A METHOD TO ESTIMATE SAVINGS OF LED LIGHTING INSTALATION IN PUBLIC BUILDINGS
The Case Study of Secondary Schools in Serbia

by

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This paper examines the potentials of saving electric energy in school lighting by replacing the existent systems of lighting with more adequate ones which are based on light-emitting diode technology. Our primary goal is to present the methodology used in this analysis since it can be used to determine potential savings in lighting systems of any public building. We have performed the detailed analysis of nine high schools located in Kragujevac, Serbia. The first step was to collect the data about the numbers and types of systems utilized, as well as about the habits of their users. This has revealed the share of electricity consumption for lighting in total electricity consumption. The replacements for each existent light source have been proposed taking into consideration the projected value of light flux depending on the purpose of each room. The calculations of potential savings through the replacement of lighting systems have been conducted taking into consideration not only the savings in electric energy but also the savings made through the maintenance cost reduction. Based on the results, the potential savings range from 53-62% while the payback period for the analysed schools is about four years in average.

Key words: *light-emitting diode*, *lighting, energy saving, public buildings*

Introduction

Numerous studies have shown that 20 to 40% of globally used energy is utilized in building sector whose release of GHG reaches one third of global emission [1-3]. Buildings have potential to reduce energy consumption from 30 to 80% [4, 5].

According to IEA, the total consumption of final energy in the World in 2013 reached 3478 Mtoe with the share of electric energy consumption of about 22% (771 Mtoe). The share of commercial and public sector in total energy consumption was 14% (487 Mtoe) with 52% (251 Mtoe) of electric energy [2]. The building sector uses 64% (246 Mtoe) of produced electric energy while 50% is used in commercial and public sector, fig. 1.

According to Eurostat data [6], the consumption of final energy in EU 28 is 1104 Mtoe which is about 18% of total global energy consumption [7]. The building sector and commercial sector in EU 28 use about 41% of final energy [6].

The energy consumption in Serbia, as a developing country and an EU candidate is about 8.71 Mtoe per year with 27% (2.31 Mtoe) of electric energy consumption. In total electric energy consumption, 71% (1.64 Mtoe) is used in building sector with 18% (0.42 Mtoe) in commercial and

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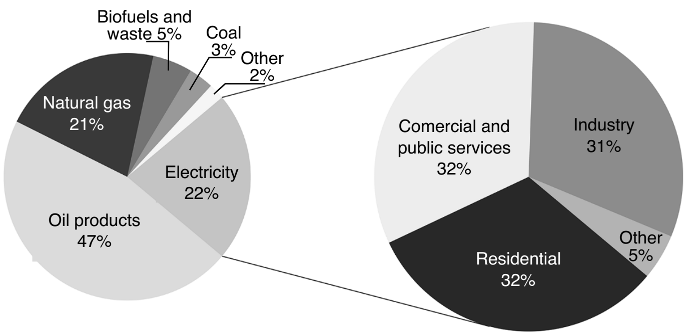

Figure 1. Global final energy consumption according to sectors [2]

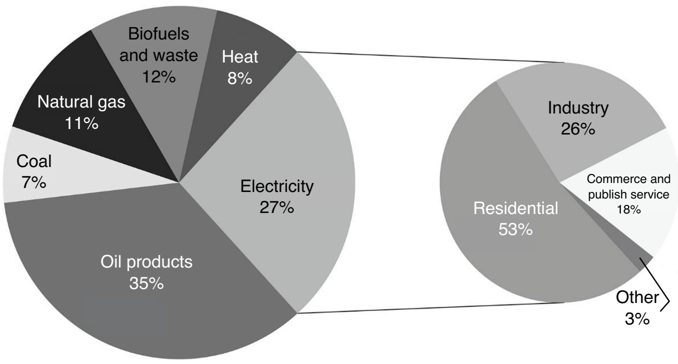

Figure 2. Final energy consumption in Serbia

public buildings, fig. 2. In these buildings, the share of electric energy consumption in total final energy consumption is 53% [8] (fig.3).

According to numerous studies, the share of energy consumption for lighting in total electric energy consumption in public buildings ranges from 30 to 60% [9-13].

The latest data reveal that 7% of primary energy in the developed countries is used for different types of lighting [14]. According to US Department of Energy [15], energy used for lighting has a share of about 7% in total final energy consumption, and 18% in electric energy consumption. In Canada [16], energy used for lighting in commercial sector has a share of 10% in total final energy consumption and 24% in electricity consumption. In Sweden, the share of energy used for lighting in total final energy consumption amounts to 23% of electric energy [17], and in Italy that value is about 16.4% [18]. In commercial buildings, lighting takes about 25-35% of total energy consumption [19].

In order to reach the norms of energy savings in buildings in terms of lighting [20-22], the best solution is to replace an existent system with energy-efficient one which would have the same emission flux and lower energy consumption [23]. The review reveals that the replacement of older lighting installations (T12 fluorescent lamps) with modern energy-efficient T5 lamps with HF ballasts could provide up to 40% energy savings. An additional 40% of energy savings could be obtained by using a combination of more energy-efficient luminaires, task/ambient lighting, occupancy switch-off and daylight dimming, making it possible to achieve totally 80% energy savings compared to older T12 fixed lighting installations [11, 24-32].

