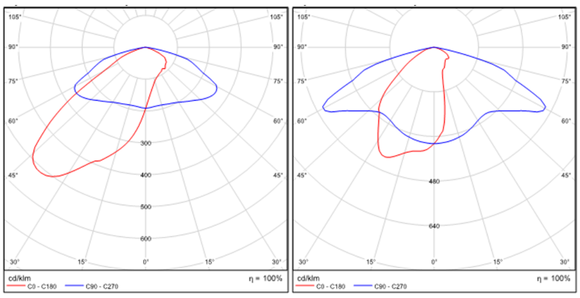


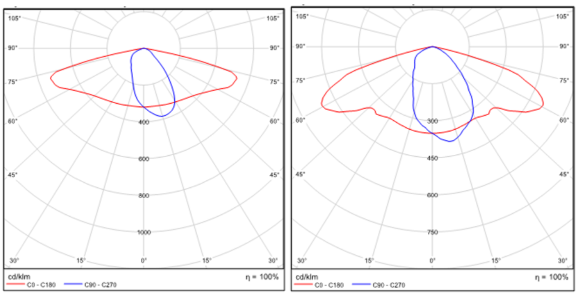
Fig. 3. Simulation model and variables used to calculate road lighting parameters.

Simulation calculations were performed for lighting variants including the use of lighting fixtures [12] with different light distribution *I* (mainly in the transverse plane), for different distances of the luminaire from the road *a*, as a function of the mounting height *h* and the inclination of the luminaire-boom α.

During the study, a series of simulations were performed and the average luminance and uniformity were determined. The calculations assumed lighting class M6, a pole spacing (*d*) of 30 m, a range of luminaire-to-roadway distance (*a*) from 0 to 4 m, pole height (*h*) from 7 to 9 m, and boom inclination (α) from 0 to 15°. Lighting class M6 was chosen due to the type and nature of the road (local road with low speed limit and low traffic intensity). The calculations took into account a road surface with a medium-rough structure, characterized by CIE R3 class. The used luminaires had a power of 102 W, with the luminous intensity distribution curves shown in Figure 4.



(a) (b)



(c) (d)

Fig. 4. Luminous intensity distribution curves of the luminaires used in simulation calculations: distribution R1 (a), R2 (b), R3 (c), R4 (d).

3 Analysis of the results

Selected calculation results of the average luminance L_m and the overall uniformity U_o for the analyzed luminaires as a function of the luminaire inclination, for different distances from the road and a suspension height of 7 m are presented in Figures 5-12. For the assumed lighting class M6, the required minimum values of luminance and general uniformity are respectively L_m=0,3 cd/m^2 and U_o=0,35. They constitute the basic criterion for assessing lighting and a reference point when comparing the results of the analysis of different luminaire variants and layouts.

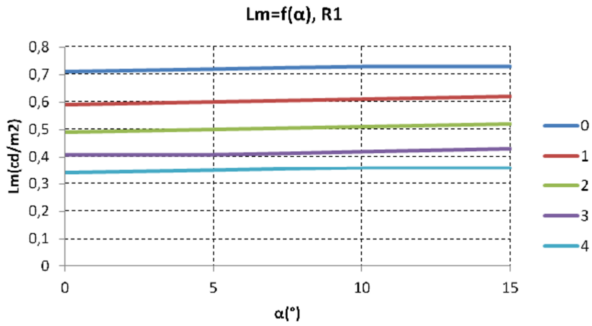


Fig. 5. Characteristics of the dependence of the road luminance on the luminaire inclination, at different luminaire distances R1.

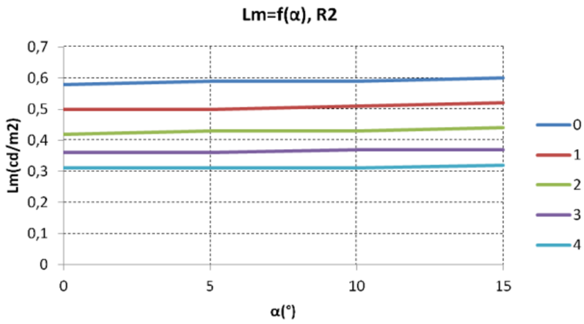


Fig. 6. Characteristics of the dependence of the road luminance on the luminaire inclination, at different luminaire distances R2.

