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Notes on LED Installations in Street Illumination

The paper presents a study made on choosing LED street lighting installations, such that the quality requirements for exterior artificial lighting are fulfilled. We analyze two types of LED street lighting installations from a technical point of view, together with lighting level and brightness values obtained during the measurements. Following on the field measurements, the lighting quality parameters are calculated, and, for the lighting installation with the best performance, optimal mounting suggestions are made. The optimal quality parameters are calculated by simulations using the Dialux software. The same software and the same light sources we also compute an optimal street lighting by determining the size of the installation that provides the best lighting parameter values.

Keywords: lighting level, lighting installation, brightness, optimization

1. Introduction

Safe and secure pedestrian and motorized traffic at night is drastically improved with an appropriate street lighting system.

This paper presents a case study on the choice of a LED lighting installation (LLI) and its proper installation, so that the best brightness parameter values are insured.

In choosing an LED lighting installation, end-users are especially interested in the luminous efficiency, which, in commercial technical specifications, is specified as lm /led, and not in lm/W. At the same time, less importance is given to the proper installation of an LLI, such that all functional and normative requirements (lighting uniformity, luminance uniformity) are fulfilled. Brightness and lighting parameter values which an LLI must respect are different for different streets and depend on various factors: traffic speed, average number of vehicles in one day, type of traffic participants, etc. These factors must be considered when designing a lighting installation.

This work examines two types of LLI, installed on an existing pole, from a technical, economical and lighting point of view. Based on field measurements and computations we establish which LLI performs best. Since we observed that the brightness parameters of the lighted surface do not follow the current regulations, we design another lighting installation by modifying the height of the LLI on the pole, the inclination angle of the LLI compared to the horizontal line, the support size, the console size. Since the DIALux software library does not include the LLI models analyzed by us, in this design we choose an LLI with the same luminous flux.

To optimize the lighting installation using the DIALux software we optimally designed an LLI by finding the optimal technical measurements for the assembly. The solution we propose gives the best lighting parameters on the specific street and LLI we looked at.

2. Lighting Indicators and Computing Elements of the Exterior Lighting Systems

Regulations in use [1], [2] provide quality indicators which must be enforced by any exterior lighting system (ELS). Quality indicators depend on various factors, like: the type of roadway, the road destination, the vehicle flow, and whether the pedestrian access routes are present or absent.

Due to their well-known advantages (higher luminous efficacy, small overall size, longer lifetime, better reliability), LED street lighting installations (LLI) are more and more used on the market [2], [3], [4], [5].

Choosing a particular type of LLI presumes prior computations to find the installation's luminous characteristics and to establish the quality indicators for the luminous area. The main parameters to compute for the luminous area of interest are the lighting, E, and the luminance, L. The differences between the two computation results, one based on E and one based on L, are significant. Using the luminance to compute the ELS parameters leads to more conclusive results, especially because the illumination distribution on the carriageway does not give satisfactory information due to the imperfect diffusion of the asphalt carpet which is highly dependent on the carpet's color and moisture [2,6].

In street lighting the most important luminous indicators are:

- The minimum, E_{min}, average, E_{med}, and maximum illumination, E_{max}, measured over the entire surface of interest. The values for the minimum and the maximum illuminations are determined by field measurements on the surface of interest. The averate illumination, E_{med}, can be found with the following relation:

$$E_{med} = \frac{\sum_{i=1}^{n} E_i}{n} \quad (1)$$

where n is the number of elementary surfaces in which the analyzed surface was divided, measurements being made in their centers, and E_i is the illumination measured at the centre of surface i;

- The general uniformity of the illumination, $U_0(E)$, given by:

$$U_0\left(E\right)=\frac{E_{\min}}{E_{\mathrm{m}ed}} \tag{2}$$

- The minimum, average, and maximum luminances, L_{min}, L_{med}, and L_{max}, over the entire surface of interest. The minimum and maximum luminance values on the analyzed area, along the axis of the traffic lane, $L_{min.1}$, and $L_{max.1}$, are determined by field measurements done on the analyzed surface. The average luminance, L_{med}, can be computed by:

$$L_{med}=\frac{\sum_{i=1}^{n} L_i}{n} \tag{3}$$

where n is the same as in relatino (1), and L_i is the luminance measured at the centre of the elementary surface i;

