ENERGY EFFICIENCY INCREASE IN PUBLIC LIGHTING SYSTEMS

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Worldwide most public lighting fixtures use outdated technologies with sodium, metal halide, mercury lamps, and there is a high potential to save energy by switching to LED. Projects to increase energy efficiency in public lighting involve optimization measures in order to choose the optimal solution in compliance with the performance criteria specified in the standards for public lighting. This paper presents methods of optimization in the process of modernization of public lighting system. It is analyzed both the optimal variant of placing the lighting fixtures in the variant of partial modernization but also in the variant with total modernization. Lighting calculations and optimizations were performed using several types of lighting fixtures with different optics and light flux. The indicator of the annual energy consumption for the public lighting installation. is calculated in the two analyzed variants. It was established that the optimal final option is the one that cumulatively meets the following requirements: the chosen luminaire has the lowest installed power among those proposed, the distance between the poles is the largest, the poles have the lowest height of the proposed variants, the consoles have the lowest length, for minimal investment costs.

Keywords: LED, street lighting, energy efficiency, optimized street arrangement

1. Introduction

In accordance with the national legislation on energy efficiency, improving energy efficiency in all identified areas is a strategic objective of the national energy policy. Energy efficiency has a major contribution to achieving security of electricity supply, saving primary energy resources and reducing greenhouse gas emissions in order to increase the quality of the environment.

In the field of public lighting there is a high possibility of increasing energy efficiency and thus reducing electricity consumption and greenhouse gas emissions, given that equipment with outdated technology is still used.

It is estimated that globally less than 18% of the 350 million street lighting fixtures are LEDs and less than 2% are connected, providing enormous

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opportunities to save electricity, to improve quality of lighting and reduce power quality impact of lighting systems [1-4].

2. Design stages

Starting a project to replace the equipment of the public lighting system in order to increase energy efficiency involves optimization solutions for choosing the appropriate option from several possible options.

The optimization process in public lighting systems requires the fulfillment of the performance criteria specified in the international standard for lighting CEN / TR 13201-2003 related to the lighting classes regarding: average luminance L_{av} [cd/m^2], total luminance uniformity $U_0 = L_{min}/L_{med}$, uniformity longitudinal luminance U_l [%] = L_{min}/L_{max}, maximum physiological blindness Ti [%] and ratio of adjacent area SR [5].

The key elements of the public lighting system that can be varied in order to choose the optimal solution from a technical and economic point of view, in accordance with the lighting quality recommendations are [6-12]:

- **Mounting height of the luminaires:** the higher the mounting height of the luminaires, the higher the value of the luminous flux of the luminaires and therefore the installed electrical power of the luminaire will be high in order to ensure optimal luminance;
- **Arrangement of poles:** Lighting poles can be placed unilaterally, alternately bilaterally, bilaterally face-to-face, or axially depending on the situation on the ground;
- **The spacing between the poles** must be optimally chosen to ensure the smallest possible number of poles on the illuminated street section;
- **Luminaire:** It must be located so as to have the necessary optics and adequate luminous flux in order to meet the performance criteria specified in the standard;
- **The fixing bracket** of the luminaire must be optimally dimensioned in terms of length and inclination.

There are two types of approaches to increasing energy efficiency in public lighting systems:

- partial modernization;
- total modernization.

Partial modernization is an approach that focuses on retrofit solutions, namely replacing existing lighting fixtures with LED technology, maintaining or replacing the fixing brackets of lighting fixtures, keeping the poles and its location.

The total modernization implies the possibility of replacing all the elements of the public lighting system, respectively lighting fixtures, consoles, poles. In this situation, new poles can be used, or the existing poles can be optimally replaced if they are technically and functionally compliant. Total modernization involves higher investment costs compared to partial modernization, including additional works for the location of the power supply network.

3. Optimizations using lighting calculation programs

The most well-known and used lighting calculation program is DIALux, used by both designers and lighting equipment manufacturers [13]:

DIALux is used for the following types of lighting projects:

- calculation of interior lighting for buildings, industrial halls, warehouses, sports facilities;
- calculation of exterior lighting for streets, parks, parking lots, sports fields;

energy calculation related to lighting fixtures located in Dialux;

- 2D and 3D lighting simulation in Dialux;
- optimization of lighting fixtures placement.