The calculation results indicate that for R1 and R2 luminaires, the average luminance for a given distance is only slightly dependent on the slope and decreases with increasing distance from the road. The obtained values are within the required range for class M6, with the R2 luminaire and the longest distance meeting the requirements to a minimal extent.

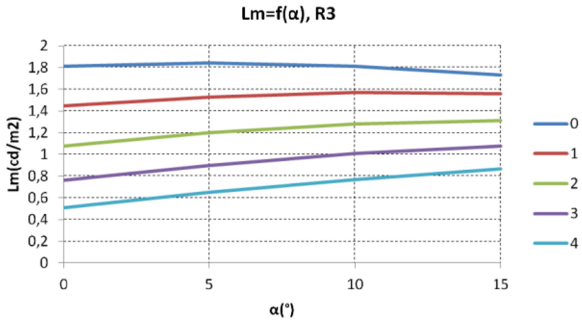


Fig. 7. Characteristics of the dependence of the road luminance on the luminaire inclination, at different luminaire distances R3.

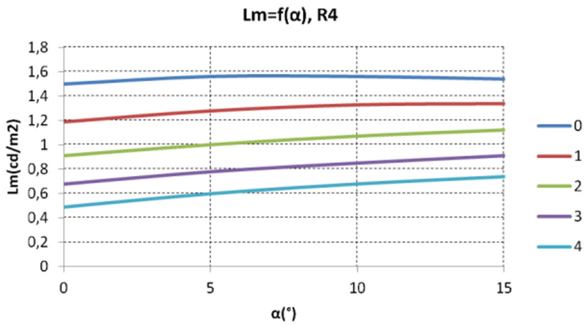


Fig. 8. Characteristics of the dependence of the road luminance on the luminaire inclination, at different luminaire distances R4.

For R3 and R4 luminaires, the luminance changes more significantly, increasing with increasing tilt angle at distances of 1 to 4 m. The effect of distance on luminance change is significant. At the minimum distance, a slight increase in luminance values can be observed for medium tilt angles. Furthermore, the luminance values achieved are significantly higher than for the R1 and R2 distribution variants (above the required levels for class M6). The exact luminance values are listed in Table 1.

Table 1. Luminance values for the analyzed variants of luminaire arrangement and distribution.

		R1	**R2**	**R3**	**R4**
a	**α**	**L_m ($L_{m\ min} \geq 0,3$)**			
[m]	**[°]**	**[cd/m^2]**			
0	0	0,71	0,58	1,81	1,5
0	5	0,72	0,59	1,84	1,56
0	10	0,73	0,59	1,81	1,56
0	15	0,73	0,6	1,73	1,54
1	0	0,59	0,5	1,45	1,19
1	5	0,6	0,5	1,53	1,28
1	10	0,61	0,51	1,57	1,33
1	15	0,62	0,52	1,56	1,34
2	0	0,49	0,42	1,08	0,91
2	5	0,5	0,43	1,2	1
2	10	0,51	0,43	1,28	1,07
2	15	0,52	0,44	1,31	1,12
3	0	0,41	0,36	0,76	0,68
3	5	0,41	0,36	0,9	0,78
3	10	0,42	0,37	1,01	0,85
3	15	0,43	0,37	1,08	0,91
4	0	0,34	0,31	0,51	0,49
4	5	0,35	0,31	0,65	0,6
4	10	0,36	0,31	0,77	0,68
4	15	0,36	0,32	0,87	0,74

The next step was to analyze the overall uniformity as a function of luminaire inclination. The results obtained for luminaire variants R1-R4 are presented in Figures 9-12.

