ANALYSIS OF EXISTING STREET LIGHTING - REPLACEMENT WITH ENERGY EFFICIENT IN SMALL POPULATED AREAS

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Abstract. The article presents an analysis of outdoor artificial lighting on the territory of a settlement (municipality). The main objective of the article is to describe the state of the existing street lighting and to propose various energy-saving measures to increase the energy efficiency of outdoor artificial lighting systems, reduce the municipality's electricity costs (direct and indirect). A proposal to increase the security and operational characteristics of street lighting systems on the territory of the municipality. Energy-saving measures are considered: replacement of existing street lighting with new energy-saving ones, implementation of a control and monitoring system, and use of renewable sources for outdoor artificial lighting. Investment assessment, payback period and buyback period, saved carbon emissions, and how much the municipality's conventional energy consumption has been reduced.

Keywords: energy efficiency, street lighting, costs

1. INTRODUCTION

One of the main tasks of outdoor artificial lighting systems (street, on pedestrian paths, in park spaces, architectural, advertising, decorative lighting, etc.) is to ensure the safe movement of vehicles and pedestrians in the evening and during nighttime by creating conditions for increasing the lighting throughout the streets and road networks in general.

Street lighting is the dominant component of outdoor public lighting for the population of municipalities in Bulgaria. Street lighting improves road visibility, increases the safety of motor vehicle traffic at night. Good street lighting is a crucial prerequisite for reducing fatal road accidents; thus, carefully setting it up would bring about a drastic decrease. Also, good street lighting leads to increased security for residents and a decrease in criminal activity. Street lighting, as part of outdoor

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artificial lighting, is a factor in emphasizing the urban features of settlements. Thanks to it, a unique night view of the respective cities and villages is created. Ensuring quality street lighting is a necessity that creates conditions for round-the-clock activity[7]. The primary task of street lighting is to ensure the smooth movement of vehicles and pedestrians. Good lighting enables drivers to assess the situation on the road properly and pedestrians to avoid taking risky actions. General information shows that a quarter of serious road accidents occur at night, despite reduced traffic. The annual need for artificial lighting is approximately 4,000 hours. At this time, the number of accidents increases significantly.

2. DESCRIPTION OF THE TASKS AND RESULTS OF THE ANALYSIS OF THE CONSIDERED PROBLEM

The purpose of the energy analysis for outdoor artificial lighting on the territory of the Pravets municipality is:

1. Increasing the energy efficiency of street lighting and reducing electricity consumption through the implementation of a package of technical measures.
2. Improving the indicators of street lighting in accordance with the following standards for street lighting – СД CEN/TR 13201-1; БДС EN 13201-2; БДС EN 13201–3; БДС EN 13201–5.
3. Reducing the direct costs of the municipality for street lighting, while ensuring high-quality lighting.
4. Ensuring safe movement of motor vehicles, increasing the safety of pedestrian movement at night, and creating a comfortable night atmosphere.
5. Reducing criminal activities in the dark. [7,8].

The following tasks are set for solution:

1. Defining approaches and methods for renewing street lighting in the municipality in order to improve the lighting environment, reduce electricity consumption, and reduce operating costs based on the existing state of the system and energy consumption over the last three years.
2. Analysis of the current state of street lighting from the point of view of lighting, energy, and operational efficiency.
3. Assessment of lighting characteristics in the light of modern requirements for standardization of street lighting.
4. Selection of appropriate light sources.
5. Study of the possibilities for implementing modern street lighting management systems.
6. Comparative analysis of street lighting in the municipality according to the criterion of effectiveness of modernization options.
7. Recommendations for monitoring and operation of the street lighting system.

8. Improving the security and safety of the population by designing street lighting that meets national and European standards.

In its overall construction and implementation, the energy audit is built on the basis of systematized rules and procedures aimed at revealing potential energy-saving opportunities based on an analysis of the operation of the object from a sufficiently long past period until the moment of its implementation.

The assessments were made on the basis of preliminary studies, analytical calculations, and measurements carried out on the existing and operating street lighting.

Energy system of Pravets municipality:

The built electricity supply infrastructure in the Pravets municipality covers 100% of the population. All 11 settlements in the municipality are provided with a high and medium voltage power grid [1,8].

In order to increase energy efficiency and reduce energy costs in the public sector, Pravets Municipality has implemented a project to replace 1,190 high-pressure sodium lamps with units of power 36 W, 50 W, 70 W, 100 W, and 150 W. In the period 2017-2019, Pravets Municipality invested in the construction of new street lighting routes, replacement of lighting fixtures with new energy-saving LED lighting fixtures, and installation of photocells [1-8].