In addition to used power, the design of lighting system can also take into consideration the factors of heating (the quantity of heat produced through lighting), since it can have a significant influence on energy needs for cooling during the summer period [33]. With the recent increment of market penetration of light-emitting diode (LED) lightning technology, one of the interesting measures for increasing the efficiency of lighting systems in public buildings is the replacement of the existent systems with LED technology.

Lighting systems based on LED technology have become present on the market relatively recently. The characteristics of led lighting include more efficient usage of electricity, longer life, high level of light efficiency, flexible design and insignificant heat transfer. All the mentioned characteristics make this type of lighting source more attractive than other traditional light sources. The LED systems are not popular only as a modern design solution to contemporary architecture but they also have a significant value in terms of energy efficiency and can be applied as replacements for the existent lighting systems [34, 35].

Many manufacturers and distributers of LED lighting claim that through the usage of LED tubes the savings of up to 70% of electric energy can be made in respect to conventional fluorescent tubes. Doing so, they usually focus on potential savings of electric energy and all benefits of the longer life, neglecting the level of light efficiency of LED lighting [36-38].

The LED lighting has multiple advantages in respect to traditional lighting sources in terms of health and environment protection since it is made according to Restriction of Hazardous Substance Directive principles and it does not contain lead, mercury, cadmium nor hexavalent chromium which are harmful for the environment.

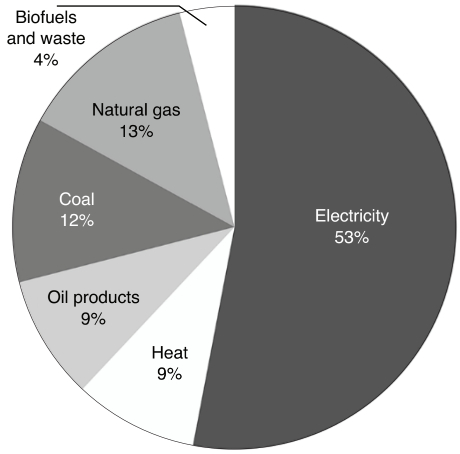

Figure 3. Energy consumption in commercial and public buildings in the Serbia

The LED lighting offers directed lighting (exactly where it is needed) unlike fluorescent lighting which emits lighting in numerous directions which means that light is not needlessly lost with LED technology. Secondly, there is a tendency that fluorescent lighting has a reduced lifespan when it is integrated with different sensors and/or other controlling devices. Quite contrary, LED lighting works perfectly with controlling systems [39, 40].

The purpose of the paper is to present the savings calculation methodology for the replacement of existing lighting systems with led systems in public buildings, taking into consideration not only the savings in electric energy, but also the savings made through the reduction of maintenance costs. The methodology presented in this paper is significant since it can be applied on all public buildings. The methodology is efficient but still simple enough so that it can be used by energy managers in order to reveal potential savings. Further on, it can be used to improve efficiency of lighting systems.

Methodology

This chapter introduces the methodology for determination of potential energy savings and cost savings when the existent lighting sources are replaced with adequate LED lighting sources. The first step was to collect the data from monthly electricity bills for the time period of at least one year including the system for charging electric energy consumption (tariff classes), total electric energy consumption and total costs of electricity. Besides, this phase of analysis includes detailed inspection of all buildings under investigation and interviews with users in order to obtain data about the numbers and types of lighting systems as well as the habits of their users. This is important in order to evaluate time engagement of lighting systems in buildings.

The electric energy consumption for lighting on yearly basis must be calculated for each type of the lighting system taking into consideration the differences in nominal power of light source as well as the fact that light sources are not equally engaged during one year. Based on the collected data about the number, power and type of lighting systems, as well as the working hours of each light source, the annual electric energy consumption for lighting is calculated with following equation:

$$ECL = \sum_{i=1}^{n} \sum_{j=1}^{m} NLH_j \ P_j \ H_{j,i} \tag{1}$$

where ECL [Wh per year] is the annual electricity consumption for lighting, NLH_j [–] – the number of light sources of j-type of lighting, P_j [W] – the nominal power of light source of j-type of lighting, H_j [h per year] – the estimated annual working hours of light source of j-type of lighting in i-tariff class, n [–] – the number of tariff classes, m [–] – the number of lighting source types.

The share of energy consumption for lighting in total electric energy consumption POL [%] is:

$$POL = ECL / AEC \, 100 \tag{2}$$

where AEC [Wh per year] is annual electric energy consumption.

Based on the values obtained for electric energy consumption for lighting, data about tariff systems of charge (category, class) and the price of electricity, the cost of electric energy used for lighting CEL, [€ per year] are calculated with:

$$CEL = \sum_{i=1}^{n} ECL_i \, EP_i \tag{3}$$

where ECL_i [kWh] is the electric energy consumption for lighting in i-tariff class and EP_i [€/kWh] – the average price of electric energy in i-tariff class.

