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Optimizing Street Lighting Systems Design

This work presents solutions to improve the quality parameters for outdoor illumination. The work starts from a case study which measured the outdoor lighting quality indicators on a street of the town Reşiţa. We measured levels of lighting and brightness, and we computed various lighting indicators. The obtained values were then compared to the values recommended by actual technical norms observing that they do not fit into the normed limits. Using the Dialux software we calculated the optimal mounting variant of the lighting installation for the street under lighting analysis. In the optimizing software we kept the pole's height and place in space constant to the values in the real situation. This work presents new variants of lighting installations that can ensure the best lighting indicators possible.

Keywords: lighting level, optimization methods, brightness

1. Introduction

At the direct request of public stakeholders in the town of Reşiţa, several lighting measurements on different city streets were done. The aim was to estimate the quality of the electric lighting installations provided by various companies. In most of the cases, we found that the measured lighting indicators were complying neither to the original project nor to the current standards and norms.

Presently, there are situations where the lighting systems designers adapted standardized projects for street types having characteristics partially similar with those for which the project design was done. Thus, no special attention was paid to the street specifics, like street dimensions, number of traffic lanes, distance between light poles, height of the light source, etc. Often during project execution, the data in the project's design were not followed. All these have led to improper outdoor lighting systems that discontented the citizens in the affected areas.

This paper suggests a solution to the redesign of the lighting systems for each street, taking into account each street's specific characteristics. Maintaining the pole position layout and of the electric power absorbed by the lighting system, the authors of this paper, using the DIALux software environment [4], aimed at finding the version with the best lighting parameters for the examined streets.

Considering the lighting system's energy efficiency, we made simulations to ensure the lighting indicators [1], [2], [3] for different light sources with different luminous efficiency.

2. Current Status of the Main Street Lighting System

In this section, we closely examine the current lighting situation on a main city street (called "V" in this paper). When the very first street lighting installation was realized on the city street, the light sources first mounted functioned with a 250 W electric power. As technology evolved, new and more efficient lighting sources were later mounted on the existing poles, following a design project denoted in this paper as "design project M."

The roadway dimensions and the lighting system characteristics measured in the field are shown in Table 1, where they are directly compared to those in the design project M.

Table 1.

Characteristic	Field value	Project M value
Street width [m]	9	9
Distance between poles [m]	33.5	35
Light source height [m]	7.4	9
Crutch length[m]	-	0.3
Mounting type	unilateral	unilateral
Source type	LVS	LVS
Source power [W]	250	171
Luminous flux [lm]	31200	16900

For the type of street we look at (type ME5), Table 2 presents the lighting indicator values for the current norms (NTE), for the existing project, and the values based on field measurements.

Table 2.

Lighting parameter	NTE value	Project M value	Field determined value
Average illumination E_{med} [lx]	7.5	18	21.6
Average luminacy L_{med} [cd/m^2]	0.5	1	0.38
Luminance uniformity U_0(L)	0.35	0.44	0.12
Luminance uniformity along the road axis U_1(L)	0.4	0.53	0.14

Analyzing the data in tables 1 and 2 we conclude that the street "V" project does not comply with the actual street dimensions. Furthermore, the lighting parameters determined by field measurements, with the exception of the average illumination, have much smaller values than the required standard values and those stated in the design project. The average lighting does respect the current norms and the design project, but in street lighting, the average lighting is not decisive. The decisive lighting parameter, which must be considered in the design of outdoor street lighting, is the luminance, L.

3. Designing the Lighting System for the Examined Main Street

In this section we describe the steps to follow in order to arrive at an optimal lighting system, starting from the existing positions of the pole and existing light sources. Hence, the design of the examined lighting system was done in the following stages:

A. Recreate the original design project using the same luminaire as the ones in the existing project and the same field characteristics (street, poles, pole positions). We call this the effective project (or project E);
B. Maintaining the field characteristics (street type, poles, pole positions), choose different lighting systems. We call this the updated project (or project U);
C. Using the luminaire type chosen in the previous stage, optimize project U by modifications to the pole height, luminaire inclination. We call the obtained design project the optimized project (or project O).

For each of the three projects we determined the lighting parameter values, which were compared with the values recommended by current norms and standards.