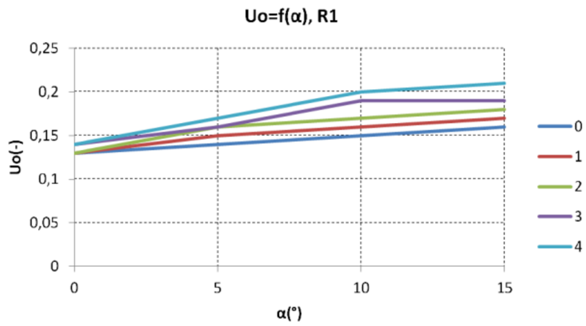


Fig. 9. Characteristics of the dependence of the overall uniformity on the luminaire inclination, at different distances, luminaire R1.

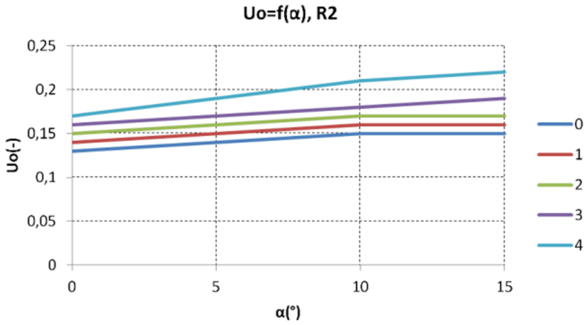


Fig. 10. Characteristics of the dependence of the overall uniformity on the luminaire inclination, at different distances, luminaire R2.

The uniformity analysis shows that its values increase with increasing distance and inclination angle. For R1 and R2 luminaires, the highest uniformity values are obtained at greater distances. For R3 and R4 luminaires, the situation is reversed; for the smallest distances, uniformity is higher, and the relationship between uniformity and inclination is stronger, so increasing the inclination angle has a greater impact on uniformity than for R1 and R2 luminaires. Regardless of the trend, not all variants meet the uniformity requirements for class M6. The required overall uniformity values are only achieved at the largest inclination angles for R3 and R4 luminaires. The exact uniformity values are listed in Table 2 (values lower than required for class M6 are marked in red).

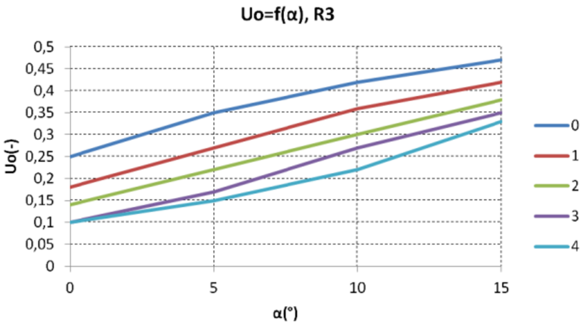


Fig. 11. Characteristics of the dependence of the overall uniformity on the luminaire inclination, at different distances, luminaire R3.

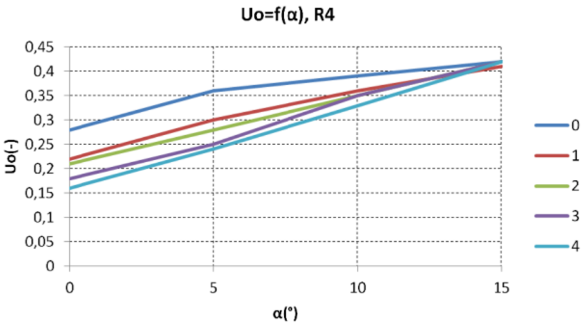


Fig. 12. Characteristics of the dependence of the overall uniformity on the luminaire inclination, at different distances, luminaire R4.

Table 2. Overall uniformity values for the analyzed variants of luminaire arrangement and distribution.