- The general luminance uniformity, $U_0(L)$, given by:

$$U_0\left(L\right)=\frac{L_{\min}}{L_{\mathrm{m}ed}} \tag{4}$$

- The longitudinal luminance uniformity, $U_1(L)$, along the traffic lane axis, in the travel direction of the area of interest, determined by the relation:

$$U_1\left(L\right)=\frac{L_{\min 1}}{L_{\max 1}} \tag{5}$$

- The threshold index, TI, which characterizes the estimation of the glare caused by the luminance of the light sources in the visual field, related to the average road luminance. For normal roads the threshold index, TI, is defined by [2], [6]:

$$\mathrm{TI}=65\frac{L_{\mathrm{voal}}}{L_{\mathrm{med}}^{0,8}}\ [\%] \tag{6}$$

and for tunnel roads:

$$\mathrm{TI}=95\frac{L_{\mathrm{voal}}}{L_{\mathrm{med}}^{1,05}}\ [\%] \tag{7}$$

where L_{voal} is the fog luminance, determined with the following empiric relation:

$$L_{\mathrm{voal}}=k\cdot\sum_{i=1}^{p}\frac{E_{\mathrm{i}}}{\theta_{\mathrm{i}}^{2}} \tag{8}$$

In relation (8): k is a coefficient that takes into consideration the observer’s age (commonly, k = 10); p is the number of disturbing sources in the visual field, 20º above the driver's sight axis (like other LIIs, billboards, etc.); E_i is the illumination on the eye's retina, in vertical plan on the sight axis, given by the disturbing source S_i, in the visual field; θ_i is the angle between the driver's sight direction and the direction where the disturbing source S_i is seen.

- The adjoined area report, SR, defined as the ratio between the average illumination on a 5 m wide stretch (or less if the space does not allow), on both sides of the road, E_{medt}, and the average illumination of the traffic road on a width of 5 m, or half the width of each movement direction (when the road is less than 5 m wide), E_{medc}:

$$SR = \frac{E_{medt}}{E_{medc}} \tag{9}$$

For each type of road, the minimum and/or maximum values of the mentioned indicators are standardized.

3. Comparative analysis and determination of quality indicators

We present in this section the technical characteristics of two types of LII as well as the luminous indicators determined by field measurements and computations. For the lighting installation to fulfill its functional role and to ensure a certain comfort to the traffic participants, the luminous indicators must fall into certain value ranges recommended by the technical standards and regulations.

We made the analysis on an area of 210 m^2, $35m \cdot 6m$, that has been divided into 21 elementary areas. The surface was illuminated at the two ends, consecutively, with two LIIs of the type:

- TGCS-LED-400-140W with 64 LEDs, 140W maximum power, a luminous flux of about 12000 lm, 150 x 820 x 420 mm, 9 kg heavy, 65 IP protection degree, accepted environmental temperature within (-40ºC ÷ 50ºC), color temperature within (4500 ÷ 6000K), color rendering index Ra > 70, power factor greater than 0.95, over 50,000 hours functioning time, insulation class 1, supply voltage (120 ÷ 270)V, 50/60 Hz;

- ST-100-36-WH-S with 36 LEDs, 100 W maximum power, a luminous flux of about 12000 lm, 80 x 360 x 248 mm, 4.9 kg, 66IP protection degree, accepted environmental temperature within (-40ºC ÷ 45ºC), color temperature within (4000K ÷ 5000K), color rendering index Ra > 70, minimum 50,000 hours functioning time, insulation class 1, supply voltage (90 ÷ 260)V, 50Hz, with the choice of changing the LLI inclination angle.

We acquired numerical data about illumination and luminance levels in the work plan. The acquisition was made during a moonless night, on a dry working plan (street). The two lighting installations mentioned above were placed successively on one pole placed at one end of the lighting surface, the distance between the surface and the lighting source was 8.158 m.

Using the measured data and relations (1-5), we computed the luminous indicators for each LLI. Table 1 shows the indicator's values for the two LLIs, where on the last table column we also show the limit values that the respective indicators should have, according to the current technical norms and regulations

Table 1.