3.1 The design of the lighting system using the currently installed light source

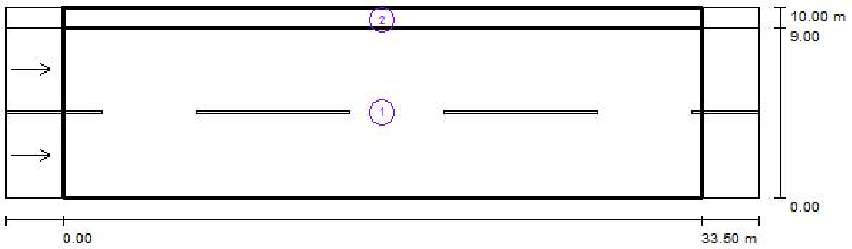
Since the lighting parameter actual values do not comply with the lighting indicator values listed in the current norms, we designed an implementation project for the "V" street with the help of the DIALux software environment. The project maintains the street dimensions and pole locations as in field.

Taking into account all the characteristics of the examined street, the design project we realized indicates a 0.5 retention factor, a ME5 street lighting class, and a CE5 sidewalk lighting class.

Figure 1 shows the results of using DIALux to realize this project (project E). We observe that the lighting parameter values in this design are actually very small when compared to those given in the original project and to the values given in the actual lighting norms and standards [5], [6], [7].

Poor lighting and luminance quality are noticed in Figure 2 as well, which shows the lighting isolines, E, and the luminance isolines, L, obtained with a design that uses the street's and lighting system's characteristics.

Street "V" / Photometric results



Conservation factor: 0.50

Scale 1:283

The list area calculation

1 Estimation field street 1
Length: 33.500 m, Width: 9.000 m
Raster: 12 x 6 Points
The atached street elements:1
Carpet: Porous Asphalt (UK), q0: 0.050
Selected illumination class: ME5

Not all the photometric requirements are fullfilled

	L_m [cd/m²]	U0	Ul	TI [%]	SR
Calculated values:	0.02	0.08	0.05	/	0.80
Class type necessary values:	≥ 0.50	≥ 0.35	≥ 0.40	≤ 15	≥ 0.50
Fullfilled/Unfullfilled	✗	✗	✗	/	✓

2 Estimation field sidewalk 1
Length: 33.500 m, Width: 1.000 m
Raster: 12 x 3 Points
The atached street elements: Sidewalk 1.
Selected illumination class: CE5

Not all the photometric requirements are fullfilled

	E_m [lx]	U0
Calculated values:	0.62	0.05
Class type necessary values:	≥ 7.50	≥ 0.40
Fullfilled/Unfullfilled	✗	✗

Figure 1. Lighting indicators values in the design project E.

