Reconstruction of the Street Lighting System as a Tool for Electrical Energy Savings

Case Study

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Abstract *– Street lighting systems today are important consumers of electrical energy. Those systems are also not negligible producers of CO2. Because of that, great efforts are made (especially today) to find optimal solutions to save electrical energy in street lighting. In this paper, we give a literature review in the fields of street lighting energy audit and possibilities of electrical energy savings in street lighting. Then, a case study report of the city of Široki Brijeg (Bosnia and Herzegovina) is analyzed. In this case study, one energy audit method is described and applied. After that, several scenario strategies of electrical energy savings based on reconstruction of existing street lighting systems are described and applied, too. As a result, we noticed that high electrical energy savings can be obtained by using optimally sized sodium luminaires or sodium luminaires with step-dimming ballasts. That conclusion was made after the proposed energy audit was done and the proposed scenario strategies of electrical energy savings were examined. The workflow presented here can be used for any case study.*

Keywords *– street lighting, energy audit, electrical energy saving, case study report*

1. INTRODUCTION

Public lighting was first used for security reasons. Today, street lighting is experienced as something ordinary and necessary for normal life. People do not think about what their life would be like without street lighting. Although the benefits of street lighting are far greater than disadvantages, there are some negative aspects of street lighting. Since street lighting is almost always available, people's eyes got used to it. Many of the drivers complain about loss of night vision, i.e., that it is difficult to adapt the pupil during the light-dark transition and vice versa. Also, one of the major problems of street lighting is light pollution. A large amount of light causes damage to animals and to bird migration [1]. Street lighting is also a great consumer of electrical energy. Scientific and technical literature does not sufficiently monitor the possibilities of electrical energy savings in street lighting. Furthermore, owners of street lighting (usually cities and municipalities) quite often conduct street lighting related projects without issuing quality project documentation in advance and with cheap light sources. But, that practice leads to a negative impact of street lighting electrical energy bills on the budgets of those cities or municipalities (in Bosnia and Herzegovina, those budgets are quite poor). Today, as electrical energy savings in street lighting as well as CO2 emission reduction are very important, there is a need for quality planning of new street lighting projects and for detailed analysis of savings in the existing street lighting systems (reconstruction of the existing street lighting systems). Money savings that can be achieved in street lighting (smart planning of new street lighting and reconstruction of the existing ones) can be then better invested in other needs of the budget. The existing energy audit methodologies of street lighting systems will be described in Section 2. The goal of the street lighting audit is to obtain relevant data for planning of street lighting reconstruction. The audit methodologies described here are the basis for an analysis of the current street lighting system and for planning its reconstruction. In Section 3, the existing scenario strategies of electrical energy savings in street lighting will be described as a literature review. Section 4 is an example of a (case study) report of the city of Široki Brijeg (an urban area) in terms of electrical energy savings in street lighting. The current state of street lighting in the urban area of Široki Brijeg is analyzed. It is done according to the proposed methodology of the street lighting energy audit. Also, through various scenario strategies of street lighting reconstruction, electrical energy savings in street lighting are analysed.

2. PUBLIC LIGHTING ENERGY AUDIT METHODOLOGY AS THE BASIS FOR THE CURRENT STATE ANALYSIS

A quality energy audit of street lighting represents a basis for quality analysis of the current state in street lighting. A quality methodology street lighting energy audit consists of the following: gathering basic information about the user, analysis of the available project documentation, description of the street lighting system with mapping of the existing installations, analysis of electricity bills, the correctness of the system, etc. [2]. A street lighting energy audit includes analysis of [2]:

- Electric meters, switchboards and wiring systems;
- Specific areas of street lighting;
- Types of light sources used;
- Luminaires and light sources;
- The control system and regulation.

Basic data about the street lighting system need to encompass data about the number of luminaires and light sources with their types, installed power of the system, length of the street lighting system, settlement area, the number of electric meters, the distance between street light poles, annual consumption of electricity, and average illumination [2]. According to [3], the minimum content of a street lighting energy audit contains:

- Basic data about the existing technical and project documentation;
- Geometric and technical parameters of the existing street lighting system;
- Elements of the street lighting system;
- Installed power of the street lighting system;
- Analysis of electric energy consumption and maintenance costs.