For street lighting projects, DIALux in version 4.13 contains a special section dedicated to optimizing the arrangements of lighting fixtures via Paste / Luminaire Arrangement / Luminaire Wizard / Optimized Street Arrangement Wizard.

After accessing the Optimized Street Arrangement Wizard section, you can select one or more luminaires from the Dialux catalogs, online catalogs or other databases to start the lighting optimization calculations according to the selected lighting class.

The list of variable arrangement parameters is represented by: the distance between the poles, the mounting height of the bodies which can sometimes coincide with the height of the pole, the exit of the luminaire in the console, the inclination of the console or the luminaire. These parameters are set between a minimum and a maximum with certain increment steps.

Also, you can select the type of arrangement of the poles, respectively: unilateral, bilateral alternating, bilateral face-to-face, or axially based on the characteristics of the street.

The increment steps are generally chosen as follows:

- for the distance between the poles, an increment step of at least 1 m is generally chosen;
- for the body mounting height, the increment step can be chosen of 0.5 m to correspond to the standard machining heights of the poles manufacturers. The choice of an atypical height, for example 7.25 m, can lead to a high cost of the mast in the acquisition stage and implicitly to a high investment value.

- the step of increasing the length of the console is usually 0.5 m;
- the inclination step of the console can take 1°, but usually the console manufacturers produce them with inclination angles having the increment step 5°.

The calculation made in Dialux results in several location proposals, respectively adequate, inadequate or partially adequate. The optimal option will be chosen from the appropriate arrangements based on economic taxes for an investment value as low as possible.

4. Case Study

The case study will analyze the options for optimizing the lighting system for a street type ME4a starting from an existing situation. Two situations will be analyzed, both the partial and the total modernization of the lighting system.

It was proposed for analysis a street of class ME4a, with a length of 1000 m, a lane in each direction and a width of the lane of 3.5 m having the following performance criteria according to standard CEN / TR 13201-2003:

Table 1

Performance criteria for ME4a class

Class	Luminance of the road surface of the carriageway for the dry road surface condition			Disability glare	Lighting of surroundings
	The average luminance L_{av} in cd/m^2 [minimum maintained]	U_o [minimum]	U_I [minimum]	TI in % [maximum]	SR [minimum]
ME4a	0.75	0.4	0.6	15	0.5

A maintenance factor of 0.67 was used in the lighting calculation related to a clean space with a maintenance cycle of 3 years.

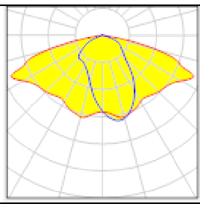
A. *Existing situation*

In the existing situation, the street is illuminated with lighting fixtures using sodium technology with lamps with a power of 150 W. The technical characteristics of the luminaire and the arrangement parameters are [14]:

Table 2

Technical characteristics of the existing lighting fixture and arrangement

Luminaire:	150 W SON-T
Light flux (luminaire)	11,444 lm
Luminous flux (lamp)	14,000 lm
Electric power of the lamp	158.0 W
Lighting efficiency of the luminaire	72.43 lm/W

Light distribution curve	
Placement	Unilateral
Distance between poles	40.0 m
Luminaire mounting height	9.58 m
Height above the useful plane (poles height)	9.50 m
Inclination of the console	15.0 °
Console length	1.5 m

Following the lighting calculations in Dialux it is observed that all the photometric requirements related to the selected lighting class ME4a are met:

Table 3

The results of the lighting calculation for the existing situation

	Lav [cd/m²]	U0	Ul	TI [%]	SR
Calculated values:	0.78	0.49	0.6	9	0.61
Required values according to the class:	≥ 0.75	≥ 0.40	≥ 0.60	≤ 15	≥ 0.50
Fulfilled / Unfulfilled:	Fulfilled	Fulfilled	Fulfilled	Fulfilled	Fulfilled

B. The redesigned situation in the partial modernization version using LED lighting fixtures

The dimensions of the console and its inclination will be varied, the rest of the parameters remaining fixed, respectively the distance between the poles, the height of the poles, unilateral location.