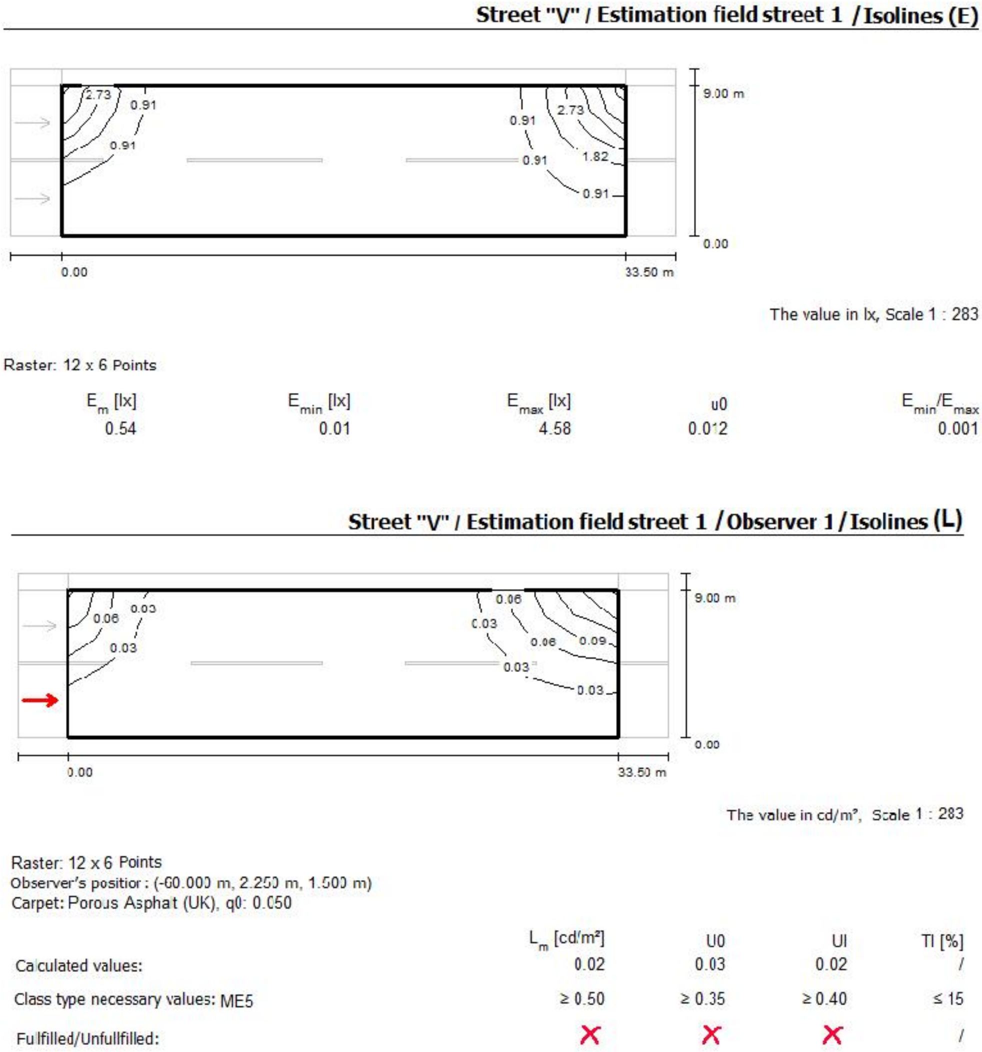
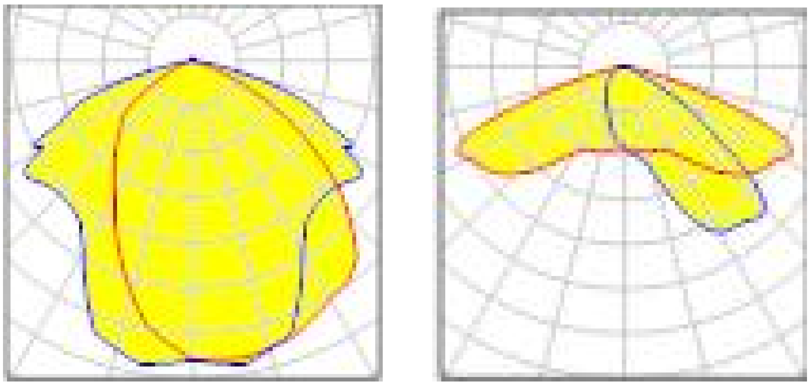


Figure 2. Lighting and luminance isolines in the design project E.

The reason for these unsatisfying results is given by the photometric curve of the utilized luminaires (see Figure 3), which is inadequate for street lighting. The existing lighting source of type GELIGHTING 42629 ET 25 G HPS 150 W, with a total power of 171 W (including the power ballast), and a 17,500 lm luminous flux cannot deliver satisfactory results since it does not show a satisfactory photometric curve.



a) b)

Figure 3. Photometric curves for a) light source of type GELIGHTING 42629 ET 25 G HPS 150 W; b) light source of type HELLA ERL_LargeL ECO RoadLine RL Large.

3.2 The design of the lighting system with a different light source

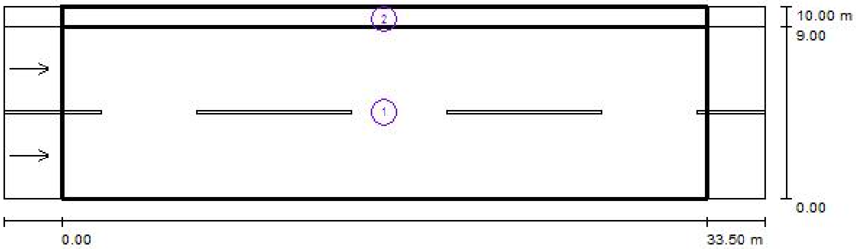
The authors of this work have set out to find, in the list of light sources known to the DIALux environment, those light sources that lead to the best lighting parameter values, while lowering the power source such that energy savings are also made. Upon reiterated computations, we choose a lighting source of type HELLA ERL_LargeL ECO RoadLine RL Large (a LED based lighting source). This light source, in addition to having a photometric curve adequate to street lighting purposes (Figure 3.b.), has a 11,500 lm luminous flux and 150 W power, which translates to using 87.7% of the source power used in the initial project.

