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Audit of road lighting installation as a tool to improve energy intensity - case study

***Abstract**. In the European Union , street lighting accounts for around 3-4% of total energy consumption. In Poland, the energy consumption of street lighting is about 1.5% of the national consumption. However, in some cities, such as Warsaw or Krakow, the energy consumption of street lighting can be up to 40% of the total electricity consumed by the city. The Energy Efficiency Act in force in Poland assumes that final energy savings of 5580 thousand toe will be achieved by the end of 2030. One of the basic tools to be used in order to achieve savings in electricity consumption is a properly conducted energy audit of such installations. There are no guidelines or other documents that could be used by auditors of such installations. In the article, based on a selected road lighting installation, the authors want to present good practices that auditors should follow.*

***Streszczenie.** W Unii Europejskiej , oświetlenie uliczne stanowi około 3-4% całkowitego zużycia energii. W Polsce, zużycie energii przez oświetlenie uliczne wynosi około 1,5% zużycia krajowego. Jednakże, w niektórych miastach, takich jak Warszawa czy Kraków, zużycie energii przez oświetlenie uliczne może wynosić nawet do 40% całkowitej energii elektrycznej zużywanej przez miasto. Obowiązująca w Polsce ustawa o efektywności energetycznej zakłada osiągnięcie oszczędności energii finalnej końca 2030 roku w wysokości 5580 tys. toe. Jednym z podstawowych narzędzi do stosowania w celu osiągniecia oszczędności zużycia energii elektrycznej jest prawidłowo przeprowadzony audyt energetyczny takich instalacji. Nie ma opracowanych wytycznych ani innych dokumentów jakimi mogli by się posługiwać audytorzy takich instalacji. W artykule na podstawie wybranej drogowej instalacji oświetleniowej autorzy chcą przedstawić dobre praktyki, którymi powinni kierować się audytorzy. (**Audyt instalacji oświetlenia drogowego jako narzędzie poprawy energochłonności – studium przypadku**).*

Keywords: energy efficiency, audit, street lighting installations, light sources.
Słowa kluczowe: efektywność energetyczna, audyt, instalacje oświetlenia ulicznego, źródła światła.

Introduction

As the world's population grows, so does the demand for energy. Despite the crisis caused by the Covid pandemic and Russia's invasion of Ukraine, long-term forecasts of electricity demand indicate that this demand will increase in the coming years [1]. This is due to many factors, including the expected increase in demand for electric vehicles and heat pumps. To meet this ever-increasing demand, the efficient use of electricity has become increasingly important in all aspects of energy consumption. One way to use electricity efficiently is to take various measures to save energy.

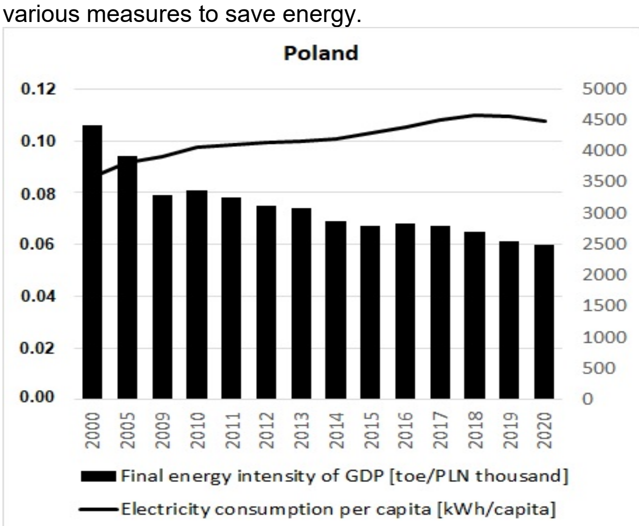

Fig.1. Change in total energy intensity in Poland against the background of total energy consumption per capita from 2000 to 2020. Source: Own study

This is shown in Fig. 1 where a clear upward trend can be seen in the case of electricity consumption per capita in Poland against the background of a decrease in the economy's energy intensity in these years in [toe/PLN thousand]. We face a dilemma how and where to save electricity so that the output power increases.