The dimensions of the console and its inclination will be varied, the rest of the parameters remaining fixed, respectively the distance between the poles, the height of the poles, unilateral placement.

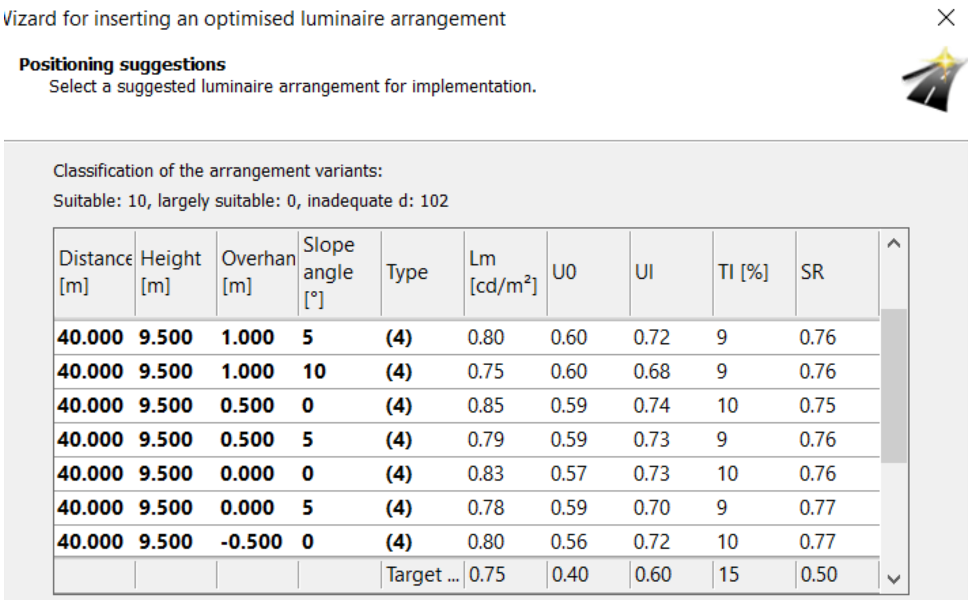
In the optimization stage, 4 LED luminaires were proposed, having the following characteristics [15]:

Table 4

The technical characteristics of the proposed LED luminaires

LED luminaire	Type 1	Type 2	Type 3	Type 4
Light flux (luminaire)	10,199 lm	8,704 lm	9,148 lm	12,586 lm
Luminous flux (of LEDs)	12,000 lm	9,600 lm	11,500 lm	14,000 lm
Electric power of the luminaire	92 W	77 W	83 W	82 W
Lighting efficiency of the luminaire	110.86 lm/W	113.04 lm/W	110.22 lm/W	153.49 lm/W

The optimizations in Dialux resulted in 10 suitable location proposals, and 102 inadequate location proposals.



Distance [m]	Height [m]	Overhan [m]	Slope angle [°]	Type	Lm [cd/m²]	U0	UI	TI [%]	SR
40.000	**9.500**	**1.000**	**5**	**(4)**	0.80	0.60	0.72	9	0.76
40.000	**9.500**	**1.000**	**10**	**(4)**	0.75	0.60	0.68	9	0.76
40.000	**9.500**	**0.500**	**0**	**(4)**	0.85	0.59	0.74	10	0.75
40.000	**9.500**	**0.500**	**5**	**(4)**	0.79	0.59	0.73	9	0.76
40.000	**9.500**	**0.000**	**0**	**(4)**	0.83	0.57	0.73	10	0.76
40.000	**9.500**	**0.000**	**5**	**(4)**	0.78	0.59	0.70	9	0.77
40.000	**9.500**	**-0.500**	**0**	**(4)**	0.80	0.56	0.72	10	0.77
				Target ...	0.75	0.40	0.60	15	0.50

Fig. 1. The proposed optimization variants using the calculation program for partial modernization.