Keeping the same location of the poles, the same mounting height and the same crutch length (0.3 m), but using the new light source, we realize the design project U, which gives the lighting indicators presented in Figure 4.

Figure 5 presents the results of the optimization process, where we immediately see that the optimal luminous parameter values are obtained for an 8.5 m light source mounting height, and a 0º luminaire inclination angle. When the pole's height is lower than 8.5 m, the optimal height can be achieved by extending the pole with a crutch.

Since the optimization process aims at finding the optimal mounting values, with total or partial lighting parameter value compliance to the actual norm recommendations, and depends on the lighting system selected, we used the montage values as reference values in the optimized project O. Therefore, we took the light source height to be 8.5 m and the light source's inclination angle to be 0º. The road and pole positioning characteristics were kept constant. The photometric results for this case are shown in Figure 6.

Street "V" / Photometric results



Conservation factor: 0.50

Scale 1:283

The list area calculation

1 Estimation field street 1
Length: 33.500 m, Width: 9.000 m
Raster: 12 x 6 Points
The atached street elements: 1
Carpet: Porous Asphalt (UK), q0: 0.050
Selected illumination class: ME5

Not all the photometric requirements are fullfilled

	L_m [cd/m²]	U0	Ul	TI [%]	SR
Calculated values:	0.55	0.58	0.54	16	0.38
Class type necessary values:	≥ 0.50	≥ 0.35	≥ 0.40	≤ 15	≥ 0.50
Fullfilled/Unfullfilled	✓	✓	✓	✗	✗

2 Estimation field sidewalk 1
Length: 33.500 m, Width: 1.000 m
Raster: 12 x 3 Points
The atached street elements: Sidewalk 1.
Selected illumination class: CE5

All the photometric requirements are fullfilled

	E_m [lx]	U0
Calculated values:	8.65	0.42
Class type necessary values:	≥ 7.50	≥ 0.40
Fullfilled/Unfullfilled	✓	✓

Figure 4. Luminous parameter values in the design project U.

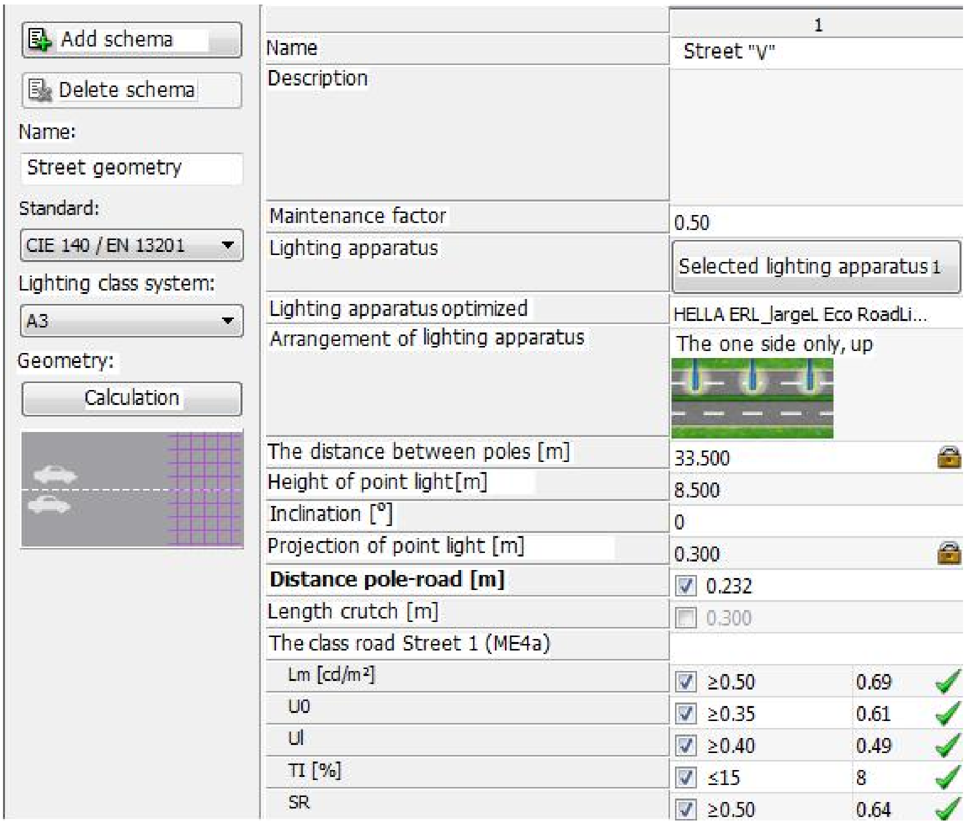
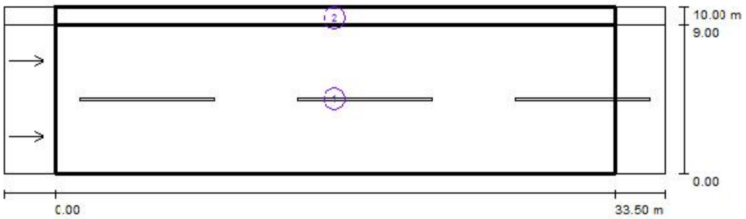