An energy audit of street lighting is a systematic process of acquiring the appropriate knowledge about existing energy consumption, and it can be performed only by an authorized natural or legal person. Public lighting infrastructure includes luminaire posts, lighting fixtures, light sources and a management system. In addition to carrying out legal obligations and integration into the EU energy standards, by means of street lighting energy audits local governments can obtain all necessary data for a complex techno-economic analysis of the local street lighting system and in this way complete the first stage of preparation for the modernization of street lighting, or implementation of energy efficiency measures. This primarily refers to the replacement of traditional light sources (which are large consumers of electrical energy) with contemporary sources and implementation of street lighting control systems. A street lighting system energy audit includes an analysis of electrical energy consumption from a supply point (i.e., an electricity meter connected directly to the distribution transformer) to the place of final consumption, in this case - light sources [4].

Analysis of technical and energy performance of street lighting systems includes [4]:

- Analysis of the connection place to the grid, distribution, switchboards and substations;
- Analysis of specific areas of street lighting;
- Analysis of types of light sources used;
- Analysis of luminaires that contain light sources; and
- Analysis of street lighting regulation and management.

The street lighting pilot project in the city of Rijeka (Croatia) [5] can be used as a model for other cities in their energy efficiency street lighting projects. Therefore, a proposed methodology includes:

- A review and database of the existing street lighting grid for mathematical modelling;
- Public lighting electric energy consumption analysis;
- Identification of different energy efficiency street lighting measures;
- Model simulation and calculation of possible electricity savings and CO_2 emission reductions;
- Feasibility analysis, investment and deployment of measures;
- Measurement and evaluation of improvements.

In [6], a detailed survey of street lighting systems is elaborated. A system upgrade project has been elaborated. To do this, many lighting simulations, energy and economic assessments in various scenarios have been performed. The obtained results show that high electrical energy and economic savings in street lighting are possible.

The adopted methodology includes the following steps [6]:

- A review of the existing street lighting grid;
- Analysis of electrical energy consumption based on both electricity bills and current operating conditions;
- Compilation of a database of the existing street lighting devices;
- Simulation of some energy efficiency actions;
- Construction of project scenarios;
- Calculation of possible electrical energy savings;
- Feasibility based on economic analysis.

In [7], the first step in creating energy efficient street lighting is to conduct an energy audit. According to the Croatian Energy Efficiency Act of 2014, municipalities are obligated to conduct an energy audit on the status of their street lighting systems every five years. The main purpose of energy audits is to present the full picture of the municipality's lighting system and point toward black spots that need reconstruction due to energy inefficiency, light pollution, or else. Every energy report must contain suggested methods for dealing with the aforementioned black spots. The second step is to create technical documentation. According to the Book of Regulations for Construction of Simple Buildings (related to the Croatian Construction Act) of 2013, work can be done without a building permit and in accordance with the main design in case of reconstruction of street lighting systems in order to enhance their energy efficiency. The main design is a subsequent step of an energy audit, where a lighting designer uses data gathered in the energy report and defines technical solutions for dealing with black spots of the lighting system. The third and the last step is (re)construction work based on the main design and the energy report. Fund's requirements are compatible through all three steps. The present state of the street lighting system – data is usually drawn from the energy audit, but limited to a certain area, the so-called black spot, for which given reconstruction is intended. Mandatory data are the number, power, type and model of luminaries, data on poles (including geometry arrangement), type of light pollution protection zone, etc. All these data are crucial for creating photometric and electrical energy consumption analysis. Photometric analysis is made by using specialized computer programs such as Relux, Dialux, and the like. Standard "EN 13201: 2003", the main European standard for road lighting also used in Croatia under the code "EN 13201: 2003", is used to determine minimal photometric values needed for traffic safe street lighting. The case where the present state of the street lighting system corresponds with all minimal photometric values of "EN 13201: 2003" is considered referent. That is usually not the case, so an assessment of the referent state must be conducted.

In [8], the usage of open source GIS tools in energy auditing of a street lighting system is described.

3. THE EXISTING SCENARIO STRATEGIES OF ELECTRICAL ENERGY SAVINGS IN PUBLIC LIGHTING

Focusing on electrical energy figures of urban lighting system refurbishments, the main technological solutions able to achieve relevant energy savings are [6]:

- Installing on/off switching systems;
- Replacing luminaires and/or light sources with other having good optics and high efficiency luminaires;
- Installing luminous flow regulators on switchboards;
- Stabilizing voltage in the system.