Before the replacement of the existent lighting systems in a room, it is necessary to determine the quantity of light needed in the room depending on its purpose of use, number and size of the windows, equipment locations. The necessary measures must be taken in order to meet the standards of light quality and intensity. Thus, the information about spatial distribution of working desks and the purpose of the classroom are necessary in order to select the most adequate light source solutions. Based on the recommended values of light fluxes depending on the room purpose, the most adequate LED options should be selected. Table 1 presents some of the adequate LED replacements for the traditional light sources.

Table 1. Equivalents of light sources [41-48]

Type of bulb		Efficacy [lmW^{-1}]	Rated avg. life [hour]	Brightness [lm]						
				220+	400+	700+	900+	1300+	2200+	3000+
Standard incandescent		8-15	750-1000	25 W	40 W	60 W	75 W	100 W	/	/
Halogen		17-25	3000	18 W	28 W	42 W	53 W	70 W	/	/
CFL		50-70	10000	6 W	9 W	12 W	15 W	20 W	/	/
Fluorescent tube	T5	90-120	20000	6 W	8 W	13 W	14 W	/	28 W	32 W
	T8	60-80	10000	10 W	/	/	15 W	18W	25W	35 W
	T12	/	10000	/	/	20 W	20 W	18 W	34 W	/
LED		80-100	50000	/	/	10 W	/	18 W	/	/
LED bulb		90-110	45000	3 W	4 W	9 W	12 W	14 W	/	/

After the adequate replacement is selected for each of the existent light sources, the potential savings which could be made through the replacement of the existent light sources could be determined. Annual energy consumption of a modified system with LED lightning ECL_{rep}, [kWh per year] can be calculated eq. (1), and annual costs of electric energy of modified system with LED lightning CEL_{rep}, [€ per year] can be calculated using eq. (3). Therefore, annual potential savings in energy consumption *PSE*, [kWh per year] can be calculated with:

$$PS_E = ECL - ECL_{rep} \tag{4}$$

and annual potential savings in electric energy consumption *PSC*, [€ per year] are:

$$PS_C = CEL - CEL_{rep} \tag{5}$$

Payback period for the investments *PBP* [year] in the light system replacement is calculated according to:

$$PBP = (IC - MC) / PS_C \tag{6}$$

where *IC* [€] is the investment costs in LED lighting and *MC* [€] – the maintenance and replacement costs of the existing lighting systems for the expected payback period of the investment.

In eq. (6), maintenance and replacement costs of LED systems were not taken into account, since the LED systems have long life expectancy (manufacturers guarantee 40,000 working hours) which is longer than expected payback period.

Potential savings *PSAP*, [€] for the certain operational period *AP*, [year] can be also determined using the equation:

$$PSAP = PS_C\, AP - MCap \tag{7}$$

where *MCap* [€] is the difference of maintenance and replacement costs for of the existent and new (LED) system in the selected time period.

The next step would be to take into consideration the maximum usage of one light source in rooms by using daylight control sensors. The installation of light sensors and presence sensors can reduce the working hours of the lighting systems and electricity consumption also prolonging lifetime of the light source. Several studies have shown that the savings made through these measures range from 7-25% [49-53]. In addition to adequate usage of lighting system by using presence sensors in order to reduce energy consumption it is necessary to raise the awareness of the users about proper energy management. It is not uncommon to see that the windows of public buildings are covered with Sun blinds or venetian blinds during the day and that the light is on which is the case of direct energy loss. The proper management of light energy with the optimal usage of day light can save 25-60% of energy used for lighting [54, 55]. Bearing in mind that financial sources of the public sector in Serbia are limited, this method of saving in lighting systems was neglected in this paper. In addition, when it comes to public buildings, the bottom-up methodology, defined by the appropriate Ministry in order to implement separate measures of energy efficiency improvement, focuses only on the replacement of inefficient light sources with more efficient ones. These aspects should be included in our future studies.

Results and discussions

The methodology introduced in previous chapter is going to be applied to high schools located in the city of Kragujevac, Serbia. Table 2, shows the data about nine analysed schools. The table shows the basic data about the school buildings under investigation: area, the number of users, consumption of electric energy, and the cost of electricity for 2014. For the calculation

Table 2. The basic data about schools and the data about electric energy consumption in 2014

Secondary schools		Area [m^2]	The number of students [–]	The numbers of employees [–]	The consumption of active energy [kWh per year]	Annual costs for electric energy [€]	Annual specific consumption [kWh per student]	Annual specific consumption [kWhm^{-2}]
First Technical school	(1)	7520	1292	168	110711	10447	85.7	9.97
Economics school	(2)	2605	750	83	59420	4811	79.2	22.81
First Grammar school	(3)	7753	1165	114	182745	3838	156.9	23.57
Second Grammar school	(4)	9500	903	92	298680	26371	330.8	31.44
Second Technical school	(5)	2301	217	62	50440	5825	232.4	21.92
Polytechnics school	(6)	13343	1496	170	247020	23945	165.1	18.51
Medical school	(7)	5000	871	/	202855	4049	232.9	40.57
Music school	(8)	1350	1256	170	54420	4258	43.3	40.31
Toza Dragović	(9)	4 500	1205	/	101518	9074	84.25	22.56

of the costs of electricity the exchange rate 1 € = 120 RSD was used. The last two columns show the indicators of specific electric energy consumption for the selected high schools which range from 10-40 kWh/m^2 or 40-330 kWh per student per year. There are huge discrepancies in electric energy consumption in schools based on the area, the number of students and the type of a school.