Following the analysis of the 10 appropriate proposals for the placement of lighting fixtures, which have as common element the type 4 body, the most technically and economically efficient option is the one in which the length of the console is 0 m and the inclination is 0 degrees, practically the body lighting is mounted on top of the pole and does not require a console.

According to the figure above, the photometric requirements in the chosen variant have the values: L_{av} = 0.83 [cd/m²], U_0 = 0.57, U_I = 0.73, TI = 10 [%], SR = 0.76.

C. The redesigned situation in the total modernization version using LED lighting fixtures

In the total modernization of the street lighting system, several types of LED luminaires will be used in optimization as a proposal to replace the existing luminaires. The total modernization offers the possibility to vary all the elements of the public lighting system, respectively the type of lighting fixtures, the dimensions and inclination of the console, the dimensions of the poles and their location on the street.

The same 4 types of LED lighting fixtures of the partial modernization version were used in the lighting optimization calculations. Depending on the location of the poles, the following proposals result [16]:

Table 5

Suitable and inadequate variants depending on the location

Placement	Suitable variants	Inadequate variants
Unilateral low placement	3,113	19,207
Bilateral face-to-face placement	7,184	15,136
Alternating bilateral placement	14,129	8,191

The choice of the optimal final option between the 3 proposals for the arrangement of the poles is the one that cumulatively meets the following requirements:

- the chosen luminaire has the lowest installed power of the proposed ones;
- the distance between the poles is the largest to result in as few poles as possible on the street;
- the poles have the lowest height of the proposed options for a low cost;
- the consoles have the shortest possible length for a low investment cost.

In the situation with unilateral placement of the poles from the 3113 suitable possibilities, the option using the type 1 body was chosen, with a distance between the poles of 47 m, the height of the pole of 8.5 m and the console with a length of 0 m, the inclination of the luminaire being 0° [15]. According to the figure below, the photometric requirements in the chosen variant have the values: L_{av} = 0.76 [cd/m²], U_0 = 0.51, U_I = 0.61, TI = 13 [%], SR = 0.71.