Characteristics of lighting fixtures.

Table 1

№	Name	**Type, power and number of luminaires**												
		HPS 50 W	HPS 70 W	HPS 100 W	HPS 150 W	CFL 25 W	CFL 36 W	CFL 55 W	„Globe“ 85W	ML 125 W	LED 40 W	LED 60 W	CFL 15 W	Total
1	Town of Pravec	90	510	69	132	426	54	116	158	75	2	40		1672
2	Villages of the Pravec municipality	447				5	498						18	968
Total number by type		537	510	69	132	431	552	116	158	75	2	40	18	2640

Source of information: Municipal Administration [1,7].

Total installed capacity of street lighting on the territory of Pravets municipality, town of Pravets.

Table 2

№	Type of luminaire	Number	Total Power (Pи)	Total installed capacity
			W	**kW**
1	HPS 50 W	537	64	34,37
2	HPS 70 W	510	87	44,37
3	HPS 100 W	69	120	8,28
4	HPS 150 W	132	175	23,10
5	CFL 25 W	431	25	10,78
6	CFL 36 W	552	45	24,84
7	CFL 55 W	116	65	7,54
8	„ Globe “ 85W	158	85	13,43
9	ML 125 W	75	140	10,50
10	LED 40 W	2	40	0,08
11	LED 60 W	40	60	2,40
12	CFL 15 W	18	15	0,27
			Total:	**179,95**

The standard defines the rules for selecting lighting classes based on lighting situations. For each lighting situation, the type of street users, the speed of movement of the main user, and the traffic load are decisive. Specific criteria are the geometry of the street, the surrounding street environment, prevailing climatic factors, etc. The level of lighting on streets and roads depends on several factors, the most important of which are the groups of road users, the permitted speed of vehicles, the volume of vehicle traffic, the presence and number of intersections, and the presence of parked vehicles according to BDS 5504-82 [7].

Electricity consumption from the street lighting system on the territory of Pravets municipality, town of Pravets.

Table 3

Town halls	2017		2018		2019		Total	
	kW	**BGN**	**kW**	**BGN**	**kW**	**BGN**	**kW**	**BGN**
village of Vidrare	17515	3003	18515	3610	20084	4142	56114	10755
village of Djurovo	41399	7388	51635	10081	44396	9327	13743	26796
village of Kalu-gerovo	16144	2959	15185	3064	15616	3391	46945	9414
village of Mana-selska reka	1239	2221	11366	2274	10015	2190	22620	6685
village of Osi-kovica	23882	4296	26592	5185	27508	5691	77982	15172
village of Osi-kovica Lakavica	16076	2953	14815	3020	14224	3105	45115	9078
town of Pravec	336888	58176	277236	51565	196876	41248	811000	150989
village of Praveshka Lakavica	9040	1625	9018	1787	9510	2000	27568	5412
village of Ravnishte	35783	6165	37450	7243	37494	7940	110727	21348
village of Razliv	30980	5507	34819	6244	30487	6420	96286	18171
village of Svode	10220	1774	9104	1759	10227	2114	29551	5647
Every-thing	539166	96067	505735	95832	416437	87568	1461338	279467

The selection of luminaires is made according to technical characteristics for replacing existing luminaires with new LED ones. The first step in implementing the measure to improve the energy efficiency of street lighting in the Pravets municipality is to determine the reference values of illumination of the current luminaires on the

different categories of streets. Numerous lighting calculations are performed on the individual categories of streets with specialized DIALux software, and the illumination of the old luminaires is determined according to the calculation methodology set in the standard, and the obtained values are accepted as reference. The selection of new luminaires is carried out according to the same indicators. After the lighting calculations are made, luminaires are selected that have sufficiently good indicators and meet the MA standard. In our case, four types of luminaires with a power of 53W, 33W, 27W, and 14W are selected. All sodium luminaires are replaced with new LED luminaires with a modern design and high quality, with reduced losses of electricity and increased light output [7].

Calculation of the power consumption of luminaires planned for delivery.

Table 4

№	**Type of luminaire**	**Luminaire power consumption ($P_{осв}$)**	**Power consumption ballast ($\Delta P_{ПРА}$)**	**Total power (Ри)**
		W	**W**	**W**
1	LED 27 W	27	0	27
2	LED 33 W	33	0	33
3	LED 53 W	53	0	53
4	LED 14 W	14	0	14
5	Solar street light LED 20 W	20	0	20

Lighting fixtures after energy-saving measure ESM No. 1.