In [6], several scenarios have been developed for electrical energy savings in street lighting for a case study in the city of Comiso (Italy). In all these scenarios, electrical energy savings have been calculated considering the associated installed power and equivalent operating hours, as described in the paper.

In [9], analysis of the main elements in street lighting is conducted so to understand how each element of street lighting affects final electrical energy consumption.

The idea that installation of luminaires at every second or even third or fourth pole is good because of electrical energy savings resulted in a system that could not be called safe traffic lighting. Ironically, when luminaires were mounted at every pole, a usual strategy was to shut down every second luminaire in late night hours in order to save energy, thus reducing traffic safety [7].

According to [7], projects created with a simple 1-for-1 method of changing old luminaries with new ones without complying with all technical requirements are not acceptable. Oversized systems designed with the idea that more light is better, often reduce a potential increase in energy efficiency.

According to [10], in the area of street lighting energy savings the most common activities include the replacement of the existing luminaires equipped with high pressure mercury (HPM) lighting sources by modern luminaires with high pressure sodium (HPS) or metal-halide (MH) lighting sources. Also, old luminaires with IP54 degree of protection (dust protected and protected against splashing water) and conventional HPS luminaires are replaced with modern luminaires with improved optics, better mechanical protection (usually IP65: dust-tight and protected against water jets) and HPS luminaires of improved photometric and technical properties. Through such actions, sometimes with reason, but more often not, attempts to reuse the existing poles, pole locations and luminaire mounting locations, are applied. Very often, taking into consideration only photometric requests, energy savings, the maintenance period and the cost of installation, HPS luminaires, characterized by poor color rendering, are inappropriately applied (in parks, at squares, promenades, shopping areas, etc.), creating an unpleasant environment. With energy savings as the goal, dimming systems are sometimes applied (in the form of step-dimming ballasts or centralized control systems), frequently without adequate information regarding their installation and application.

Recommendations relevant to energy savings [10]:

- Prior to reconstruction of street lighting a choice between an upgrade and redesign should be made;
- Special attention should be given to determination of the street lighting class;
- Measurements for determining road surface reflection properties are recommended;
- If HPS luminaires are applied, they should be with improved photometric and technical characteristics;
- Luminaires which are efficient are recommended;
- Luminaires characterized by the power factor of at least 0.95 are recommended.

According to [11], electrical energy savings (25%-70%) in the street lighting system can be managed in different ways. One simple way is proper adjustment of the timer and the most efficient one is replacement of obsolete luminaires with those that are more efficient.

In [12], the measures available to achieve the maximum output of street lighting without reducing lighting efficiency are as follows:

- Substitution of inefficient light sources and luminaries;
- Reduction of operating times;
- Reduction of power and/or the number of luminaries;
- Control system improvement.

According to [13], energy performance of the existing street lighting can be improved up to 60% by using more efficient light sources, by dynamic level control of the illumination level and by optimization of the illumination spectrum on human eye. Regulation of the level of illumination should be carried out by power control. It is recommended that the power should not be reduced below 50%.

[14] deals with street lighting management as a way of saving street lighting costs.

Energy saving in Slovenian municipalities ranges from some 10%, when renovating relatively modern lighting installations, to some 50%, when renovating very obsolete and deteriorated lighting installations. Similarly, the investment payoff time ranges between 3 years and 15 years, respectively [15]. Renovation included all luminaires, for which all luminaires were replaced with more efficient high pressure sodium (HPS) luminaires. 400 W HPM luminaires were replaced with 250 W HPS luminaires, 250 W HPM luminaires with 150 W HPS luminaires and 125 W HPM luminaires with 36 W fluorescent luminaires.

According to benchmarking as a way of thinking, municipalities' own operations are always compared with the operations of the best municipality in the data that are compared. There are some possibilities for significant savings in street lighting of the compared municipalities. They are as follows [16]:

- In relation to energy consumption: 15...40%;
- In relation to the cost of energy: 15...50%;
- In relation to maintenance: 50...70%.

Reaching these savings requires many different measures. Some of these, such as checking of the price of electrical energy, do not affect the level of lighting service in any way. On the other hand, reduction in energy consumption and the level of maintenance necessitate that suitable balance has to be searched for between the level of service and economy [16].

