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Energy efficiency analysis of lighting installations using LED technology

***Abstract**. The article discusses the important subject of the demand for electricity. It will define the concept of energy efficiency as a condition for determining the meaning of the modernization of street lighting. Then, will present two existing car parks lighting solutions: the first made on the sodium lamps, the other on the LED luminaires. Next there will be an energy-efficiency calculations for both cases and selected will be a better solution.*

***Streszczenie.** Artykuł porusza ważną tematykę zapotrzebowania na energię elektryczną. Zdefiniowane zostanie w nim pojęcie efektywności energetycznej jako warunku określającego sens modernizacji oświetlenia ulicznego. Następnie zaprezentowane zostaną dwa istniejące rozwiązania oświetlenia parkingów: pierwsze wykonane na lampach sodowych, drugie na oprawach LED. Dalej przeprowadzone zostaną obliczenia efektywności energetycznej dla obu przypadków oraz wybrane zostanie korzystniejsze rozwiązanie. (**Analiza efektywności instalacji oświetleniowych z użyciem LED**)*

Keywords: electric lighting system, energy efficiency, high-pressure sodium lamp, LED lamp.
Słowa kluczowe: elektryczna instalacja oświetleniowa, efektywność energetyczna, lampa LED, lampa sodowa wysokoprężna.

Introduction

The demand for electric energy increases rapidly in Poland. In a few years' time, the installed wattage of all the power plants in the country will not be sufficient. In order to ensure national energy security, it is necessary to decide on one of two alternatives: building new power plants and increasing the total installed wattage or introducing modern load points which will consume less power in comparison to the devices that are currently in use.

One of the ways to save electric energy is modernizing street lighting by replacing energy-consuming high pressure sodium lamps with modern LED luminaires of low wattage and high efficiency.

Energy efficiency of street lighting

The most important aspect of street lighting is providing good visibility conditions after dark that guarantee safety of use to all the road and car park users. Thus, it is important to fulfill the lighting requirements specified in the PN-EN 13201-2:2005 (U) standard – "Road Lighting – Part 2: Performance Requirements".

However, another important element is optimal selection of the light sources so as not to waste the electric energy consumed, for example, on the light pollution phenomenon (lighting unnecessary areas). This is referred to as energy efficiency and it can be defined as the relation between the installed wattage of a given lighting system and the lighting level obtained for the area examined. The relationship can take one of the following forms:

a) with respect to luminance:

$$e_E = \frac{P}{A \cdot L_m} \left[\frac{W/m^2}{cd/m^2}\right] \tag{1}$$

b) with respect to illuminance:

$$e_E = \frac{P}{A \cdot E_m} \left[\frac{W/m^2}{lx}\right] \tag{2}$$

where:
- e_E – energy efficiency of the lighting system
- P – installed wattage of the lighting system [W]
- A – lighted area [m^2]
- L_m – luminance level after a specific exploitation period [cd/m^2]
- E_m – illuminance level after a specific exploitation period [lx]

Design assumptions and standard requirements

Two car parks located on the campus of Poznan University of Technology were used as test sites for the purpose of conducting illuminance measurements and calculating the energy efficiency. One of the car parks with the following dimensions: 21×52 m was modernized – LED lighting in the form of ALFA SL 1M 36W luminaires was installed. An old lighting system in the form of high pressure sodium lamps in MALAGA SGS104 luminaires is still used in the second car park with following dimensions: 72×18 m.

According to the PN-EN 13201 standard, the Poznan University of Technology car parks examined can be, as school car parks, classified as belonging to the S4 road lighting class (table 1).

Table 1. Car park lighting requirements according to the PN-EN 13201 standard

Road lighting class	Average illuminance Eśr [lx]	Minimum illuminance Emin [lx]	Lighting uniformity Uo [-]
S4	5	1	0.25

Energy efficiency calculations were conducted on the basis of two types of data.

Initially, the lighting in the two car parks described above was designed and modeled reflecting the original dimensions as well as the lighting type and distribution. The designs were created with the help of the Relux Professional software program.

Secondly, measurements verifying the compliance of the lighting used in the car parks with the design and with the standard were conducted.

Finally, all the most important data was compiled and the energy efficiency values for the two different lighting types were calculated and compared with the assumption that the legal conditions are the same.

The design and the measurements conducted in the car park equipped with LED lighting

The designed car park with the capacity of 28 parking places is 1092 m^2 with the following dimensions: 52×21 m. The car park lighting was based on 6 LED lamps – ALFA SL 1M 36W model with the total installed wattage of 216 W.

The lamps are hanged on 6 meter high poles placed regularly along the longer sides of the car park area. The poles are equipped with 1 meter long extension arms and the lamp inclination angle is 20°. A plan view of the car park is presented on Figure 1.