Nr. crt.	Analyzed indicator	TGCS-LED-400-140W	ST-100-36-WH-S	Technical norms values
1.	Source brightness [cd/m^2]	5314	1430	-
2.	Power source [W]	140	100	-
3.	LII weight [kg]	9	4.9	-
4.	Minimum illumination E_{min} [lx]	4.2	5.1	-
5.	Maximum illumination E_{max} [lx]	33.8	50.6	-
6.	Average illumination E_{med} [lx]	18.238	22.654	-
7.	General illumination uniformity $U_0(E)$	0.23	0.335	Min. 0.4
8.	Illumination uniformity E_{min}/E_{max}	0.115	0.15	-
9.	Minimum luminance L_{min}[cd/m^2]	0.48	0.66	-
10.	Maximum luminance L_{max}[cd/m^2]	3.19	4.84	-
11.	Average luminance L_{med}[cd/m^2]	1.98	2.381	-
12.	Luminance uniformity $U_0(L)$	0.24	0.277	Min. 0.4
13.	Minimum luminance L_{min1}[cd/m^2]	0.5	0.72	-
14.	Maximum luminance L_{max1}[cd/m^2]	3.93	4.85	-
15.	Luminance uniformity $U_1(L)$	0.127	0.189	Min. 0.7

Analyzing the data in Table 1 we can draw the following conclusions:

- Each LLI examined gives a low general illumination uniformity, $U_0(E)$, and a low luminance uniformity, $U_0(L)$, the two values being below the 0.4 value recommended by the technical norms and regulations. At the same time, the luminance uniformity along the traffic lane axis, $U_1(L)$, are below the minimum value recommended by the technical norms and regulations. In this case we must establish a different LLI installation height such that the lighting parameters fall into the recommended value range.
- The ST-100-36-WH-S LLI presents better lighting indicators, with a brightness 3.72 times smaller than the other LLI, which leads to a smaller threshold index.
- With better lighting indicators, the ST-100-36-WH-S's source power represents only 71.43% from the TGCS-LED-400-140W's source power.

These findings have led us to conclude that between the two examined LLIs, ST-100-36-WH-S is better. Choosing this type of source brings further benefits:

- A 1.84 times lower weight which means an easier installation and maintenance;
- 28.57% lower electricity consumption, which for an LLI with a minimal life time of 50,000 hours translates to an economy of 2000 kWh;

- Higher illumination and luminance uniformities;
- The possibility to change the LLI's inclination angle, with positive impact on the uniformities.

In addition to these advantages the analyzed location must be optimized, that is we need to select the optimal values of the pole height, crutch length and inclination angle of the LA.

4. Design and Optimization of the Discussed Lighting System

Because the luminous indicators computed based on the field measurements do not comply to the normative requirements, the lightning system must be designed. We use the DIALux software package which assists in determining the technical characteristics of the LLI installation [7]. DIALux optimizes lightning systems depending on the pole height, crutch length and the inclination angle, until an optimal variant is reached.

Before optimizing the lighting of a traffic route using the DIALux software package it is necessary to first design the lighting system.

4.1. The Lighting System Design using DIALux. Obtained Results

The design of a lighting system is done specifically for a lighting system class that corresponds to the traffic way and to a concrete illumination type. The illumination type, or class, is determined depending on the traffic speed and on the type of traffic participants on the analyzed roadway [8]. The DIALux software can fix the lighting system's class, which is denoted with A1, A2, A3, B1, B2, C1, D1, D2, D3, D4, E1, E2. The lighting class, also called the road's class [9,10], is defined based on the type and number of crossings, number of vehicles in one day, presence of traffic participant conflict surfaces, the light pollution levels, etc. In this work we design the lighting system for a street on which the traffic is limited to 60 km/h, all traffic participants are allowed, crossings are simple ones, there is no conflict zone between traffic participants, the lighting pollution is within normal parameters, there are no vehicles parked on the side of the street, the road is dry, the daily number of vehicles is less than 7000, the degree of navigation difficulty is normal, and the ambiental lighting levels is low. In these conditions, DIALux can establish the lighting class, denoted by ME1, ME2, ME3a – ME3c, ME4a, ME4b, ME5, ME6, MEW1 – MEW6, S1-S6, CE1-CE5, A1-A5.