Detailed inspection of all the buildings under investigation revealed the lighting in analysed school buildings is primarily based on the usage of fluorescent tubes T8 which use 90% of the energy needed for lighting, tab. 3.

In order to determine the electric energy consumption for lighting, it is important to evaluate the working hours of light bulbs per day taking into consideration that light bulbs do not work equally long during winter and summer months and that they are only used during school days. In this analysis it was estimated that daily engagement of an indoor light bulb is about 5.3 hours in average. For outdoors lighting, this value is significantly higher and is about 10.5 hours during the whole year in average. Based on the estimated values of hourly working time of light sources, annual electric energy consumption for all light sources in analysed buildings and corresponding share of lighting energy in total electric energy consumption were presented in tab. 4.

In average, 37% of total electric energy in analysed schools is used for lighting. The biggest share in energy consumption for lighting reaches 54% in School 2 (the school of social and humanistic orientation). The school has neither laboratories equipped with machines and appliances nor computer laboratories with significant number of personal computers so the lighting has such a large share in total energy consumption.

Table 3. The data about existing light sources and electric energy consumption for lighting

School	The type of light bulb	Power [W]	The number of light bulbs		Annual electric energy consumption for lighting [kWh]	The share in total electric energy consumption [%]
			Outdoor lighting	Indoor lighting		
1	Fluorescent tube T8	36	0	710	37126	34%
	Incandescent	100	0	26		
	Mercury bulb with ballast	125	6	12		
2	Fluorescent tube T8	36	0	92	31911	54%
		18	0	945		
	Incandescent	100	0	40		
	Mercury bulb with ballast	125	6	8		
3	Fluorescent tube T8	36	0	1476	76746	42%
		18	0	126		
	Incandescent	100	0	49		
	Incandescent	60	0	32		
	Mercury bulb with ballast	125	8	14		
4	Fluorescent tube T8	36	0	1680	87195	29%
		18	0	455		
	Incandescent	100	0	25		
	Mercury bulb with ballast	125	6	19		
5	Fluorescent tube T8	18	0	740	19824	39%
	Incandescent	100	0	15		
	Mercury bulb with ballast	125	4	5		
6	Fluorescent tube T8	36	0	1465	96739	39%
		18	0	312		
	Incandescent	100	0	163		
	Mercury bulb with ballast	125	10	54		
7	Fluorescent tube T8	36	0	369	53702	26%
		18	80	1297		
	Incandescent	100	0	7		
	Mercury bulb with ballast	125	3	8		
8	Fluorescent tube T8	36	0	208	16636	31%
	Fluorescent tube T8	18	0	292		
	Mercury bulb with ballast	125	2	3		
9	Fluorescent T8	36	0	622	39064	38%
	Fluorescent T8	18	0	257		
	Spotlight	200	0	6		
	Mercury bulb with ballast	100	6	24		

During the analysis of the given schools, the level of light was measured in order to determine whether the currently installed light sources meet the demands prescribed by the standard. In addition, these measurements helped us determine the exact number of LED tubes which would be necessary as an adequate replacement [56, 57]. The detailed analysis has shown that all currently existent systems fulfil these requirements and that it is not necessary to replace the whole lamp housings. Instead, only the bulbs should be replaced – fluorescent tubes with LED tubes.

Table 4 presents the recommended more energy efficient light sources replacement for the existing sources in analysed buildings. All proposed replacements are based on LED technology. Technical characteristics and average market prices of existing and recommended lighting system were obtained systematising data available from different sources: web sites of lighting equipment manufacturers, catalogues of products and on-line shops.

Table 4. The comparative characteristics of the existent lighting system and LED replacements [40-47]