Road lighting practices vary from one country to another [17]. In Slovenia, in many luminaires high pressure mercury (HPM) luminaires were replaced with high pressure sodium (HPS) luminaires together with ballasts along major (state) roads. Although the achieved energy savings were considerable, the main reason for replacement was to achieve better lighting conditions. In most cases, municipalities simply replace the old luminaires with new ones on the same poles. As indicated in examples from Ljubljana and Medvode, HPS and CFL luminaires are mostly frequently used. In addition to this option, some municipalities also try to reduce energy consumption with measures like [17]:

- Reduction of voltage and also reduction of energy used;
- Use of two-step regulation ballasts to reduce luminance and power consumption in the night time;
- Switching off the lights in the night time.

One possibility to save electrical energy in street lighting is also to introduce control systems. In Finland [17], only high pressure sodium luminaires have been installed since 1993. Replacement of high pressure mercury luminaires in road lighting has been made to old poles by changing only the luminaire. Luminaire power has been chosen according to pole spacing. For example, a 250 W HPM luminaire has been replaced with a 100 W HPS luminaire. In park areas, replacement has been made by using an induction luminaire (55 W, 84 W). In Espoo, 20% of energy savings have been achieved by switching off every second luminaire between 10 pm and 6 am. In Espoo again, there are approximately 150 control centers for turning off every second luminaire. Turning off every second luminaire has been in use since 1982. There are also approximately 600 autotransformer control centers for illumination dimming. Autotransformer control centers have been used since 1995. Autotransformers reduce energy usage by 30%-40%. Also, the service life of luminaires increases.

In [18], in order to obtain the maximum possible electrical energy saving and to choose various solutions to compare, all existing and innovative technologies were analyzed, incorporating both light sources and luminous flux management. In particular, the study focused on lighting management and control and consequently on energy consumed by the street lighting system.

The current intervention strategies consist of the following choices [18]:

- Line control. This consists of replacing the existing luminaires with high pressure sodium (HPS) luminaires, and it includes the installation of astronomical clocks and line regulators of the luminous flux for those switchboards that manage sufficient electrical power to justify the investment cost;
- Remote point-to-point control. In addition to replacing the luminaires, power line digital communication features (Power Line Communication, PLC) are installed to remotely control the luminous flux of each individual luminaire (a regulator for each luminaire and a central unit for each switchboard);
- A smart lighting approach. The "Smart Lighting" approach derives from remote P2P control, but it introduces an element typical of "Smart" applications, the principle of adaptivity and energy on demand. This approach is based on having "smart and multifunctional" luminaire poles in the street lighting network, equipped with various sensors.

The current trend in electrical energy consumption reduction in street lighting is the introduction of automation and remote management solutions to control street lighting. Remote management systems with automation technology allow control of luminaire, adjustment of light levels, and luminaire or component fault reports [18].

For an intelligent lighting control system, a usual list of features includes [19]:

- Reporting the faults and conditions: failed luminaires, faulty power factor, etc.;
- Reporting the faults and conditions at the street cabinet level;
- Ensuring switching on–off of the lighting plant;
- Ensuring a dimming facility and energy metering;
- Ensuring other operational information, such as access and traffic detection, etc.

4. CASE STUDY: THE CITY OF ŠIROKI BRIJEG

4.1 CURRENT STATE AND ENERGY AUDIT OF STREET LIGHTING

The city of Široki Brijeg is placed in the South-West region of Bosnia and Herzegovina with population of about 30,000 inhabitants (10,000 in urban area). The city is 388 m^2 in area [20].

It can be seen in Figure 1 that, compared to the period 2004-2006, in 2012 electricity consumption in the street lighting sector in the city of Široki Brijeg experienced great growth. Total electrical energy consumption of street lighting in Široki Brijeg in 2012 was 1.106 million kWh [21]. Percentage of street lighting electrical energy consumption in total electrical energy consumption of Široki Brijeg is around 1%. In the EU, according to [17] and [22], percentage of street lighting electrical energy consumption in total electrical energy consumption is around 1.3%. According to [23], percentage of street lighting electrical energy consumption in total electrical energy consumption is around 3%. In Serbia, that percentage is 1.76% [24] and according to [25], it is 1.1%. In China, that percentage is almost 6% [26], and in Portugal 3% [27].