The energy efficiency potential of street lighting installations in Poland

LED technology is far more energy efficient than any previous light-emitting technology. Many innovative technologies are being developed around the world, e.g. PLED [2, 3], which are intended to improve the efficiency of the LED sources themselves or other elements of lighting installations [4]. Street lighting in Poland, according to various estimates [5,6], consumes from 1500 to 2500 GWh of electricity and is responsible for a significant part of greenhouse gas emissions. Based on estimates, it is estimated that approximately 3.3 million street and road luminaires are used in Poland. Sodium and mercury sources dominate in lighting installations, accounting for up to 60% of emitters used. These sources are characterized by a relatively low efficiency (about 40%), and the average age of such lighting installations is 15-30 years. It is estimated that by 2030, LED technology is to be used to illuminate all buildings and roads managed by the local government in the group of so-called "Progressive Cities" [6]. This is to improve the energy efficiency of communes, reduce CO_2 emissions, and reduce the costs associated with the fee for electricity consumption [7].

Fig.2. Map of communes participating in the project [8]

As part of the work carried out under the project [8], an inventory of street lighting installations was made for selected 17 communes in Poland.

The location of these communes is shown in Fig.2 depended on the requirements of the project [8] and depended on the consent of commune heads and mayors to participate in this project. The contractors strived to obtain, as far as possible, representativeness of the research, so that urban, rural and urban-rural communes could participate in it.

On the basis of data from local governments, quantitative summaries of the operated luminaires were prepared, divided into luminaires with mercury, sodium and LED sources. As shown in Fig. 3 the share of LED luminaires in relation to sodium and mercury lamps is very diverse in individual communes. It was found that there are 35.800 luminaires in total, of which only 1.56% were LED luminaires.

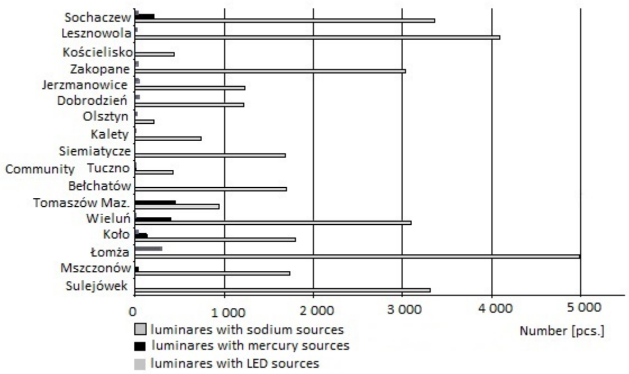

Fig.3. Quantity of lighting fixtures in municipalities [8]

On the basis of the low-emission economy plans of selected 12 cities, the share of road lighting installations in electricity consumption in relation to the total energy consumption in these cities was also examined.

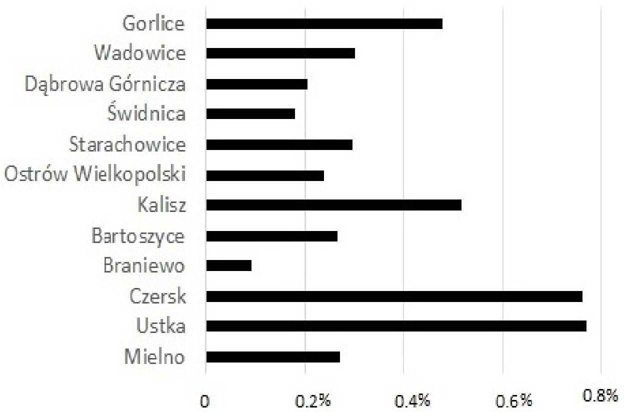

Fig.4. Percentage share of electricity consumption by road lighting installations in total electricity consumption. Source: Own study

As seen in Fig. 4 the share of road lighting installations in the total electricity consumption in the individual cities under study is very diverse and ranges from 0.09% to 0.77%, while in large voivodship cities such as Warsaw, Kraków or Wroclaw it may range from 10% to 30%. By converting, in accordance with the legislator's recommendation [9], the consumption of electricity by road lighting installations into emissions, we will obtain CO_2 emissions in [$MgCO_2$/year] for individual cities during the year, presented in Fig.5.