In the design of the exterior lighting system on traffic routes we follow these stages:

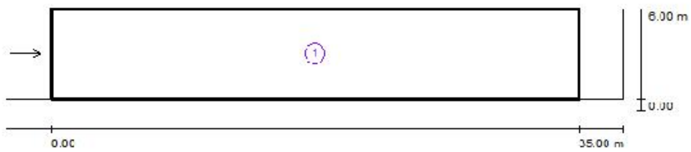
- Establish the lighting system's class. In our concrete case, the lighting system's class is A3;
- Choose the LLI's maintenance factor, which for a clean area with a three year maintenance cycle is 0.67;

- Establish the type of road arrangement (road, walking side, cyclists lane, parking space, emergency route, green space, etc.). In our concrete example we chose a one-way road;
- Define the road's characteristics: name, road width, number of traffic lanes, the road type carpet, age of the observer; We name the road "Green", the roadway width is 6 m, with black asphalt, at most 7,000 cars/day, the observer's age is 40.
- Establish the road's class according to: traffic speed, type of road users, asphalt carpet humidity, type of intersections, the number of vehicles travelling in one day, the presence of a conflict zone, the type of exterior light pollution ,the presence of parked vehicles, the difficulty in driving, the ambient brightness level. For our particular case the road's is established as being ME5, where $E_{med} \geq 10$ lx, and $U_0(E) \geq 0.4$;
- Choose, from the DIALux's database of LLIs, the type of LLI that provides the necessary light flux equal to that of the existing case, ST-100-36-WH-S. For this specific LLI we can choose from DIALux's software database the LG LS1275AFBB CE_LG LED type of Street Light LED. We choose this LLI because the software does not contain in its database the ST-100-36-WH-S LLI. Additionally in this stage the pole arrangement is defined by establishing: the mounting height (10.8 m in our case), the number of lamps on the pole (one), the distance between the poles (35 m) and the distance from the roadway (0 m);
- Choose the source type that equips the LLI based on the luminous flux, power and color temperature of the emitted light.

After going through all these stages, the software may begin its computations. In the result visualization, the luminous indicators that comply to the current norms are marked with green, the other with red. The software also displays the border values for the selected lighting class.

Figure 1 shows a picture of lighting indicator values as given by DIALux. We observe here that the glaring effect, TI, caused by the lighting sources in the visual area of the observer (other LIIs, luminous billboards, building lighting in the surroundings) is lower than the recommended standards, providing some comfort to the driver and helping to reduce glare. At the same time, the adjoining area report has a higher value than the recommended standard (SR = 0.84) contributing to the glare effect reduction.

Street 1/Photometric results



Conservation factor: 0.67 Scale 1:294

The list area calculation

1 Estimation field street "Green"
Length: 35000 m, Width:6000 m
Raster: 12 x 3 Points
The atached street elements: "Green"
Carpet: Porous Asphalt (UK), q0: 0,050
Selected illumination class: ME5

All the photometric requirements are fullfilled

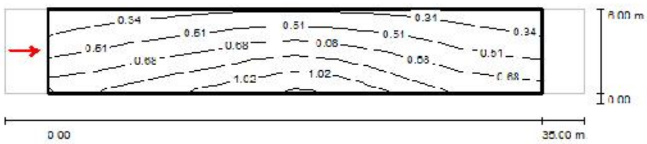
	L_m [cd/m²]	U0	Ul	TI [%]	SR
Calculated values:	0.63	0.45	0.53	12	0.84
Class type necessary values:	≥ 0.50	≥ 0.35	≥ 0.40	≤ 15	≥ 0.50
Fullfilled/Unfulfilled	✓	✓	✓	✓	✓

Figure 1. Luminous indicator values for luminance.

The equal brightness lines and the illumination lines resulting from the design and calculations are shown in Figures 2 and 3. They show a good uniformity of luminance and lighting on the surface of the analyzed road.

From the three figures we observe that the indicator values are appropriate, exceeding the imposed lower limit values for the ME5 type of road.