In Zagreb, Croatia, street lighting electrical energy consumption accounts for 0.79% in total electrical energy consumption [28]. In Osijek-Baranja County, a share of 0.8% of street lighting electrical energy consumption contributes to total electrical energy consumption [29].

The price of electrical energy utilized in street lighting (active electrical energy) in Široki Brijeg is as follows:

- Higher tariff: 0.2145 KM/kWh (in November, December, January and February) (1 KM=cca.0.5 €);
- Lower tariff: 0.1650 KM/kWh (in March, April, May, June, July, August, September and October).

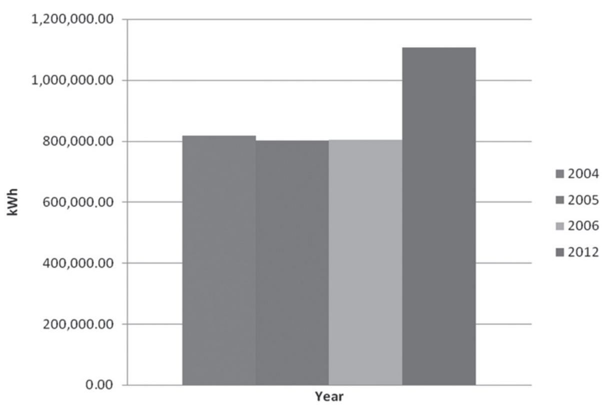

Fig. 1. Electrical energy consumption in the street lighting sector in the city of Široki Brijeg

Street lighting electricity prices abroad differ. In Croatia, the price is around 0.23 KM/kWh [30]. The EU average is around 0.18 KM/kWh [22]. In future, these prices will probably increase.

Street lighting energy audit in Široki Brijeg was made for an urban area of the city. All street lighting electrical networks were inspected and the energy audit consisted of the following two parts:

- Public lighting networks were inspected in a manner that every pole was geodetically surveyed and an ID number was given to every pole. So, for the whole urban area, an ortho-photo record of street light poles is obtained, as can be seen in the example below. Street light pole ID numbers are marked from B5 to B19 in Figure 2;
- On the other hand, street lighting electrical networks were inspected and all data about them are collected in Table 1. The inspection was performed for every electrical metering street lighting place in the urban area, one by one.

That is the only right way to get a real picture of the street lighting scene and to find out which street light electrical networks are powered from which metering place.

All electrical and economic calculations can be performed with the aforementioned energy audit in order to develop scenarios for street lighting electricity savings.

Fig. 2. Ortho-photo record of street light poles with their ID numbers

Table 1. Street lighting inspection data

pole ID	POLE			LUMINAIRE TYPE						LIGHT SOURCE TYPE			CONDUCTOR			ROAD		street name:	note:
	type	height (m)	pole orientation	type	no. of luminaires per pole	overhang (m)	boom angle (°)	boom length (m°)	mounting height (m)	no. of light sources per luminaire	rated power (W)	type	type	cross section (mm2)	length (m)	base	road width (m)		

Some of luminaires used now in the urban area of Široki Brijeg are shown in Figure 3. Those luminaires are non-cutoff optics. They are soiled with great part of light undirected (great light pollution).

Consequently, light is not directed toward ground, illumination is not satisfying, and to meet requirements of standard "EN 13201:2003", greater luminaire power is necessary than with modern cut-off luminaires.

Fig. 3. Some of luminaires used in Široki Brijeg

After performing the street lighting energy audit, street lighting system inspection data are collected in tables (as in Table 1). The main results are given below.

Here are the basic data of Široki Brijeg inspected urban street lighting:

- Total number of luminaires: 1,183;
- Total installed power: 213.97 kW;
- Electric energy consumption: 909,586.17 kWh/year;
- Electric energy cost: 169,146.50 KM/year;
- Share of urban street lighting consumption in total street lighting consumption: 76%;
- Number of electric meters: 22.

Further statistical facts can be obtained from the existing data:

- Average electrical energy consumption per one luminaire: 768.88 kWh/ year;
- Average installed power per one luminaire: 180.87 W;
- Average electrical energy consumption of street lighting per one capita: 90.96 kWh/year;
- Average installed power per one capita: 21.39 W;
- Average number of inhibitions per one luminaire: 8.45;
- Cost of electrical energy for urban street lighting per capita: 16.91 KM/year.

The average number of inhibitions per one luminaire is almost on EU level [22].