		R1	R2	R3	R4
a	α	U_o ($U_{o\ min} \geq 0{,}35$)			
[m]	[°]	[-]			
0	0	0,13	0,13	0,25	0,28
0	5	0,14	0,14	0,35	0,36
0	10	0,15	0,15	0,42	0,39
0	15	0,16	0,15	0,47	0,42
1	0	0,13	0,14	0,18	0,22
1	5	0,15	0,15	0,27	0,3
1	10	0,16	0,16	0,36	0,36
1	15	0,17	0,16	0,42	0,41
2	0	0,13	0,15	0,14	0,21
2	5	0,16	0,16	0,22	0,28
2	10	0,17	0,17	0,3	0,35
2	15	0,18	0,17	0,38	0,42
3	0	0,14	0,16	0,1	0,18
3	5	0,16	0,17	0,17	0,25
3	10	0,19	0,18	0,27	0,35
3	15	0,19	0,19	0,35	0,42
4	0	0,14	0,17	0,1	0,16
4	5	0,17	0,19	0,15	0,24
4	10	0,2	0,21	0,22	0,33
4	15	0,21	0,22	0,33	0,42

Figures 13-16 present the results of calculations of the average luminance as a function of the suspension height for various luminaires and two extreme variants of the luminaire inclination and distance from the road.

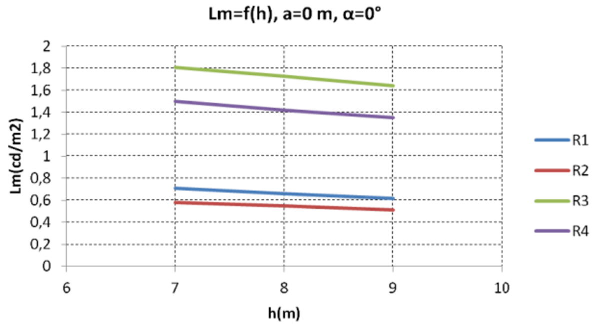


Fig. 13. Characteristics of the dependence of the road luminance on the mounting height of the luminaire for an inclination of 0° and a distance of 0 m.

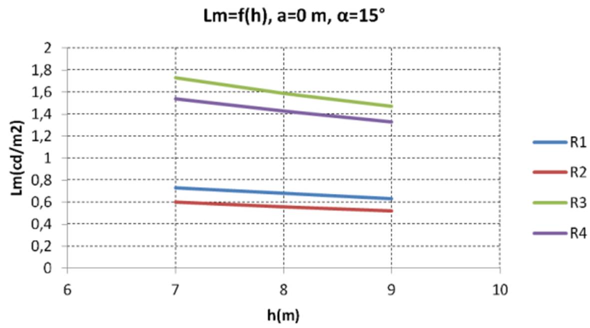


Fig. 14. Characteristics of the dependence of the road luminance on the mounting height of the luminaire for an inclination of 15° and a distance of 0 m.

When the luminaire is close to the road, the average luminance decreases with increasing height. In the second case, with a large distance between the luminaires, the average luminance for luminaires R1 and R2 remains constant, while for R3 and R4 it increases with increasing height. The required luminance levels for class M6 are maintained. The exact luminance values are listed in Table 3.

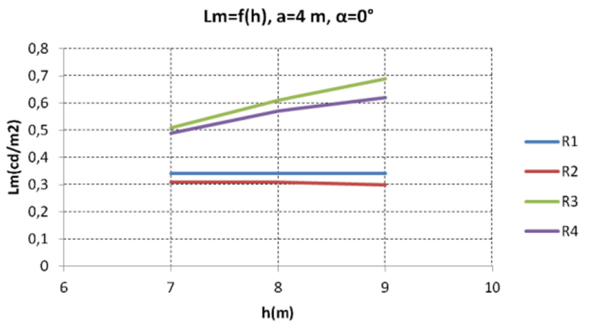


Fig. 15. Characteristics of the dependence of the road luminance on the mounting height of the luminaire for an inclination of 0° and a distance of 4 m.