Figure 5. Optimization results.

Figure 7 presents the lighting and luminance isolines plotted for the optimized project O, as well as the lighting and luminance isolines for two observers moving on the road. From these figures, it appears that all lighting indicator values are met, with the exception of the adjoining area report.

To find out which of the lighting systems analyzed provides the best lighting indicators, in the optimization program we tested 28 lighting sources. We found that, for the given street and pole characteristics, the best lighting source is the one of type HELLA ERL_LargeL ECO RoadLine RL Large.

Street "V" / Photometric results



Conservation factor: 0.50

Scale 1:283

The list area calculation

1 Estimation field street 1
Length: 33.500 m, Width: 9.000 m
Raster: 12 x 6 Points
The atached street elements:1
Carpet: Porous Asphalt (UK), q0: 0.050
Selected illumination class: ME5

Not all the photometric requirements are fullfilled

	L_m [cd/m²]	U0	Ul	TI [%]	SR
Calculated values:	0.50	0.64	0.64	13	0.47
Class type necessary values:	≥ 0.50	≥ 0.35	≥ 0.40	≤ 15	≥ 0.50
Fullfilled/Unfullfilled	✓	✓	✓	✓	✗

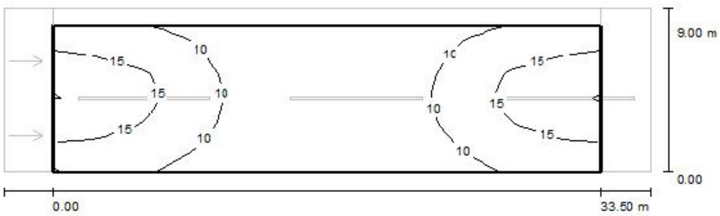
2 Estimation field sidewalk 1
Length: 33.500 m, Width: 1.000 m
Raster: 12 x 3 Points
The atached street elements: Sidewalk 1.
Selected illumination class: CE5

All the photometric requirements are fullfilled

	E_m [lx]	U0
Calculated values:	8.01	0.57
Class type necessary values:	≥ 7.50	≥ 0.40
Fullfilled/Unfullfilled	✓	✓

Figure 6. Photometric results in project O.

Street "V" / Estimation field street 1 / Isolines (E)

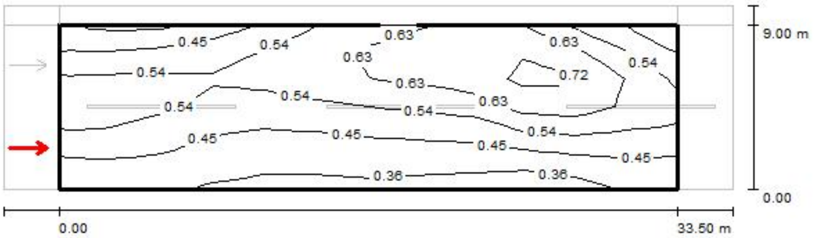


The value in lx, Scale 1 : 283

Raster: 12 x 6 Points

E_m [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min}/E_{max}
11	5.83	20	0.520	0.295

Street "V" / Estimation field street 1 / Observer 1 / Isolines (L)