A summary of luminaires used in urban street lighting is presented in Table 2 and Figure 4.

Table 2. Table of luminaires used in Široki Brijeg urban street lighting

	Sodium			Mercury			Fluo	
	Power (W)							
	70	150	250	125	250	400	65	
	number:							total:
total:	1	525	156	256	114	81	50	
	∑ 682			∑ 451			∑ 50	1,183
total in %:	58			38			4	100

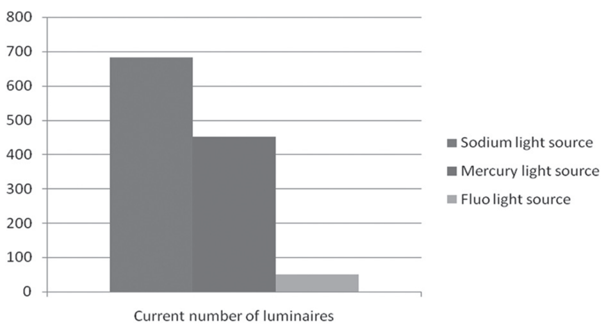

Fig. 4. Table of luminaires used in Široki Brijeg urban street lighting

Sodium light sources are dominant with 58%. Mercury light sources account for 38%. Fluo light sources represent 4% of light sources. If we compare those results with the EU [22], it can be concluded that results are close enough to the EU average.

4.2 SCENARIOS OF ELECTRICAL ENERGY SAVINGS

The basic settings for calculations are as follows:

- Energy audit is the first step in analyzing electric energy savings in street lighting;

- Reconstruction of street lighting implies replacement of old luminaires and light sources with energy efficient ones;
- All calculations exclude VAT;
- Road categories in the urban area are M2 (strategic roads) and M3a (main distributor roads);
- Calculations exclude decorative lighting, square lighting and the like;
- Working hours of street lighting: 4,251 hrs/year.

Lighting element settings (all aforementioned prices are market price values):

- The life span of modern luminaires is around 20 years and all energy saving related calculations are done for that period. Luminaires must be equipped with modern cut-off optics;
- Luminaires include modern electromagnetic ballast or electromagnetic reduction ballast with relay for dimming purposes. The life span of those ballasts is 20 years. The life span of relays is 10 years. Luminaires include a capacitor;
- The life span of modern sodium light sources is around 25,000 hours;
- Supposed dimming period - from 11.30 pm to 05.30 am (power reduction in that period is 40%).
- Luminaire price (with a light source) 70 W sodium: 230 KM.
- Luminaire price (with a light source) 100 W sodium: 250 KM;
- Luminaire price (with a light source) 150 W sodium: 280 KM;
- Luminaire price (with a light source and a relay) 70 W sodium: 290 KM;
- Luminaire price (with a light source and a relay) 100 W sodium: 310 KM;
- Luminaire price (with a light source and a relay) 150 W sodium: 336 KM;
- Price for a substitute relay with reduction ballast: 200 KM;
- Price for replacement of 70 W and 100 W sodium luminaires: 30 KM;
- Price for replacement of a 150 W sodium luminaire: 40 KM;
- Price for replacement of 70 W, 100 W and 150 W light sources: 40 KM.

Examples of new luminaires are shown in Figure 5.

1. Calculation methods

The goal is to compare electrical energy consumption between the current street lighting system and the reconstructed street lighting system. Reconstructing street lighting includes two cases:

- Installing sodium luminaires; and
- Installing sodium luminaires with step-dimming ballast and relays.

The basis of these reconstruction case studies is the exchange of dilapidated and inefficient luminaires with oversized mercury and sodium light sources with new ones and efficient luminaires with properly sized sodium sources (based on photometric calculations conducted according to “EN 13201: 2003”). Energy audits enable implementation of lighting calculation.

Fig. 5. Modern luminaires used in this case study

2. Review of terms used in calculations:

Installed power of light sources:

$$P_{inst} = \sum_{i=1}^{N} P_i \cdot n_i,\ (kW), \qquad (1)$$

where P_{inst} is installed power of light sources in kW, P_i is power of a certain light source, n_i is the total number of light sources and N is the number of light sources with different rated power.

Electric energy consumption of the street lighting system (annually):

$$W = P_{inst} \cdot t,\ (kWh), \qquad (2)$$

where W is electrical energy consumption in kWh and t refers to working hours of street lighting in the period of one year (4,251 hrs).