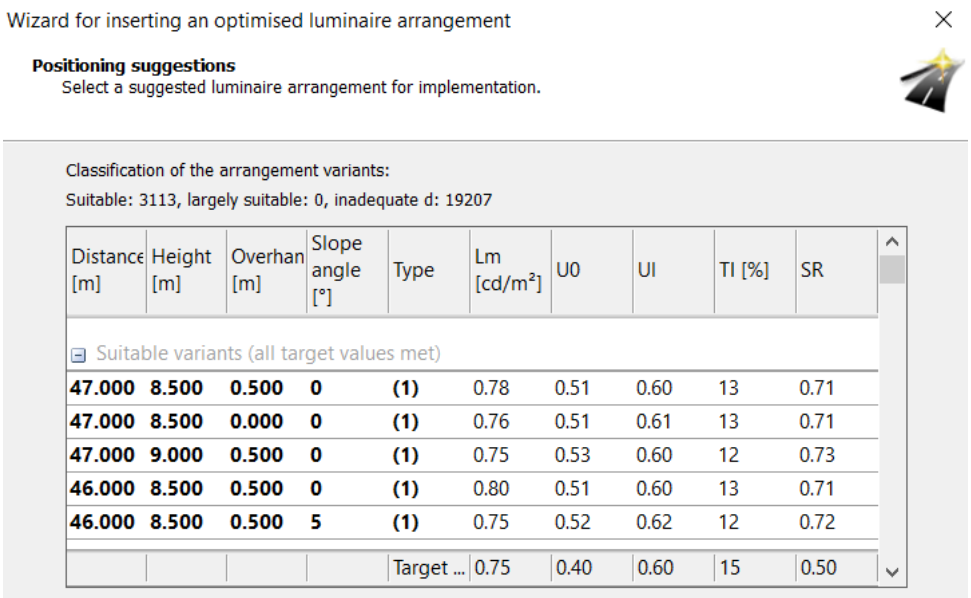
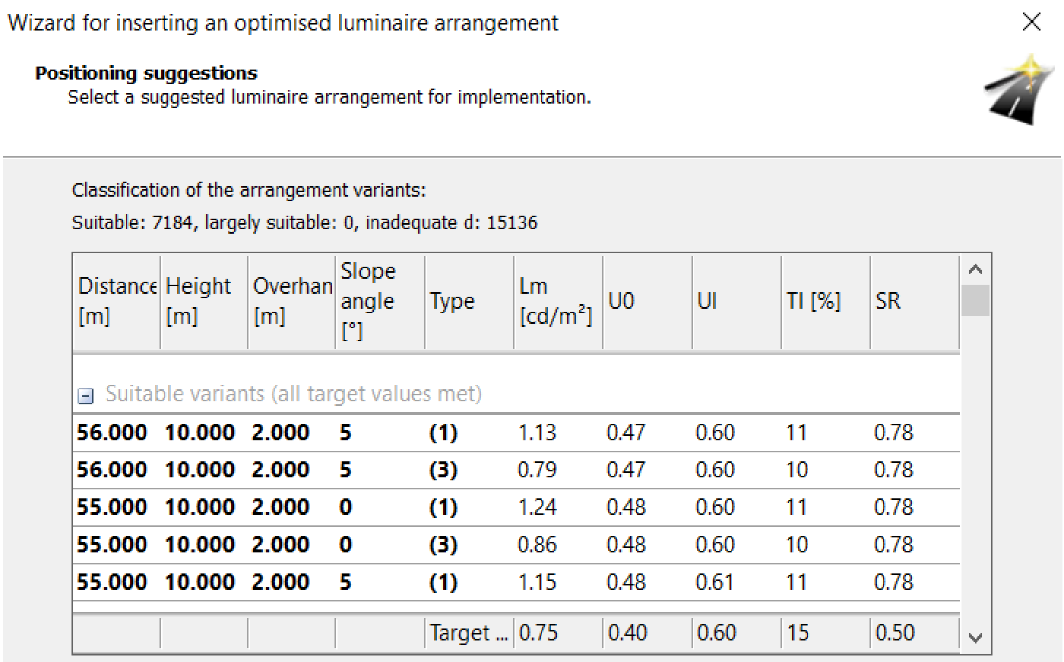


Fig. 2. The proposed optimization variants using the calculation program for total modernization with unilaterla placement of the poles.

As the street has a length of 1000 m, it results in a number of 21 poles and 21 lighting fixtures placed.

In the situation with bilateral face-to-face placement of the poles, among the 14129 suitable possibilities, the option using the type 3 body was chosen, with a distance between the poles of 56 m, the height of the pole of 10 m and the console with a length of 2 m, the inclination of the console being 0 ° [15].

According to the figure below, the photometric requirements in the chosen variant have the values: L_{av} = 0.86 [cd/m²], U_0 = 0.48, U_I = 0.60, TI = 10 [%], SR = 0.78.



Distance [m]	Height [m]	Overhan [m]	Slope angle [°]	Type	Lm [cd/m²]	U0	UI	TI [%]	SR
Suitable variants (all target values met)									
56.000	**10.000**	**2.000**	**5**	**(1)**	1.13	0.47	0.60	11	0.78
56.000	**10.000**	**2.000**	**5**	**(3)**	0.79	0.47	0.60	10	0.78
55.000	**10.000**	**2.000**	**0**	**(1)**	1.24	0.48	0.60	11	0.78
55.000	**10.000**	**2.000**	**0**	**(3)**	0.86	0.48	0.60	10	0.78
55.000	**10.000**	**2.000**	**5**	**(1)**	1.15	0.48	0.61	11	0.78
				Target ...	0.75	0.40	0.60	15	0.50

Fig. 3. The proposed optimization variants using the calculation program for total modernization with alternating bilateral placement of the poles.

As the street has a length of of 1000 m, it results in a total number of 34 poles and 34 lighting fixtures.