<table>
<tr><th colspan="5">The existing lighting system</th><th colspan="5">The recommended replacement</th></tr>
<tr><th>Type of lighting</th><th>Nominal power [W]</th><th>Light flux [lm]</th><th>Lifetime [hour]</th><th>Price [€]</th><th>Type of lighting</th><th>Nominal power [W]</th><th>Light flux [lm]</th><th>Lifetime [hour]</th><th>Price [€]</th></tr>
<tr><td rowspan="2">Fluorescent tube</td><td>18+3*</td><td>800</td><td rowspan="2">≈10000</td><td rowspan="2">1.1</td><td rowspan="2">Led tube</td><td>10</td><td>920</td><td rowspan="2">>50000</td><td>4.6</td></tr>
<tr><td>36+6*</td><td>1620</td><td>18</td><td>1620</td><td>7</td></tr>
<tr><td rowspan="2">Incandescent</td><td>60</td><td>800</td><td rowspan="2">≈1000</td><td rowspan="2">0.4</td><td rowspan="2">Led bulb</td><td>7</td><td>800</td><td rowspan="2">>40000</td><td>6.25</td></tr>
<tr><td>100</td><td>1350</td><td>12</td><td>1650</td><td>8</td></tr>
<tr><td>Mercury bulb</td><td>125+33*</td><td>6000</td><td>≈7000</td><td>3</td><td rowspan="2">Led spotlight</td><td>80</td><td>6100</td><td rowspan="2">>40000</td><td>13.4</td></tr>
<tr><td>Spotlight</td><td>200</td><td>4000</td><td>≈3000</td><td>5</td><td>50</td><td>4000</td><td>25</td></tr>
</table>

*nominal power of the ballast

The LED systems with the same or similar value of the light flux use significantly less energy. For instance, 57% less energy consumption is with LED tubes comparing to fluorescent tubes and 88% with LED bulbs comparing to traditional mercury bulbs.

All analysed high schools belong to low voltage or medium voltage consumers. According to national electricity tariff system there are two tariff classes for each consumer: higher (valid from 7:00 a. m. to 11:00 p. m.) and lower (the rest of the day). Taking into count annual electricity costs and consumed electricity in each of tariff classes, average price of electricity was calculated for each school.

Table 5 shows the economic evaluations of the recommended measures. When calculating electricity costs, it was assumed that indoor light bulbs consume electricity in higher tariff class period while outdoor light bulb consumes electricity in lower tariff class period. With recommended replacements of the existing system with LED solutions the consumption of electric energy can be reduced by 53-60% which can reduce the electricity costs for 20-30%.

The costs of the investments were determined based on the market price of the product and the number of light sources needed in the buildings, while the maintenance costs were calculated as replacement costs of the light sources in the payback period taking into consideration their lifetime and number of working hours per year. The economic analysis did not take into account possible changes in inflation rate since the expected payback period is less than five years.

Table 5. Potential savings of replacing traditional systems with LED technology

School	Electricity consumption after the replacements [kWh/year]	Potential savings [kWh/year]	Savings [%]	Investment costs [€]	Maintenance costs for traditional system before payback time [€]	Average price of electricity [€/kWh]		Investment payback period [year]
						Lower tariff	Higher tariff	
1	15834	21292	57%	5475	866	0.052	0.052	4.54
2	14463	17448	55%	5200	1270	0.047	0.071	3.59
3	31501	45245	59%	11887	1950	0.062	0.062	3.89
4	37619	49576	57%	14516	1500	0.07	0.07	3.77
5	9044	10780	54%	3630	530	0.047	0.071	4.21
6	38292	58447	60%	13950	1460	0.031	0.064	3.33
7	25274	28428	53%	8814	1900	0.021	0.064	4.81
8	7580	9056	54%	2880	350	0.047	0.07	4.08
9	16928	22136	57%	6134	650	0.047	0.07	3.52

The analysed schools paid different prices for electricity because they used different tariff system and classes. For each of the school average price of electricity in lower and higher tariff was calculated based on total costs for the electricity and corresponding active power consumption in each of the tariff.

Based on the data presented in tab. 4, it is obvious that the application of LED lighting systems instead of traditional ones (fluorescent tube, incandescent bulbs, *etc.*) leads to significant savings and attractive investment payback time (around four years in average).

Figure 4, shows cumulative savings which can be made in ten years period (period when failure of a LED lump should not occur) for School 2 whose consumption of electric energy for lighting is 54% of total electricity consumption. After ten years, the replacement with LED lightning in the school would make potential savings of 8709 €. The analysed period can be even longer, because the average annual engagement is from 1000-4000 hours for indoor lighting and 3800 hours for outdoors lighting, but taking into consideration the rapid development of new technologies, ten-year-period is enough to prove the high profitability of the investments into the replacement of traditional lighting systems with new LED light sources.

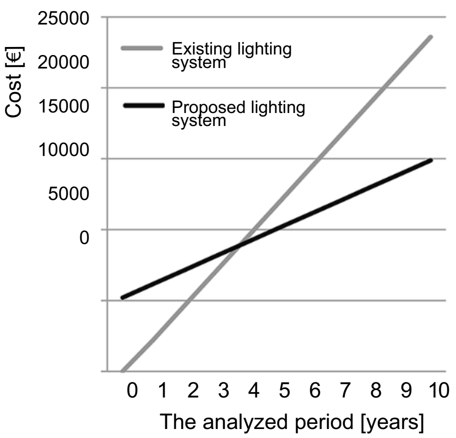

Figure 4. Cumulative costs of the existent and recommended system of lighting

Concluding remarks

The primary goal of this paper was to present the methodology for evaluating potential savings in lighting systems of public buildings by replacing the existent light sources with LED technology. This study performed on schools reveals that the proposed methodology is efficient and easy to use by energy managers. It can be applied in any techno-economic analysis for any public building with necessary modifications in terms of tariff system, electricity price and lighting characteristics and needs.