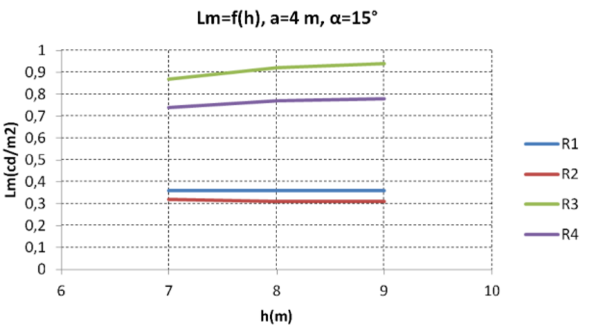


Fig. 16. Characteristics of the dependence of the road luminance on the mounting height of the luminaire for an inclination of 15° and a distance of 4 m.

Table 3. Luminance values for the analyzed variants of luminaire arrangement and distribution.

	h	[m]	7	8	9
	a	α	L_m ($L_{m\ min} \geq 0{,}3$)		
	[m]	[°]	[cd/m²]		
R1	0	0	0,71	0,66	0,62
	0	15	0,73	0,68	0,63
	4	0	0,34	0,34	0,34
	4	15	0,36	0,36	0,36
R2	0	0	0,58	0,55	0,51
	0	15	0,31	0,31	0,3
	4	0	0,6	0,56	0,52
	4	15	0,32	0,31	0,31
R3	0	0	1,81	1,73	1,64
	4	0	0,51	0,61	0,69
	0	15	1,73	1,59	1,47
	4	15	0,87	0,92	0,94
R4	0	0	1,5	1,42	1,35
	4	0	0,49	0,57	0,62
	0	15	1,54	1,43	1,33
	4	15	0,74	0,77	0,78

Figures 17-20 show the results of calculations of general uniformity as a function of suspension height for various luminaires and two extreme variants of luminaire inclination and distance from the road. The exact uniformity values are listed in Table 4 (values lower than required for class M6 are marked in red).

In all cases, the uniformity values increase with increasing luminaire suspension height.

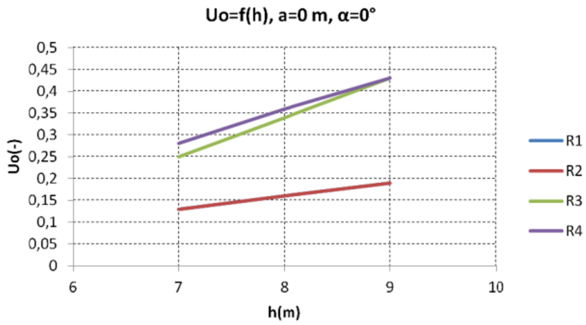


Fig. 17. Characteristics of the dependence of uniformity on the mounting height of the luminaire for an inclination of 0° and a distance of 0 m.

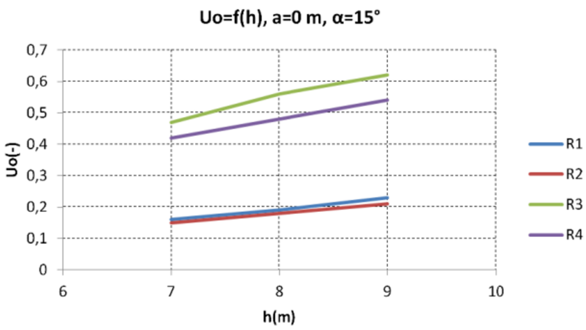


Fig. 18. Characteristics of the dependence of uniformity on the mounting height of the luminaire for an inclination of 15° and a distance of 0 m.

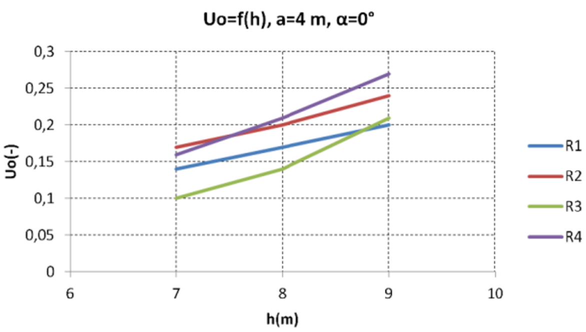


Fig. 19. Characteristics of the dependence of uniformity on the mounting height of the luminaire for an inclination of 0° and a distance of 4 m.