In the situation with bilateral alternating placement of the poles, among the 7184 suitable possibilities, the option using the type 2 body was chosen, with a distance between the poles of 60 m, the height of the pole of 7.5 m and the console with a length of 2 m, the inclination of the console being 0 ° [15]. According to the figure below, the photometric requirements in the chosen variant have the values: L_{av} = 1.16 [cd/m²], U_0 = 0.51, U_I = 0.63, TI = 12 [%], SR = 0.63.

Classification of the arrangement variants:
Suitable: 14129, largely suitable: 0, inadequate d: 8191

Distance [m]	Height [m]	Overhan [m]	Slope angle [°]	Type	Lm [cd/m²]	U0	Ul	TI [%]	SR
Suitable variants (all target values met)									
60.000	**7.500**	**2.000**	**0**	**(1)**	1.42	0.51	0.64	12	0.65
60.000	**7.500**	**2.000**	**0**	**(2)**	1.16	0.51	0.63	12	0.63
60.000	**7.500**	**2.000**	**0**	**(3)**	0.98	0.51	0.64	11	0.65
60.000	**7.500**	**2.000**	**5**	**(1)**	1.33	0.51	0.62	11	0.66
60.000	**7.500**	**2.000**	**5**	**(2)**	1.08	0.51	0.64	11	0.65
				Target ...	0.75	0.40	0.60	15	0.50

Fig. 4. The proposed optimization variants using the calculation program for total modernization with unilateral placement of the poles.

As the street has a length of 1000 m, it results in a total number of 33 poles and 33 lighting fixtures. Following the analysis of the 3 ways of placing the pillars and the optimizations in the variant with total modernization, the variant with unilateral mounting was chosen. This variant contains the luminaire type 1, with a distance between the poles of 47 m, the height of the pole of 8.5 m and the console with a length of 0 m, the inclination of the luminaire being 0 °. Thus, 21 poles and 21 lighting fixtures will be installed.

5. Annual electricity consumption after modernization

The European standard for public lighting EN 13201-2: 2015 defines the annual energy consumption (ED) indicator as:

$$DE = \sum Pi \cdot tj / A \tag{1}$$

In which:

- D_E - the indicator of the annual energy consumption for the public lighting installation [Wh/m^2];
- P_i - operational power associated with the jth period of operation [W];
- t_j - the duration of the period j of the operation profile when the power Pj is consumed [hours];
- A - the size of the illuminated surface of the same arrangement [m^2];

For the existing sodium situation [13]:

$$DE = 25 \cdot 156W \cdot \frac{4000\ ore}{1000m*7m}$$

$$D_E = 2{,}228.57\ [\text{Wh/m}^2]$$

For the situation with partial modernization using LED technology [17]:

$$DE = 25 \cdot 82W \cdot \frac{4000\ ore}{1000m*7m}$$

D_E=1,171.42 [Wh/m^2]

For the situation with total modernization using LED technology [17]:

$$DE = 21 \cdot 92W \cdot \frac{4000\ ore}{1000m*7m}$$

D_E=1,104 [Wh/m^2]

The annual energy consumption (DE) indicator is 47.43% lower in the situation of partial modernization compared to the existing situation and 50.46% lower in the situation of total modernization compared to the existing situation.

6. Conclusions

In this paper it is presented a method of optimization in public lighting systems in order to increase energy efficiency.

The optimization was performed using the Dialux lighting calculation program which contains a section dedicated to the arrangement variables, fulfilling the performance criteria specified in the international standard for lighting CEN / TR 13201-2003.

The case study was prepared for a ME4a type street with a length of 1000 m and a width of 7 m in two variants for the partial modernization as well as the total modernization of the public lighting system.

In the case of total modernization, all parameters were varied, including the location of the bilateral, bilateral alternating and bilateral face-to-face poles.

It was established that the optimal final option is the one that cumulatively meets the following requirements: the chosen luminaire has the lowest installed power among those proposed, the distance between the poles is the largest, the poles have the lowest height of the proposed variants, the consoles have the lowest length.

The optimization showed that the annual energy consumption (DE) indicator is 47.43% lower in the situation of partial modernization compared to the existing situation and 50.46% lower in the situation of total modernization compared to the existing situation.

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