Street 1 / Estimation field "Green" / Observes 1 / Isolines (L)



The value in cd/m², Scale 1 : 294

Raster: 12 x 3 Points
Observer's position: (-60.000 m, 3.000 m, 1.500 m)
Carpet: Porous Asphalt (UK), q0: 0.050

	L_m [cd/m²]	U0	Ul	TI [%]
Calculated values:	0.63	0.45	0.53	12
Class type necessary values: ME5:	≥ 0.50	≥ 0.35	≥ 0.40	≤ 15
Fulfilled/Unfulfilled:	✓	✓	✓	✓

Figure 2. Lighting indicator values for the luminance and their isocandle lines.

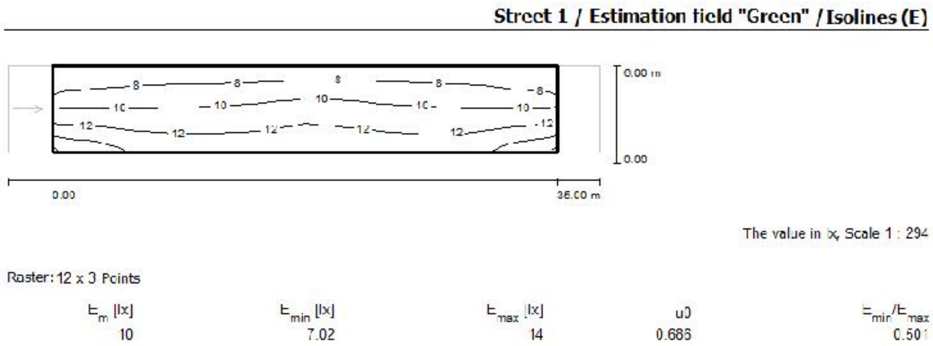


Figure 3. Lighting indicator values and isolux curves.

4.2. Lighting System Optimization with DIALux. Obtained Results

From the previous images we cannot conclude that the designed lighting system is also the best. To find the best lighting system version we use the optimization function available in the DIALux software package. This function asks for value ranges for: the distance between poles, the pole height, LLI inclination angle, LLI console length, the distance between the pole and the roadway or the crutches length.

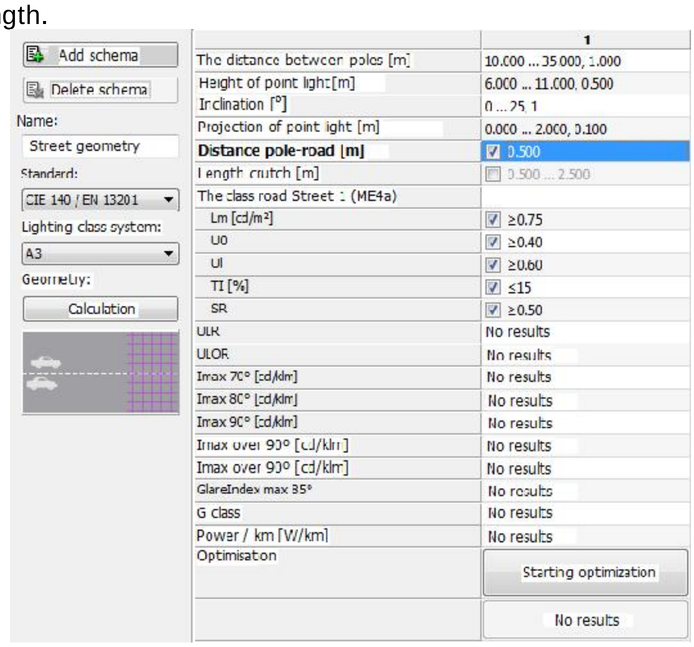


Figure 4. Setting measure ranges for the indicators to be optimized.