Costs of the street lighting system (annually) are generally as follows:

$$W_{KM} = \sum_{\substack{i=1,2,3 \\ j=1,2}} P_{inst} \cdot T_i \cdot d_i \cdot c_j,\ (KM), \quad (3)$$

where W_{KM} is cost of the street lighting system in KM, T_i refers to working hours of street lighting in seasonal period (there are three seasons with different working hours of lighting: summer: 9 hrs, winter: 15 hrs and spring/autumn 11 hrs), d_i is the number of days in one season (122 days in summer, 120 days in winter and 123 days in spring/autumn), and c_j is the price of electrical energy in KM/kWh (higher tariff in winter and lower for the rest of the year).

Street lighting system annual costs when there are relays for dimming mode (reduced costs) are as follows:

$$\begin{aligned} W_{KMred} = (&\sum_{\substack{i=1,2,3 \\ j=1,2}} P_{inst} \cdot (T_i - T_r) \cdot d_i \cdot c_j) + \\ &+ (\sum_{\substack{i=1,2,3 \\ j=1,2}} P_{instred} \cdot T_r \cdot d_i \cdot c_j), \end{aligned} \quad (4)$$

where W_{KMred} is electrical energy consumption of street lighting with step-dimming ballasts in kWh, T_r represents reduced working hours of street lighting in dimming mode (six hours a day) and $P_{inst.red}$ is installed power in kW of light sources in dimming mode.

Annual electricity cost savings ($W_{KMsaving}$) referring to the existing street lighting system ($W_{KMexisting}$) and the new one (W_{KM}) are:

$$W_{KMsaving} = W_{KMexisting} - W_{KM},\ (KM), \quad (5)$$

or for reduced mode:

$$W_{KMsaving} = W_{KMexisting} - W_{KMred},\ (KM), \quad (6)$$

where $W_{KMexisting}$ are electrical energy costs in the existing street lighting system (with the existing luminaires).

Investment in new luminaires with installing:

$$\begin{aligned} W_{KMinvest} = (&W_{KMluminaires} + W_{KMinstall}) \\ &\cdot n_s,\ (KM), \end{aligned} \quad (7)$$

where $W_{KMluminaires}$ is a new luminaire price, $W_{KMinstall}$ is a new luminaire installing price and n_s is the total number of luminaires. A similar expression is given for investment in luminaires with step-dimming ballast with only price changes.

Factor deterioration of a light source:

Factor deterioration = (1 / life expectancy of a light source in years)

The number of replaced light sources annually:

Number of replaced light sources = factor deterioration of light source x number of light sources

The total exploitation cost is the sum of investment costs and maintenance costs. In this case study, it is the sum of investments in a new lighting system and maintenance costs in a 20-year period.

A simple return period:

Simple return period = exploitation cost (KM) / electrical energy savings (annual) (KM)

4.3. RESULTS

Summary results are shown in Table 3, taking into account the following scenarios: current state - existing consumption of street lighting ($W_{KMexisting}$): (i) a new state obtained by calculations (W_{KM}), (ii) a new state obtained by calculations including a dimming effect (W_{KMred}), (iii) a new state with replacing only mercury light sources with sodium light sources based on only luminous flux criteria without calculations (iv).

Table. 3. Street lighting inspection data

	i	ii	iii	iv
Installed power of light sources (kW):	213.97	125.13	125.13	176.34
Electrical energy consumption (kWh):	909,586.47	531,927.63	422,313.75	749,621.34
Electrical energy costs (KM):	169,146.50	98,917.14	79,047.00	139,399.40
Saving compared to current state (kWh):		377,658.84	487,272.72	159,965.13
Saving compared to current state (KM):		70,229.36	90,099.50	29,747.10

5. CONCLUSION

In this paper, an energy audit of street lighting is proposed. We have also proposed several scenario strategies of electrical energy savings in street lighting based on reconstruction of the existing street lighting system. The proposed energy audit and scenario strategies of electrical energy savings are applied in one case study. Its results, based on the proposed methods of energy audit and reconstruction of existing street lighting systems, show that possibilities of electrical energy savings in street lighting are enormous. The proposed methods presented in this paper are general and applicable to any case study. Future work would be focused on implementation of LED lighting though various investment scenarios.

6. REFERENCES

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