The study presented in this paper is also significant since it shows that potential savings in lighting systems in public buildings, which can be performed through the replacement of the traditional lighting systems with LED lighting, are considerate. The replacements like these can save up to 60% of electric energy costs for lighting. If other factors which influence the electric energy costs are taken into consideration (for tariff systems where engaged power and reactive energy are charged for) the savings can be even higher. Even though the initial investment into LED systems is relatively high, the payback period for the whole investment is less than five years which is acceptable, taking into consideration the lifetime of these systems and the fact that it is expected that the price of electricity will raise in the future. The investment into replacement of the existent lighting systems with LED technology is especially attractive to those buildings with high share of electric energy consumption on lighting (40-60%) such as schools, kindergartens, universities. These nine schools analysed in this paper spend 29400 € on lighting and 17100 € can be annually saved with new LED solutions. In addition to electric energy consumption for lighting, LED technology can reduce the emission CO_2. Taking into consideration emission factor for Serbian national electricity grid [58], the reduction of CO_2 emission in the schools can be estimated to 140 tons per year.

It is important to note that the appropriate choice of LED solutions is an important factor which influences the efficiency of lighting systems. There are a large number of unreliable manufacturers and suppliers who want to attract more customers through lower initial investment which eventually may result in the reduction of planned long-term benefits in terms of energy saving since the lighting sources may have lower energy efficiency, inappropriate colour or unknown life expectancy.

Nomenclature

AEC – annual electric energy consumption, [Wh per year]
AP – certain operational period, [year]
CEL – cost of electric energy used for lighting, [€ per year]
CEL_{rep} – annual costs of electric energy of modified system with LED lightning, [€ per year]
ECL – annual electricity consumption for lighting, [Wh per year]
ECL_i – electric energy consumption for lighting in *i*-tariff class, [kWh]
ECL_{rep} – Annual energy consumption of modified system with LED lightning, [kWh per year]
EP_i – the average price of electric energy in *i*-tariff class, [€ per kWh]
H_j – the estimated annual working hours of light source of *j*-type of lighting in *i*-tariff class, [h per year]
IC – the investment costs in LED lighting, [€]
MC – maintenance and replacement costs of the existing lighting systems for the expected payback period of the investment, [€]
MCap – difference of maintenance and replacement costs for of the existent and new (LED) system in the selected time period, [€]
m – number of lighting source types, [–]
NLH_j – number of light sources of *j*-type of lighting, [–]
n – number of tariff classes, [–]
P_j – nominal power of light source of *j*-type of lighting, [W]
PBP – Payback period for the investments, [year]
POL – share of energy consumption for lighting in total electric energy consumption, [%]
PSAP – Potential savings, [€]
PS_C – annual potential savings in electric energy consumption, [€ per year]
PS_E – annual potential savings in energy consumption, [kWh per year]