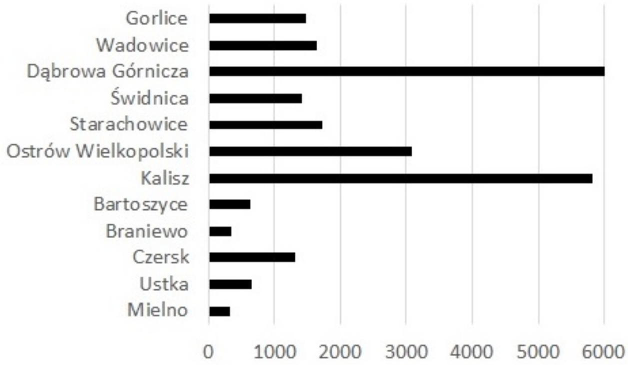

Fig.5. Annual CO_2 emissions in [$MgCO_2$/year] from road lighting installations for the cities studied. Source: Own study

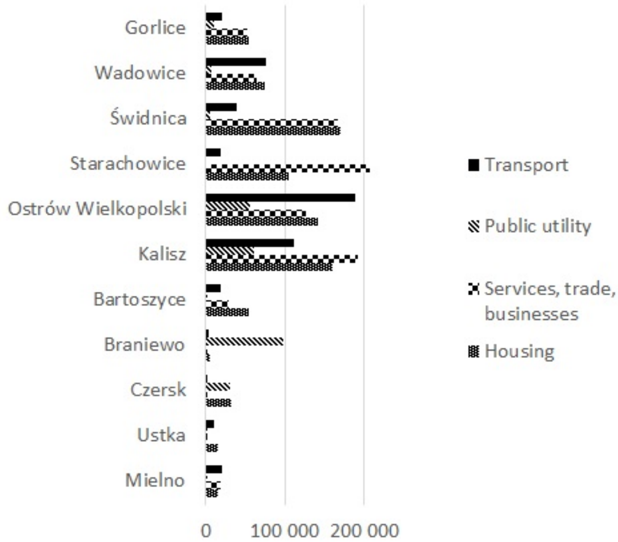

Fig.6. Annual CO_2 emissions in [$MgCO_2$/year] of various utility sectors for the cities studied. Source: Own study

For comparison, in fig. 6. annual CO_2 emissions for various sectors in the examined cities are presented. Only Dąbrowa Górnicza was omitted, for which CO_2 emissions were significantly higher and obscured the comparative picture. As can be seen, these emissions are many times higher in relation to road lighting installations. This does not mean that you should avoid them and not react to their lowering. Another conclusion is whether in the case of funds for modernization and investments in order to reduce emissions, such an analysis should not be carried out and funds should be allocated in the first place where the ecological effect will bring the best results.

In order to consciously and responsibly carry out the modernization of street lighting, which often has to be associated with investments - according to the authors, an inseparable element is to conduct an energy audit of such an installation. In the article, the authors present selected elements of an example of an energy audit of a road lighting installation containing, in their opinion, the necessary elements required on the basis of the required legal acts and the Standards in force in Poland.

Energy audit of a road lighting installation - a case study

The purpose of the audit of road lighting installations is to test the entire system and determine the possibilities of increasing energy efficiency and reducing the costs of lighting use, as well as determining the advisability of undertaking a modernization investment and indicating the optimal way of its implementation.

In the world literature [10,11,12,13], the authors present various approaches to increasing energy efficiency and describe various parameters characterizing street lighting installations. In Poland, apart from the Energy Efficiency Act [14], in which the legislator described in detail the required efficiency indicators and detailed Ministerial Regulations [9], auditors are obliged to apply the regulations contained in the Standards [15,16,17,18,19] when performing an audit.