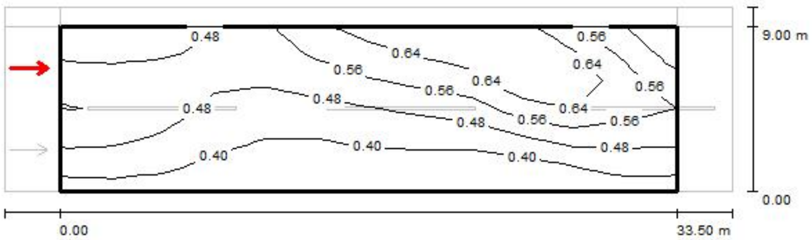


The value in cd/m², Scale 1 : 283

Raster: 12 x 6 Points
Observer's positior: (-60.000 m, 2.250 m, 1.500 m)
Carpet: Porous Asphalt (UK), q0: 0.050

	L_m [cd/m²]	U0	Ul	TI [%]
Calculated values:	0.52	0.64	0.83	10
Class type necessary values: ME5	≥ 0.50	≥ 0.35	≥ 0.40	≤ 15
Fullfilled/Unfullfilled:	✓	✓	✓	✓

Street "V" / Estimation field street 1 / Observer 2 / Isolines (L)



The value in cd/m², Scale 1 : 283

Raster: 12 x 6 Points
Observer's positior: (-60.000 m, 2.250 m, 1.500 m)
Carpet: Porous Asphalt (UK), q0: 0.050

	L_m [cd/m²]	U0	Ul	TI [%]
Calculated values:	0.50	0.65	0.64	13
Class type necessary values: ME5	≥ 0.50	≥ 0.35	≥ 0.40	≤ 15
Fullfilled/Unfullfilled:	✓	✓	✓	✓

Figure 7. Lighting and luminance isolines observed in design project O.

4. Comparative analysis

To better understand the luminous parameter values obtained with the different project designs we show these values side by side in Table 3.

Table 3

Lighting charateristic	NTE	Project E	Project U	Project O
Average luminance L_{med} [cd/m^2]	≥ 0.5	0.02	0.55	0.5
Luminance uniformity $U_0(L)$	≥ 0.35	0.03	0.58	0.64
Luminance uniformity along the traffic lane axis $U_1(L)$	≥ 0.4	0.05	0.54	0.64
Threshold index TI [%]	≤ 15	-	16	13
Adjoining area report SR	≥ 0.5	0.8	0.38	0.47
Average street lighting E_{meds} [lx]	≥ 7.5	0.54	8.65	11
Average sidewalk lighting E_{medt} [lx]	≥ 7.5	0.62	8.65	8.01
Lighting uniformity $U_0(E)$	≥ 0.4	0.05	0.42	0.57

The values in table 4 marked with a bold font point out the values complying with the recommended standards and norms (NTE). We observe in this table that, compared to the parameter values derived from the updated project, the average luminance value decreased after the optimization, while the luminance uniformity value increased by 10%. At the same time the luminance uniformity on the traffic lane axis increased by 18.5%, while the threshold index, TI, falls into the current standard value range.

With regard to the lighting, the optimization process delivers a good lighting both on the street and on the sidewalk. The lighting uniformity is by 35.7% higher if we the optimization design project instead of the update design project.

4. Conclusion

The design of a lighting system must be done taking into account all the little details of the street on which the system is to be installed. It should not be allowed that standardized projects are adapted to streets having similar dimensional characteristics with those in the standardized project. Not taking into account all the field details will lead to an improper classification of the street type and, consequently, to inappropriate lighting parameter values for the respective street.

At the same time, after the lighting system is installed and functioning, it is recommended that an audit takes place, the auditors being impartial individuals with no involvement in the design or the implementation of the lighting system.

The marketing and outdoor use of LED based lighting systems in street lighting contribute to achieving better lighting parameters and lower levels of energy consumption.

Failing the SR indicator's value by 0.03 (0.47 to 0.5 in Figure 6) is no reason to look for another option. In order to make this indicator comply with the recommended standards we would need to increase the height of the lighting source mounting point and the source's power, which would lead to higher installation costs flowing into the pole building and energy consumption. For this concrete situation the optimized project can be considered to be the best since all important lighting parameter values (luminance, uniformity, threshold index) are within accepted value ranges. The lamp power used in the optimized design is by 12% lower than the lamp power in the existing project, and by 40% lower than the lamp power installed before the first "update", leading to energy savings.

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[6] ***** CEN/TR 13201-1.

[7] **** Stockmar A., Adaptive Road Lighting according to CIE Publication 115:2007. E-street Workshop Oslo, 2007. Online at http://www.e-streetlight.com/Documents/Forum%20Oslo/lci%20lowres.pdf (last retrieved: August 2014)

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