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References

[1] ***, WBCSD, Energy Efficiency in Buildings-Transforming the Market, Technical Report, 2009
[2] ***, The IEA Website, 2015, Available: http://www.iea.org/
[3] Amir, S., *et al.*, A Model for Optimal Energy Planning of a Commercial Building Integrating Solar and Cogeneration Systems, *Energy*, *61* (2013), Nov., pp. 211-223
[4] ***, Sbci, S. B. A. C. I., (2012), Why Buildings, Available: http://www.unep.org/sbci/AboutSBCI/Background.asp
[5] Salleh, M. N. M., *et al.*, Users Perception of Energy Efficiency in School Design, Asian Conference on Environment-Behaviour Studies, *Procedia – Social an d Behavioral Sciences*, *170* (2015), pp. 155-164
[6] ***, The Eurostat Website, (2015), Available: http://ec.europa.eu/eurostat, (assessed on: 02-17-2016)
[7] ***, U. S. Department of Energy, Buildings Energy Data Books, Available: http://buildingsdatabook.eren.doe.gov/, (assessed on: 02-17-2016)
[8] ***, Energy Balance of Serbia Republic, (2015), Available: http://www.mre.gov.rs, (assessed on: 02-17-2016)
[9] Philip, C. H. Yu., Chow, W. K., A Discussion on Potentials of Saving Energy Use for Commercial Buildings in Hong Kong, *Energy*, *32* (2007), 2, pp. 83-94
[10] Manuel, J. H. O., Jose Ramon de, A. D., Comparative Study of Energy – Efficiency and Conservation Systems for Ceramic Metal – Halide Discharge Lamps, *Energy*, *52* (2013), Apr., pp. 258-264
[11] Julian Di, S., Energy Efficiency and the Environment: the Potential for Energy Efficient Lighting to Save Energy and Reduce Carbon Dioxide Emissions at Melbourne University, Australia, *Energy*, 25 (2000), 9, pp. 823-839
[12] Marco, B., *et al*., Improvement of Energy Efficiency and Quality of Street Lighting in South Italy as an Action of Sustainable Energy Action Plans, The Case Study of Comiso (RG), *Energy*, *92* (2015), Part 3, pp. 394-408
[13] ***, Energy Information Administration and Green Econometrics Research According to the EIA. Available: http://www.eia.gov/consumption/commercial/, (assessed on: 02-17-2016)
[14] Powell, K., Lessons from the Field, Solid-State Lighting Program: U. S. Department of Energy, http://apps1.eere.energy.gov, (assessed on: 02-17-2016)
[15] ***, DoE, 2012. U.S. Lighting Market Characterization, Solid-State Lighting Program: U. S. Department of Energy
[16] ***, Natural Resources Canada (NRCan), 2012, Energy Use Data Handbook, 1990 to 2009
[17] Bladh, M., Krantz, H., Towards a Bright Future, Household Use of Electric Light: A Microlevel Study, *Energy Policy*, *36* (2008), 9, pp. 3521-3530
[18] ***, Program Agreement MSE/ENEA, Financial-Economic Solutions for the Redevelopment of Public Lighting, Lumiere, March, 2011
[19] Dubois, M.-C., Blomsterberg, A., Energy Saving Potential and Strategies for Electric Lighting in Future North European, Low Energy Office Buildings: A Literature Review, *Energy Buildings*, *43* (2011), 10, pp. 2572-2582
[20] ***, International Organization for Standardisation, ISO 13790: Energy Performance of Buildings – Calculation of Energy Use for Space Heating and Cooling, ISO Publication, Geneve, 2008
[21] ***, European Committee for Standardisation, EN 15193: Energy Performance of Buildings – Energy Requirements for Lighting, Available: http://www.iar.unicamp.br/lab/luz/ld/normas%20e%20relat%F3rios/en_15193-1_energy_requirements_for_lighting.pdf
[22] ***, European Committee for Standardisation, EN 12464-1: Light and Lighting – Lighting of Work Places – Part1: Indoor Work Places, Brussels, 2011
[23] Salata, F., *et al*., An Economic Perspective on the Reliability of Lighting Systems in Building with Highly Efficient Energy: Acase Study, *Energy Conversion and Management*, *84* (2011), Aug., pp. 623-632
[24] Nadel, S. M., A Review of U. S. and Canadian Lighting Programs for the Residential, Commercial and Industrial Sectors, *Energy – The International Journal*, *18* (1993), 2, pp. 145-158
[25] Hollander, J. M., Schneider, T. R., Energy Efficiency: Issues for the Decade, *Energy – The International Journal*, 21 (1996), 4, pp. 273-287
[26] Piette, M. A., *et al*., Diamond, R., Findings from a Low-Energy, New Commercial – Buildings Research and Demonstration Project, *Energy – The International Journal*, *20* (1995), 6, pp. 471–482
[27] Giovani, C., *et al*., Retrofitting Solutions for Energy Saving in a Historical Building Lighting System, *Energy Procedia*, *78* (2015), Nov., pp. 2669-2674