A properly implemented energy efficiency audit should consist of two basic parts. The first part includes an assessment of the technical condition of the installation, which should include the following activities:

- technical inventory,
- calculation of energy consumption estimates based on the inventoried installed power,
- taking measurements to assess the existing state,
- determination of factors influencing energy consumption (site inspection and interviews with users),
- presentation, in physical units, of total baseline energy consumption.

It should be remembered that in the case of an inventory of road lighting installations, the technical inventory should include:

- road parameters:
  a) road category in terms of lighting requirements [16],
  b) the width of the roadway,
  c) type of surface,parametry,
- lighting elements:
  a) luminaire power,
  b) type (kind) of the luminaire,
  c) the distance between the luminaires,
  d) luminaire suspension height,
  e) distance of the luminaire from the edge of the road (overhang),
  f) luminaire suspension angle,
  g) type of outriggers,
  h) type and numbering of poles,
  i) spacing between columns,
  j) layout of the luminaires (right-hand, left-hand),
  k) name (number) of the transformer station.

For a detailed inventory of lighting points, a geolocation system should be used, thanks to which it is possible to upload data to the map. Photographic documentation is also necessary.

Part 2 concerns the assessment of the expected effects as a result of the implementation of the project, including mainly:

- indication of the implemented project aimed at reducing energy consumption,
- description of the assumptions made and an indication of the data sources used for the calculations,
- method of data analysis, calculation methods and applied mathematical models, calculation results, in particular achieved energy savings, ecological effects.

The auditor prepares a variant modernization model based on the prepared photometric designs that will confirm the requirements of standards [15,16,17,18,19] regarding road lighting. It should also consider proposing a smart lighting control system.

One of the streets in a small county town in the north of Poland was chosen as a case study. An inventory of the entire road lighting installation and the necessary measurement data were made. As a result, the results presented in Table 1 were obtained.

Photometric measurements were made for a road classified in the standard and the obtained measurement results were compared with the standard ones, which are presented in Table 2.

Table 1. Results of road lighting installation inventory. Source: Own study

PARAMETER	THE RESEARCH RESULTS
Lighting category	M5
Road surface	Asphalt
Road width	6 m
Pole type	concrete type ZN+OZ
Number of poles	4+5 (11)
Pole height	8 m
Distance from the edge of the road	4 m
Distance between poles	50 m
Boom height	0.3 m
Boom angle	5°
Boom length	1.5 m
Types of luminaires	SGS 203 + MALAGA
Luminaire power	250 W
Light source type	soda
The color of the light	yellow
Number of luminaires	8+1 (9)
Fixing the luminaire	4 under the power line, 5 on the cable line
QUALITY PARAMETERS	
Visual guidance	Good
Color rendering	Low (sodium lighting)
Installation aesthetics	Partly unsightly

Table 2. Results of photometric measurements of road lighting installation. Source: Own study.

PARAMETER	RESEARCH RESULTS	NORM
Average surface luminance Lm[cd/m^2]	2.18	0.5
Total uniformity U0	0.13	0.35 (lowest value)
Longitudinal uniformity Ul	0.12	0.40 (lowest value)
Interfering glare [%]	26,00	15 (maximum)

The main measure of the correctness of the audit here is the order of magnitude saved thanks to the modernization of electricity lighting on an annual basis. It is worth remembering that reducing electricity consumption by replacing lighting with LED technology is not tantamount to improving the energy efficiency of a given facility. There are voices from the electrical industry related to the assembly and maintenance of electrical installations that such modernization of lighting does not always bring financial savings, and in extreme cases it may even generate losses or have a negative impact on the electrical network. This is related to the sometimes low quality of LED lighting equipment or the implementation of the energy audit in the wrong way, e.g. not taking into account the photometric solids of the luminaires installed before and after modernization (no photometric calculations and measurements).

In many cases, lighting audits and modernizations performed mainly consist in replacing conventional luminaires or light sources with their equivalents, replacements made in LED technology. The regulation of the minister [9] contains information related to a simplified lighting audit, which consists mainly in determining the parameters of electricity savings. