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The Importance of Optimal Design in Outdoor Light Source Positioning

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In this work we underline the importance of the optimal design for outdoor light systems such that light posts and sources are placed correctly. We present a case study where we considered a city road section equipped with LED sources. On this section, we measured technical luminous coefficients, which were then compared with values listed in standard and normative documentation. Based on this we did a new design that had to follow certain requirements on street and lighting post configuration. Comparing the two designs we conclude that, to have an optimal street light system, the engineer must aim for the best possible design and consider this when deciding on the position of the light sources.

Keywords: *LED sources, optimization, design, technical luminous factors.*

1. Introduction.

In 2012, within the European Union, it was decided that electrical efficiency must be increased by high efficiency electric equipment purchases and by a reduction in electricity consumption [1], [2]. Worldwide, light sources use 19% of the total electricity consumption [3].

To reduce the energy consumption of light systems using low efficiency light sources, more and more towns and cities have replaced the light sources with higher efficiency ones. However, in the large majority of cases, the light sources were replaced without any measurements of the luminous parameter values before and after the replacement.

In several cases, the light systems' layout does not follow the project design (light source positions, mounting height, pole arm length, pole arm angle, etc.), or the lighting system is not optimised to the particularities of the surface to be illuminated, deviating from the European outdoor lighting standards and norms [4], [5].

According to the Operation C competition requirements (Street Lighting area) of the Priority Axis 3-3.1 (Supporting energy efficiency and intelligent management of the energy consumption from renewable energies for public infrastructure, including public buildings and homes, of the Regional Operational Program 2014-2020) photometric measurements are required before and after light source replacement [6].

In relation to street lighting, the current trend towards smart cities aims to:

- Contribute to higher energy efficiency at the same time with implementing the luminous coefficients provided in standards and norms;
- Reduce light pollution [7], [8];
- Ensure light conditions for pedestrian face recognition [9];
- Use monitoring and control systems based on sensor networks that communicate by wireless protocols [10].

In this work we present an analysis of a street sector where the street lighting system uses LED sources where we underline the importance of correct light pole placements. To this end we present the technical luminous coefficients obtained by the application of an optimal design.

2. Technical Lluminous measurements on a street sector using LED street light sources.

The geometrical characteristics of the street sector where we measured the lighting coefficients are:

- 1st side walk width – 2 m;
- Bike lane width – 1.25 m;
- Green area width – 1.56 m;
- 1nd road lane width – 7 m;
- Median lane width – 0.25 m;
- 2st road lane width – 3.35 m.;
- 2nd side walk width – 3.52 m.

The street lighting system layout on the analysed street section is as follows:

- Distance between poles – 36 m;
- Pole height – 13 m;
- Console length – 2.5 m;
- Number of luminaire per light pole – 1;
- Pole distance to the road surface (pole setback) – 1 m.

The light sources technical characteristics are:

- Maximal power - 127 W;
- Nominal luminous flux – 16,360 lm;
- Output luminous flux – 13,740 lm;
- Colour temperature – 4,000 K.

Figure 1 shows a representation of the road sector we analysed.

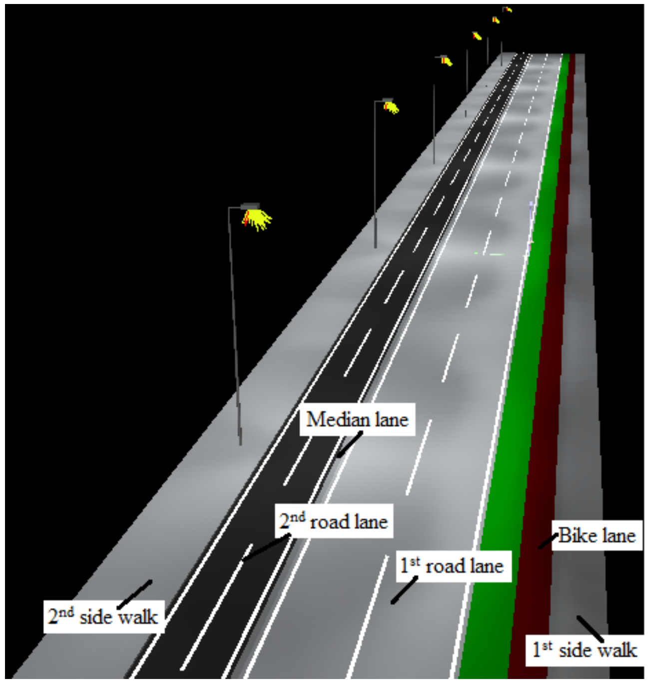

Figure 1. Graphical representation of the analysed road sector.

We made measurements between two consecutive light poles, during a moonless night, in dry conditions. On the road surface we analysed we fixed 60 uniformly distributed measurement points.

According to the current norms, the pedestrian illumination class is CE5, for bicycles is S5, and for roads is ME5.

Table 1 shows the measured illuminance for the 60 points. For the second road lane, these fall in the 10.4 – 40.9 lx range, with an average illuminance of 20.035 lx, while for the first road lane, the illuminance ranges from 11 lx and 40.3 lx, with a 12.925 lx average.

Using the equations defined in the literature [11], [12] and in the standards and norms [13], [14] we computed the general illumination uniformity for the 1st carriageway as:

$$U_{01}(E) = \frac{E_{\min}}{E_{med}} = \frac{10.5}{20.035} = 0.524, \tag{1}$$

and for the second carriageway as:

$$U_{02}(E) = \frac{E_{\min}}{E_{med}} = \frac{11}{21.925} = 0.502, \tag{2}$$

The illumination uniformity for the first carriageway is:

$$U'_{01}(E) = \frac{E_{\min}}{E_{\max}} = \frac{10.5}{40.9} = 0.256, \quad (3)$$

and for carriage 2 is:

$$U'_{02}(E) = \frac{E_{\min}}{E_{\max}} = \frac{11}{40.3} = 0.273, \quad (4)$$

Table 1. The measured illuminance for the 60 points

1st road lane	25.4	25.5	15.2	13.0	17.2	10.5	12.1	15.7	24.6	24.6
	40.9	23.8	17.0	13.5	19.5	13.4	11.0	14.5	25.2	38.1
2nd road lane	38.4	20.6	17.2	17.1	20.3	16.4	11.4	13.4	22.1	37.1
	35.6	19.8	17.8	25.2	19.3	19.4	17.6	13.8	22.5	35.3
	40.3	34.5	33.0	24.3	17.2	17.2	19.9	27.7	33.1	37.7
	19.9	15.6	13.6	13.0	12.0	11.3	11.2	11.0	20.4	23.8

Table 2 presents the luminance values measured for this road sector. For the second carriageway, these range from 0.36 cd/m^2 to 1.57 cd/m^2, with an average luminance of L_{med} = 0.803 cd/m^2. For the first carriageway the luminance values range from 0.37 cd/m^2 to 1.66 cd/m^2, with an average luminance of L_{med} = 0.799 cd/m^2.

Table 2. The luminance values measured for the 60 points

1st road lane	Obs. 4	1.42	1.07	0.6	0.51	0.66	0.61	0.44	0.58	1.04	1.36
	Obs. 3	1.49	0.84	0.58	0.41	0.65	0.42	0.36	0.49	0.96	1.57
2nd road lane	Obs. 2	1.60	0.84	0.73	0.64	0.65	0.47	0.37	0.48	1.66	1.49
		1.27	0.81	0.58	0.70	0.61	0.49	0.47	0.39	0.67	0.77
	Obs. 1	1.23	1.07	0.85	0.59	0.42	0.40	0.61	1.09	0.83	1.08
		1.34	1.01	0.66	0.61	0.62	0.51	0.57	0.52	1.15	1.14

The minimum, maximum, and average luminance values on the two lane axes for the first carriageway are:

- Observer 1: L_{min11} = 0.4 cd/m^2, L_{med11} = 0.817 cd/m^2, L_{max11} = 1.23 cd/m^2;
- Observer 2: L_{min12} = 0.37 cd/m^2, L_{med12} = 0.893 cd/m^2, L_{max12} = 1.6 cd/m^2.

For the second carriageway, the minimum, maximum, and average luminance values measured on the two lane axes are:

- Observer 3: L_{min23} = 0.44 cd/m^2, L_{med23} = 0.829 cd/m^2; L_{max23} = 1.42 cd/m^2;
- Observer 4: L_{min24} = 0.36 cd/m^2, L_{med24} = 0.777 cd/m^2, L_{max24} = 1.57 cd/m^2.

Using the equations defined in the literature [11], [12] and in the standards and norms [13], [14] we computed the general luminance uniformity for the first carriageway as:

$$U_{01}(L)=\frac{L_{\min}}{L_{med}}=\frac{0.37}{0.799}=0.463, \tag{5}$$

and for the second carriageway:

$$U_{02}(L)=\frac{L_{\min}}{L_{med}}=\frac{0.36}{0.803}=0.448, \tag{6}$$

The general and longitudinal luminance uniformity for the first road lane, first observer are:

$$U_{011}(L)=\frac{L_{\min 11}}{L_{med 11}}=\frac{0.4}{0.817}=0.489, \tag{7}$$

$$U_{111}(L)=\frac{L_{\min 11}}{L_{\max 11}}=\frac{0.4}{1.23}=0.325, \tag{8}$$

while for observer 2 these are:

$$U_{012}(L)=\frac{L_{\min 12}}{L_{med 12}}=\frac{0.37}{0.893}=0.414, \tag{9}$$

$$U_{112}(L)=\frac{L_{\min 12}}{L_{\max 12}}=\frac{0.37}{1.6}=0.231, \tag{10}$$

The general and longitudinal luminance uniformity on the second road lane, for the third observer, are:

$$U_{023}(L)=\frac{L_{\min 23}}{L_{med 23}}=\frac{0.44}{0.829}=0.530, \tag{11}$$

$$U_{123}(L)=\frac{L_{\min 23}}{L_{\max 23}}=\frac{0.44}{1.42}=0.829, \tag{12}$$

and for observer 4 these are:

$$U_{024}(L)=\frac{L_{\min 24}}{L_{med 24}}=\frac{0.36}{0.777}=0.463, \tag{13}$$

$$U_{124}(L)=\frac{L_{\min 24}}{L_{\max 24}}=\frac{0.36}{1.57}=0.777, \tag{14}$$

From these computations we see that for observers one and 2, the longitudinal luminance uniformities (8), (10) do not fall within the normed limit values for the illumination class ME5 (which requires that these values are higher than 0.4).

3. The optimal design of the lighting system

To realise an optimal design for the lighting system we analyse we used the DialLux software package where we chose the following optimisation variables (Figure 2):

- The height of the light point must be between 11 m and 15 m, with a 0.2 m search step;
- The light inclination angle must be between 0º and 15º, with a 2º search step;
- The light point console exit should be between -2 m and 2 m, with a 0.2 m search step.

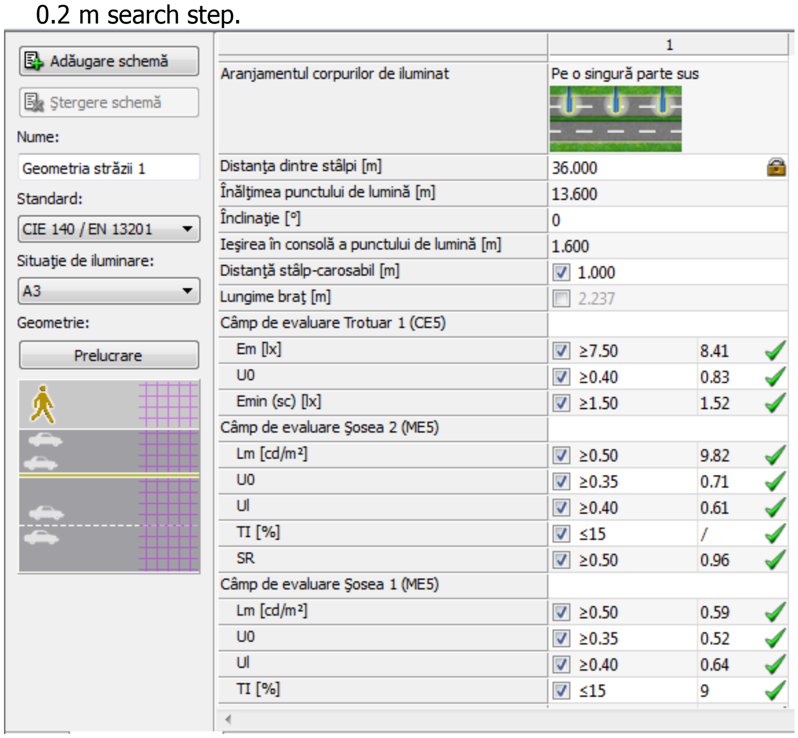

Figure 2. Optimisation results.

Since the light poles cannot be exchanged, in the optimisation process we had to maintain the current distance between them (36 m), the pole setback to the road surface (1 m). We slightly changed the light source types to agree with actual product catalogues. Thus, the maximum power is now 129 W, the exit luminous flux is 13,870 lm, and the colour temperature is 4,000 K.

Figure 2 presents the results of the optimisation process done with DialLux, where we took into account the sidewalk where the lighting posts are installed and the two road lanes. We obtained the following installation characteristics:

- The height of the light point – 13.6 m;
- The inclination angle – 0º;
- The light point console exit – 1.6 m;

Console length – 2.237 m.

Figure 3 shows the illumination iso-lines for the two carriageways, while Figure 4 shows the luminance iso-lines from observer 4 to observer 1.

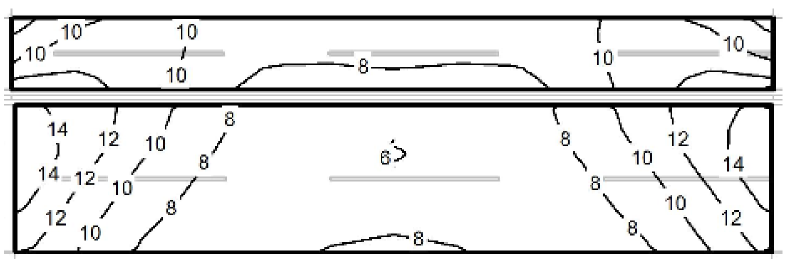

Figure 3. Illumination iso-lines.

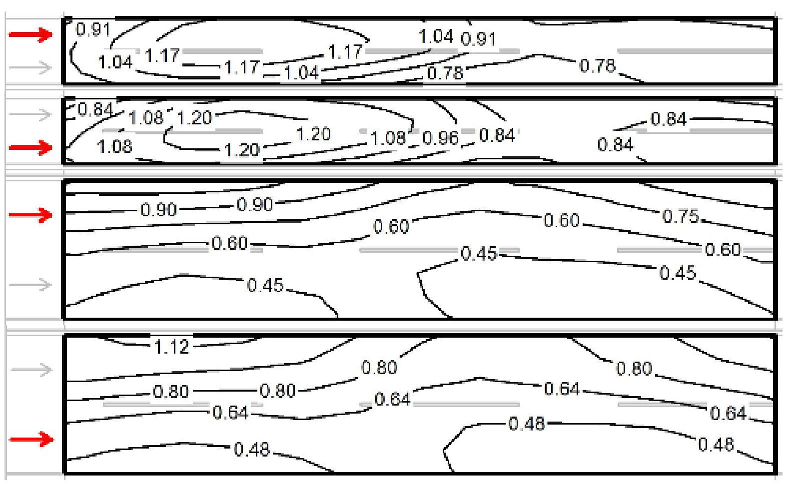

Figure 4. Luminance iso-lines.

4. Comparative analysis of the results

We compared the results obtained from measurements with those specified in standards and norms, and with the values obtained from the optimal design (see Table 3).

Table 3. The results obtained from measurements

Road	Technical luminous parameter	Measured	Design	Norm values
1	E_{min} [lx.]	11	5.9	
	E_{med} [lx.]	21.925	8.86	$\geq$ 10
	E_{max} [lx.]	40.3	15	
	$U_{01}(E)$	0.524	0.666	$\geq$ 0.4
	$U'_{01}(E)$	0.256	0.402	
	L_{med11} [cd./m^2]	0.817	0.67	$\geq$ 0.5
	L_{med12} [cd./m^2]	0.893	0.59	$\geq$ 0.5
	$U_{011}(L)$	0.489	0.52	$\geq$ 0.35
	$U_{111}(L)$	0.325	0.75	$\geq$ 0.4
	$U_{012}(L)$	0.414	0.55	$\geq$ 0.35
	$U_{112}(L)$	0.231	0.64	$\geq$ 0.4
2	E_{min} [lx.]	10.5	6.90	
	E_{med} [lx.]	20.035	9.61	$\geq$ 10
	E_{max} [lx.]	40.9	13	
	$U_{02}(E)$	0.502	0.718	$\geq$ 0.4
	$U'_{02}(E)$	0.273	0.543	
	L_{med23} [cd./m^2]	0.829	0.97	$\geq$ 0.5
	L_{med24} [cd./m^2]	0.777	0.97	$\geq$ 0.5
	$U_{023}(L)$	0.53	0.71	$\geq$ 0.35
	$U_{123}(L)$	0.829	0.59	$\geq$ 0.4
	$U_{024}(L)$	0.463	0.67	$\geq$ 0.35
	$U_{124}(L)$	0.77	0.62	$\geq$ 0.4

Analysing the results in Table 3 we note that, although the measured illuminances do respect the norms and standards, and are even higher than those resulted in the optimal design, the illuminance uniformities are much lower than those we obtained by the optimisation process. The same is valid for the luminance values, which are higher than the values obtained by the optimisation process, but the luminance uniformities in the optimal design are much better.

The average illuminance for all observers follow the standards and norms, but the longitudinal luminance uniformity measured for observers 1 and 2 does not follow the standards and norms, while for observers 3 and for, the uniformity is too high.

4. Conclusions.

The large margins between the minimal and maximal illumination values cause discomfort and induce a tiredness state to the traffic participants. To avoid these, it is recommended that the outdoor lighting systems have good uniformity. This cannot be achieved without field measurements done before and after the light sources are replaced.

The large differences in the luminance longitudinal uniformity measured for observers 1 and 2 compared to observers 3 and 4 indicates that the light sources are not positioned correctly. Their repositioning must be done in conformity with the results given by the optimisation process.

This analysis underlines the need to carry out and search for an optimal design, such that, when the installation follows the design as close as possible, the luminous technical parameters are best.

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