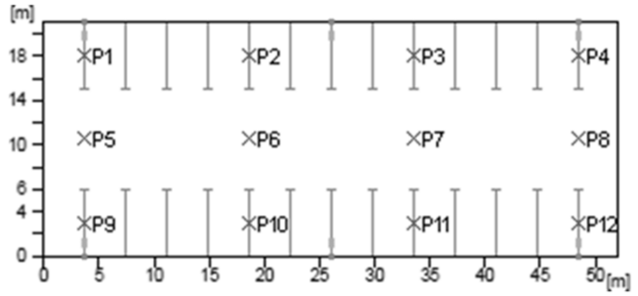

Fig.1. Plan view of the car park with LED lighting with markings indicating the illuminance measurement points

Illuminance measurements conducted on the car park surface were performed at night thanks to which the influence of natural light was eliminated. It was not possible, however, to separate the car park area from the lighting in its vicinity. This can lead to certain deviations from the values assumed in the design. Considering the dimensions and the intended use of the lighted area as well as the type of the light source, it is sufficient to perform one measurement per every 100 m^2. With the total car park area of 1092 m^2, the measurement grid includes 12 points (Fig. 1). Measurement results are presented in table 2.

Table 2. Results of illuminance measurements conducted in the car park equipped with LED lighting

No.	Measurement point	Illuminance [lx]			Uniformity
		E_m	E_{min}	E_{avg}	U_o
1.	P1	23	7	15.17	0.46
2.	P2	15			
3.	P3	12			
4.	P4	22			
5.	P5	11			
6.	P6	8			
7.	P7	7			
8.	P8	10			
9.	P9	24			
10.	P10	16			
11.	P11	13			
12.	P12	21			

After calculations conducted in the RELUX program, illuminance distribution presented on Figure 2 was obtained. The average illuminance value was E_{avg}=8.3 lx, and the minimum illuminance value was E_{min}=3.8 lx, which, in turn, gave the uniformity value of U_o=0.46.

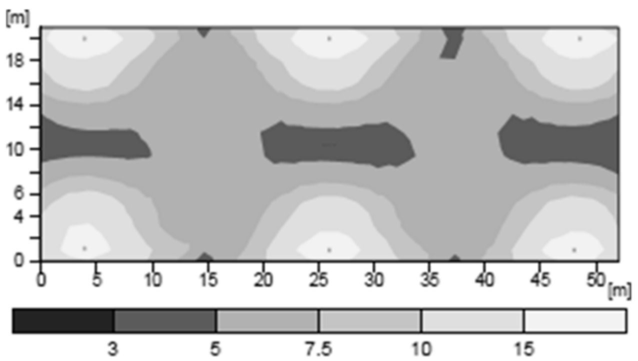

Fig. 2. Illuminance distribution on the car park surface with electroluminescent lighting

The measurements conducted confirmed the accuracy of the lighting installation design and verified the compliance with the standard. The newly installed LED lighting of the car park gave measurement results higher than the ones assumed in the design. However, according to the design assumptions, measurement results will be satisfied till the end of the warranty period. In relation to that, a certain maintenance factor influenced by different phenomena, such as dirt accumulation or weakening of the luminous lux emitted by the lamps over time or even full termination of the light source. Hence the discrepancies between the calculation results and the illuminance measurements. However, lighting uniformity is identical in both cases, which really should not change over time.

The design and the measurements conducted in the car park equipped with sodium lighting

The car park equipped with high pressure sodium lighting has the following dimensions: 72×18 m and its total area is 1296 m^2. 3 Philips Malaga SGS104 luminaires with the Philips SON-TPP150W sodium lamps are installed over the car park. The installed wattage is 507 W.

The lamps are hanged on 12 m high poles placed regularly along one of the longer sides of the car park. The inclination angle of the luminaires is 45° and they are protruding towards the middle of the car park on 1 meter long extension arms. The placement of the lamps is presented on the plane view of the car park (Fig. 3).

Fig.3. Plane view of the car park with high pressure sodium lamps with markings indicating the illuminance measurement points

Similarly to the measurements conducted in the car park equipped with LED lamps, in the case of sodium lamps it is also enough to perform one measurement per every 100 m^2. The measurement grid including 15 measurement points was used for the purpose of illuminance measurements for total car park surface area of 1296 m^2 (Figure 3). Measurement results are presented in table 3.

Table 3. Results of illuminance measurements conducted in the car park equipped with sodium lighting

No.	Measurement point	Illuminance [lx]			Uniformity
		E_m	E_{min}	E_{avg}	U_o
1.	P1	19	3	10.8	0.28
2.	P2	11			
3.	P3	23			
4.	P4	15			
5.	P5	20			
6.	P6	11			
7.	P7	8			
8.	P8	14			
9.	P9	9			
10.	P10	13			
11.	P11	4			
12.	P12	3			
13.	P13	5			
14.	P14	3			
15.	P15	4			

Calculations performed in the RELUX program for the car park lighted by means of high pressure sodium lamps provided illuminance distribution which is presented on Figure 4. The average illuminance value was E_{avg}=12.1 lx, and the minimum illuminance value was E_{min}=3.1 lx, which, in turn, gave the uniformity value of U_o=0.26.