Table 5

№	**Type of luminaire**	**Number**	**Total power (Ри)**	**Total installed capacity**
-	-	-	**W**	**kW**
1	LED 53 W	198	53	10,49
2	LED 33 W	375	33	12,38
3	LED 27 W	521	27	14,07
4	LED 14 W	1542	14	21,59
5	Solar LED 20 W	4	0	0,00
			Total	**58,52**

Energy consumption of the street lighting system after implementation of the luminaire replacement measure.

Table 6

Energy consumption of a Street Lighting system after implementation of ESM No. 1			
Total installed capacity	Working hours per year	Energy consumption from the Electricity Distribution Network	Emissions generated after Energy Saving Measure
kW	hours	kWh /y	t CO2 / y
58,52	4000	234096	276,23

Technical and economic indicators of measure 1.

Table 7

Technical and economic indicators of ESM No. 1						
Energy saving	Price of electricity Energy	Saving money on energy	Savings from E&P	Emissions saved	Investment	Redemption period
kWh /y	BGN / kWh	BGN / year	BGN / year	t CO2 / y	BGN	months
1104919	0,210	232515,93	0,00	1303,80	940 096,54	48,52

Introduction of "Intelligent LED Street Lighting Management and Monitoring System".

This measure is usually defined as an operation-related measure that directly affects the savings of electricity from the Street Lighting system by implementing an effective operating mode of street lighting. The introduction of such a system allows for additional savings of electricity consumption of up to 10% based on constant monitoring of the system status and making correct management decisions to control energy consumption.

Among the capabilities of the system are planning of electricity costs for outdoor lighting; integration of other public activities into the intelligent outdoor lighting control system; easy addition of the outdoor lighting system and its electronic model with new sections. The system has the ability to provide centralized remote control and diagnostics of multiple lighting fixtures, without any restrictions on their quantity and location. The effect of such an automated control system is control of electricity costs,

significant improvement of the operational characteristics of the street lighting system, and the ability to continuously monitor the status of the system and control the work of the operating enterprises. Lighting control (street lighting, park lighting, or other objects) is carried out by illumination and/or at the onset of sunset at the respective point. Through this control system, external lighting systems (street and park) will become adaptive to the environment and will operate only then and as much as is necessary for safe vehicle movement and external lighting systems may not be completely turned off (i.e. there are options for dimming the lighting), thereby saving electrical energy and increasing the safety of people on the streets at night [7].

The control and monitoring system (CMS) has the following functions:

1. Remote control and monitoring – allows for local and remote configuration of devices and street lighting cassettes in a separate area of a small or large city. Allows for remote control and management of a separate branch of the street cassette (group management). Commands can be executed on a schedule or on demand using centralized software.

2. Data collection and presentation – the system collects, validates, aggregates, and processes data and telemetric information about the functioning of the equipment and load modes, measures parameters related to the effective operation of the street lighting system, and outputs reports and analyses.

3. Alarms and security – the system supports alarms for events such as a problem with the end device (lamp), attempts to manipulate the power cassette equipment, etc.

4. Quality control – the system monitors the quality of electrical energy (power supply network) used for street lighting.

5. Lamp status control – the system reports on lamp failures, lamp parameters (dimming, operating voltage), operating hours /lighting/, etc. The system remotely registers the technical condition of the lamps at any time.

6. Energy saving – the dimming of each device can be adjusted to seasonal and geographical features.

7. Monitoring the parameters of each lighting fixture - I, U, P, 0C, operating hours, number of starts, etc.

8. Reports – the system generates various reports and reports in case of problems and unauthorized manipulations. When a given event occurs (e.g., when a given parameter exceeds set minimum/maximum limits), selected users are notified to take the appropriate measures.

9. The system has an easy and convenient web interface and an expandable and decentralized server architecture. The following modules are available:

a. Database – stores all the information necessary for the operation of the system;

b. Communication module – with the ability to service a practically unlimited number of endpoints. Provides simultaneous access to the database and automates the data collection process. The module records and tracks all processes and actions in the system and operations/alarms in it. Performs automatic time synchronization between end devices.

10. Archiving of data in the system is in accordance with the best IT practices. The system automatically summarizes old data and generalizes the submitted information. Two types of archives are performed:

a. Full – the full content of the database is extracted and stored;

b. Incremental – only changes are extracted.

The implementation of each measure separately or in combination is a matter of management decision and budgetary or financial capabilities, after which the most expedient option from an economic point of view for their implementation will be determined after the preparation of investment projects for the reconstruction of the street and park lighting system.

The proposed system aims to achieve the following results:

- Saving electricity;
- Increasing the efficiency of street lighting;
- Achieving low operating costs and effective management of street lighting;
- Providing additional functionalities for building a specialized communication infrastructure;

The possibilities for implementing modern street lighting monitoring and control systems (SMS).