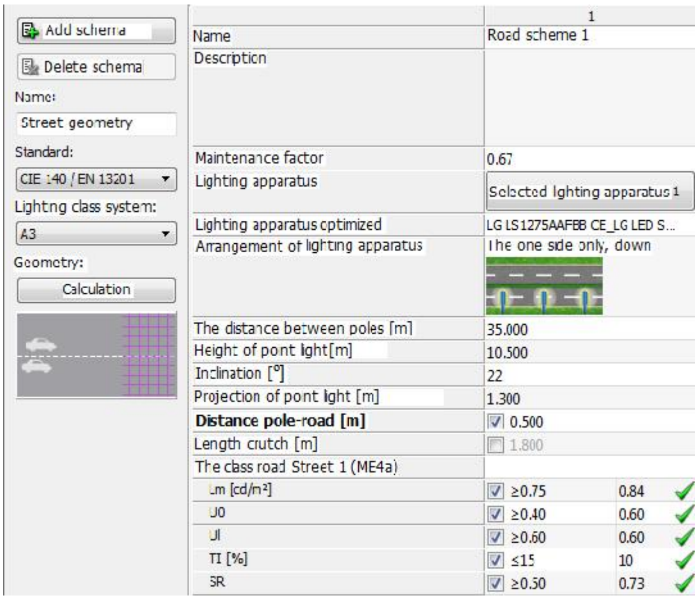


Figure 5. Luminous indicator values obtained from the optimization calculus.

Figure 4 shows a screenshot of the dialogue where the variation intervals of the above mentioned measures, as well as the iteration step are set. In our given case, the distance between the poles is between 10 m and 35 m, the iteration step being at 1 m.

The optimization process, which takes longer to compute the smaller the iteration steps are, outputs the values of the parameters mentioned above, which ensure the optimal luminous indicators values. If the user wishes to further optimize the installation design, he or she can additionally aim at the lowest cost possible, taking into account the costs to install and realize the poles and crutches.

For the analyzed case the resulted values of the luminous indicators are shown in Figure 5. The pole height was found to be optimal for a height value at the upper end of the allowed height range (10.5 m to 11 m), which is expected, knowing that with height increase, we obtain a greater uniformity, a lower glare factor and a higher report of the adjoining area. At the same time, placing the pole at 0.5 m from the roadway necessitates a 1.3 m crutch on which the LLI is mounted, while the inclination angle of the LLI must be of 22°.

To easily compare the measurement results with those obtained from classical design and with those obtained from the optimization process above, we display all these values side by side in Table 2.

Table 2.

Nr. crt.	Analyzed indicator	ST-100-36-WH-S	Classical design	Optimiza-tion
1.	Minimum illumination E_{min} [lx]	5.1	7.02	6.74
2.	Maximum illumination E_{max} [lx]	50.6	14	13
3.	Average illumination E_{med} [lx]	22.654	10	10
4.	Illumination uniformity U_0(E)	0.335	0.686	0.663
5.	Illumination uniformity E_{min}/E_{max}	0.15	0.501	0.531
6.	Medium luminance L_{med}[cd/m^2]	2.381	0.63	0.84
7.	Luminance uniformity U_0(L)	0.277	0.45	0.6
8.	Longitudinal luminance uniformity U_1(L)	0.189	0.53	0.6
9.	Threshold index TI [%]	-	12	10
10.	Adjoining area report SR	-	0.84	0.73

5. Conclusion

We have shown in this work that the lighting installations, of any kind, cannot be mounted on poles in an ad-hoc manner, without previously computing the luminous indicators. In support of this assertion the values presented in Table 1 show that mounting the lighting source at a certain height, on an available pole, has led to unsatisfactory luminous indicators.

To reach indicator values that comply with the current technical norms and regulations it was necessary to actually design the lighting system and to modify its mounting parameters. If the use of existing poles is aimed for, it is necessary that crutches are used such that the lighting apparatus can be placed at the optimal height.

The optimization calculation in the DIALux software uses luminance as the main optimization measure, for the exterior lighting, as it is shown in Fig. 4, Fig. 5 and Table 2. The roadway luminance is the parameter that directly influences the observer’s eye; while correct roadway lighting does not necessarily mean that, a point on it is clearly observable.

The criteria that must be considered when choosing a certain type of lighting system are both the luminous and energy efficiency. The importance of a good design must be given particular attention, such that optimal values are found for the distance between poles, distance between poles and roadways, height of the light source, inclination angles, console dimensions. Only installations mounted using these optimal parameter values insure good luminous indicators of the lighting system.

Using a luminous design software, like DIALux, eliminates situations where lighting systems use up too much electric energy to produce heat or contribute to the luminous pollution.

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