The results of the measurements are close to the results of the calculations. The conclusion that can be drawn from that fact is that the lighting installation that has been in use for over a dozen years is seriously worn out. The light sources have lower luminous efficacy and the luminaires are dirty due to which it is not possible to obtain adequate luminous flux, which is not the case for new lighting installations. Despite the fact that the installation using high pressure sodium lamps is worn out to a considerable extent, it still meets the requirements of the PN-EN 13201 standard.

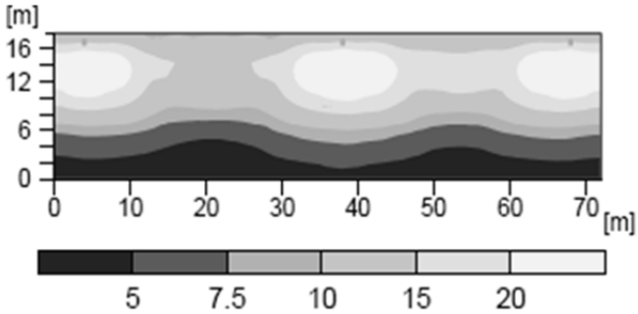

Fig. 4. Illuminance distribution on the car park surface with high pressure sodium lighting

Energy efficiency comparison between LED lamps and sodium lamps

Equation (2) expressed by means of illuminance values should be used when calculating the energy efficiency of car park lighting as the standard requirements pertaining to car parks refer to illuminance. The average illuminance value (5 lx) required by the standard was used as the Em parameter in the calculations as the design should comply with the standard requirements throughout a specific period of time, at least till the end of the warranty period.

The energy efficiency is:

a) for the car park equipped with LED lighting:

$$e_E = \frac{P}{A \cdot E_m} = \frac{216W}{1092m^2 \cdot 5lx} = 0.03956 \left[\frac{W/_{m^2}}{lx}\right] \quad (3)$$

b) for the car park equipped with sodium lamps:

$$e_E = \frac{P}{A \cdot E_m} = \frac{507W}{1296m^2 \cdot 5lx} = 0.07824 \left[\frac{W/_{m^2}}{lx}\right] \quad (4)$$

Table 4. Comparison of different parameters of electroluminescent lighting and high pressure sodium lighting

No	Parameter	Electroluminescent lamps	Sodium lamps
1.	Light source	Alfa LED SL 1M 36W	Philips SON-TPP 150W
2.	Number of lamps	6	3
3.	Installed wattage	216 W	507 W
4.	Annual electric energy consumption	864 kWh	2028 kWh
5.	Lighted area	1092 m^2	1296 m^2
6.	Wattage per unit area	0,2 W/m^2	0,39 W/m^2
7.	Energy efficiency	0,04 $W/m^2/lx$	0,078 $W/m^2/lx$
8.	Average illuminance	15,17 lx	10,8 lx
9.	Average luminance level	3,79 cd/m^2	2,7 cd/m^2
10.	Lighting uniformity	0,46	0,28
11.	Color rendering index	>80	>65
12.	Total luminous flux	17916 lm	52500 lm

The energy efficiency calculations for the car park lighting clearly indicate the advantage of electroluminescent light sources. Their efficiency is twice as high as the efficiency of lighting based on high pressure sodium lamps. Comparing other parameters of both lighting types, LED diodes also prove to be more advantageous (table 4).

While analyzing the energy efficiency of electroluminescent lighting and high pressure sodium lighting, one has to note that the installation using LED lamps consumes much less power – 216 W in comparison to 507 W of power consumed by sodium lamps. Lower wattage means lower electric energy consumption which means lower maintenance costs. LED lamps consume half of the electric energy per unit area compared to high pressure sodium lamps.

Conclusion

Electroluminescent light sources are perfect for street lighting purposes, constituting a good alternative to high pressure sodium lamps. Everywhere where low levels of luminance or illuminance are required, LED lamps provide better energy efficiency. Thanks to the white light of light-emitting diodes, higher color rendering index values can be obtained with relatively low power consumption. Better detail discrimination influences the safety of the cars and, especially, of the pedestrians walking across the car park.

Massive replacement of street lighting to a modern LED light source are blocked by the prices of luminaires, which could be even four times higher than the pressure sodium lamps. However, along technology develops, the LED products will become cheaper and the whole street lighting investment pays for itself quickly.

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