The system should enable centralized remote control and diagnostics of lighting fixtures in "real time", without restrictions on their quantity and location.

To achieve coverage of a sufficiently large area with a relatively small permissible power, the structure is built based on wireless connections and communication through the network of mobile operators and the use of a GPRS module.

The intelligent control system consists of the following modules:

- GPRS Module.
- Server.
- Software for a finished product with multiple applications and capabilities.

The structure thus built will allow control and diagnostics of lighting in individual streets, neighbourhoods, and intercity roads of any size, where it can also be used for traffic management. Its functional diagram is shown in the figure below.

The main functions of the system will allow management, diagnostics, alarms, and analyses of lighting in any size individual streets, neighborhoods, and intercity roads, namely:

Management – to allow all points (streetlights) to be managed individually or in groups in real time by remotely setting the operating modes, such as: soft start, light intensity by time zones, special light modes, etc.

Diagnostics – to allow it to be carried out periodically, at pre-set time intervals, or at a randomly selected moment in the event of a certain event or need. The main parameters monitored on the lighting fixtures are voltage and temperature.

Analyses – to allow, based on the information accumulated by the system, depending on the rights and requirements of the user, to issue reports on energy consumption

by regions and periods for defective lighting fixtures, for accidents and problems in the electrical network, and for electricity theft.

Alarms – to allow analyses to be processed instantly and to notify the user immediately of a predefined situation – increase or decrease in power, consumption, voltages, and temperatures.

Monitoring – real-time information about most of the parameters of the street lighting system.

The savings from the measure are calculated based on the technical indicators shown in Table 8:

Energy consumption of an MA system after implementation of ESM No. 1.

Table 8

Energy consumption of a street lighting system after implementation of ESM No. 2			
Total installed capacity	Working hours per year	Energy consumption from the Electricity Distribution Network	Emissions generated after Energy Saving Measure
kW	hours	kWh /y	t CO2 / y
58,52	4000	234096	276,23

Savings from implementing ESM 2.

Table 9

Technical and economic indicators of ESM No. 2						
Energy saving	Price of electricity Energy	Saving money on energy	Savings from E&P	Emissions saved	Investment	Payback Period
kWh /y	BGN / kWh	BGN / year	BGN / year	t CO2 / y	BGN	months
14046	0,210	2955,75	0,00	16,57	205 320,00 BGN	833,58

The study of the energy efficiency survey is the basis for determining the energy characteristics of the street lighting system, for drawing up energy efficiency programs and implementing energy-saving measures, as well as for subsequent management of the street lighting energy system.

So as to achieve the intended results of the energy efficiency survey is necessary to introduce rules for the operation and maintenance of energy systems, as well as the introduction of energy monitoring.

Energy monitoring controls the maintenance of energy consumption at the intended regulatory level. The analysis of monitoring data is the basis for making decisions about the operation, maintenance, repair, and renovation of the system.

The measuring instruments for carrying out energy monitoring will be the elements of the introduced automated street lighting management system. The energy monitoring functions will be performed using the "Intelligent Street Lighting Management and Control System", by collecting and analysing data:

─ current electricity consumption
─ electricity consumption for a certain period of time
─ number of operating hours of the system, etc.

3. CONCLUSION

The aim is for the reconstructed lighting to receive a high positive rating and have a good vision for the residents of Pravets municipality and the city of Pravets, contributing to the development and operation of street lighting in a new way, making maximum use of good European practices.

Summarized indicators from the implementation of the package of energy-saving measures:

Table 10

1	Baseline electricity consumption	Eb	1339015	kWh/y
2	Electricity consumption after ESM without RES	Eesm	220050	kWh/y
3	Total value of the project grant	S	1153298,14	BGN
4	Amount of greenhouse gas emissions	C	1320,76	ton CO2 / y
5	Investment efficiency	I	873,21	BGN/ ton CO2
6	Price of electricity	P	0,210	BGN/kWh
7	Value of annual energy savings	Sesm	235539,02	BGN
8	Redemption period	ROI	58,76	months
9	Final consumed electricity from ERM	E	219730	kWh/y

The proposed measures in this case are cost-effective. Replacement of luminaires with very good characteristics and energy-efficient operation, and long life according to catalogue data. The control and monitoring system is preferable to be introduced in cities, whereas in small settlements it would not be so cost-effective. For this very reason, it is necessary for each task to conduct a thorough examination and survey of the specifics of each settlement and adequate justification for each energy-saving measure to be introduced.

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