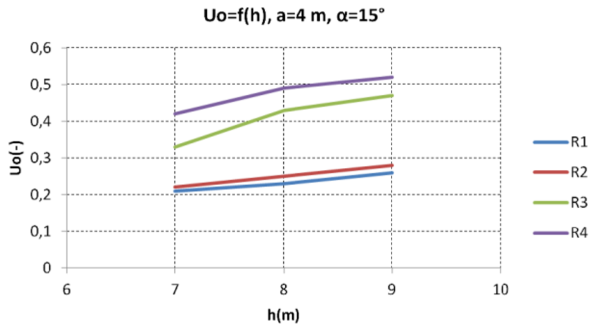


Fig. 20. Characteristics of the dependence of uniformity on the mounting height of the luminaire for an inclination of 15° and a distance of 4 m.

Table 4. Overall uniformity values for the analyzed variants of luminaire arrangement and distribution.

	h	[m]	7	8	9
	a	α	U_o ($U_{o\,min} \geq 0{,}35$)		
	[m]	[°]	[-]		
R1	0	0	0,13	0,16	0,19
	0	15	0,16	0,19	0,23
	4	0	0,14	0,17	0,2
	4	15	0,21	0,23	0,26
R2	0	0	0,13	0,16	0,19
	0	15	0,17	0,2	0,24
	4	0	0,15	0,18	0,21
	4	15	0,22	0,25	0,28
R3	0	0	0,25	0,34	0,43
	4	0	0,1	0,14	0,21
	0	15	0,47	0,56	0,62
	4	15	0,33	0,43	0,47
R4	0	0	0,28	0,36	0,43
	4	0	0,16	0,21	0,27
	0	15	0,42	0,48	0,54
	4	15	0,42	0,49	0,52

The achieved luminance and uniformity levels depend on the luminaire's distribution. For the variants with R1 and R2 luminaires, the required uniformity values were not achieved. For R3 and R4 luminaires, and for the small distance and inclination angle at the lowest height, the required uniformity was not achieved, while at the maximum inclination and distance for the R3 luminaire, the uniformity was slightly less than required. However, for the large distance and small inclination, the required uniformity was not achieved in any case.

4 Conclusion

Depending on the luminaire's distribution and height, distance, and inclination configuration, imprecise installation can result in significant luminance and uniformity values diverging from the planned values, resulting in poor lighting conditions and energy efficiency. Among the many available street lighting luminaire distribution variants, some are more or less sensitive to deviations in the inclination angle or mounting distance under specific conditions. This is important because typical mounting brackets used in luminaires feature stepless inclination angle adjustment in 5° increments. The presented analysis results include examples where a 5° deviation (which may be the result of imprecise installation) from the intended angle can result in divergent results, leading to parameter values (e.g., uniformity) falling below the required levels.

Proper design and luminaire selection in terms of power, distribution, and positioning for the lighting situation are essential, but equally important is proper installation, which includes proper light direction. Despite proper design procedures during the implementation phase, installation errors or inaccuracies may result in significant deviations from the planned luminance and uniformity values. Another potential problem may be increased glare.

In summary, the issue is complex and requires more extensive research and analysis, but the problem can occur. Therefore, it seems worthwhile to develop a solution that supports correct luminaire positioning during installation, especially when modernizing existing lighting installations. This solution would allow for the correct angle of inclination relative to the illuminated road surface, depending on the luminaire's distribution characteristics.

The article was realized within the framework of the internship of Marcin Leśko, realized at the Faculty of Electrical Engineering and Informatics of the Technical University in Kosice from 1 August 2025 to 31 August 2025. The internship concerned scientific cooperation in the following areas: energy efficiency of lighting systems, modeling and construction of light-optical systems, street lighting, lighting control systems.

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