[28] Dubois, M. C., Blomsterberg, A., Energy Saving Potential and Strategies for Electric Lighting in Future North European, Low Energy Office Buildings: A Literature Review, *Energy and Buildings*, *43* (2011), 10, pp. 2572-2582
[29] Krarti, M., *et al*., A Simplified Method to Estimate Energy Savings of Artificial Lighting Use from Daylighting, *Building and Environment*, *40* (2005), 6, pp. 747-754
[30] Delvaeye, R., *et al*., Analysis of Energy Savings of Three Daylight Control Systems in a School Building by Means of Monitoring, *Energy and Buildings*, *127* (2016), Sept., pp. 969-979
[31] Fontoynont, M., *et al*., Economic Feasibility of Maximising Daylighting of a Standard Office Building with Efficient Electric Lighting, *Energy and Buildings*, *110* (2016), Jan., pp. 435-442
[32] Liu, J., *et al*., Fuzzy Logic Controller for Energy Savings in a Smart LED Lighting System Considering Lighting Comfort and Daylight*, Energy and Buildings*, *127* (2016), Sept., pp. 95-104
[33] Sun, L., *et al*., Simulation and Evaluation of the Peak Temperature in LED Light Bulb Heatsink, *Microelectronics Reliability*, *61* (2015), Jine, pp. 140-144
[34] Caicedo, D., *et al*., Occupancy-Based Illumination Control of LED Lighting Systems, *Lighting Research and Technology*, *43* (2011), 2, pp. 217-234
[35] Hoelen, C., *et al*., Remote Phospor LED Modules for General Illumination: Towards 200 lm/W General Lighting LED Light Sources, *Proceedings,* 8th SPIE – Eight International Conference on Solid State Lighting, San Diego, Cal., USA, 2008
[36] Myer, M. A., *et al*., CALIPER Benchmark Report-Performance of T12 and T8 Fluorescent Lamps and Troffers and LED Linear Replacement Lamps, Prepared for the U. S. Department of Energy by Pacific Northwest National Laboratory, PNNL-18076, 2009
[37] ***, Energy Efficient Behavior Blog, Incandescent *vs* CFL *vs* LED: Which Saves More Energy, Available: http://class5energy.com/blog/incandescent-vs-cfl-vs-led-which-saves-more-energy/, (assessed on: 02-17-2016)
[38] Wang, J. C., A Study on the Energy Performance of School Buildings in Taiwan, *Energy and Buildings*, *133* (2016), Dec., pp. 810-822
[39] Rossi, M., Pandharipande, A., Personal Lighting Control with Occupancy and Daylight Adaptation, *Energy and Buildings*, *105* (2015), Oct., pp. 263-272
[40] Caicedo, D., Pandharipande, A., Daylight-Adaptive Lighting Control Using Light Sensor Calibration Prior-Information, *Energy and Buildings*, *73* (2014), Apr., pp. 105-114
[41] ***, LED Lighting Retrofits, BU Sustainability, Available: http://www.bu.edu/sustainability/what-were-doing/energy/led-lighting-retrofits/, (assessed on: 02-17-2016)
[42] ***, Hitachi LED Lighting, Available: http://www.hitachi.com/environment/showcase/solution/appliances/led_lighting.html, (assessed on: 02-17-2016)
[43] ***, Introducing the Most Energy Efficient LED Lighting Solution for Your Home or Office, Evobrite, Available: http://www.evobrite.com/, (assessed on: 02-17-2016)
[44] ***, Your Guide To Buying Led Light Bulbs, EDEN Ilumination, Available: http://www.edenillumination.co.uk/blogs/news/tagged/buying-led-light-bulbs, (assessed on: 02-17-2016)
[45] ***, How LED Lighting Can Save Our Planet – And Why It's Not Happening, TIMnovate, Available: https://timnovate.wordpress.com/2013/03/09/how-led-lighting-can-save-our-planet-and-why-its-not-happening/, (assessed on: 02-17-2016)
[46] ***, LED Light Bulbs Review – Choose the Best LED Bulbs, Lighting Ideas, Available: http://www.lighting-ideas.net/2015/06/LED-bulbs-review.html, (assessed on: 02-17-2016)
[47] Tagare, D. M., *Reactive Power Management*, Electric Engineering, MCGraw-Hill Education, India, 2004
[48] Xianming, Y., *et al*., Optimal Maintenance Planning for Sustainable Energy Efficiency Lighting Retrofit-Projects by a Control System Approach, *Control Engineering Practice*, *37* (2015), Apr., pp. 1-10
[49] Pandharipande, A., Caicedo, D., Daylight Integrated Illumination Control of LED Systems Based on Enhanced Presence Sensing, *Energy and Buildings*, *43* (2011), 4, pp. 944-950
[50] Stolshek, J. D., Koehring, P. A., Ultrasonic Technology Provides for Control of Lighting, *IEEE Transactions on Industry Applications*, *20* (1984), 6, pp. 1564-1572
[51] Li, Z. K., *et al*., Airborne Ultrasonic Potential in Intelligent Control, *Proceedings,* 5th IEEE International Symposium on Intelligent Control, Philadelphia, Penn., USA,1990, pp. 1261-1265
[52] Magori, V., Walker, H., Ultrasonic Presence Sensors with Wide Range and High Local Resolution, IEEE Transaction on Ultrasonics, *Ferroelectrics and Frequency Control*, *34* (1987), 2, pp. 202-211
[53] Li, D. H. W., Lam, J. C., Evaluation of Lighting Performance in Office Buildings with Daylighting Controls, *Energy and Buildings*, *33* (2001), 8, pp. 793-803

[54] Reinhart, C. F., Effects of Interior Design on the Daylight Availability in Open Plan Offices, *Proceedings,* ACEEE Summer Study on Energy Efficient Buildings, Pacific Grove, Cal., USA, 2002, pp. 1-12

[55] Galasiu, A. D., Veitch, J., Occupant Preferences and Satisfaction with the Luminous Environment and Control Systems in Daylight Offices: A Literature Review, *Energy and Buildings*, *38* (2006), 7, pp. 728-742

[56] ***, Schools – A Guide to Energy Efficient and Cost Effective Lighting, Sustainable Energy Authority of Ireland, Available: http://www.seai.ie/Publications/Your_Business_Publications/Technology_Guides/General_Lighting_Guide_FNL.pdf, (assessed 11.12.2016)

[57] ***, Rules of Norms School Space, Equipment and Teaching Aids for School, Available: http://www.sacuvajmoratkamitrovica.org/wp-content/uploads/2014/07/Pravilnik-o-normativima.pdf, (assessed 05.02.2017)

[58] ***, Regulations on Energy Efficiency in Buildings, Official Gazette of Republic of Serbia, No. 61/2011, Available: http://www.ingkomora.org.rs/strucniispiti/download/ee/PRAVILNIK_O_EEZ_za%20obuku.pdf, (assessed on: 02-17-2016)

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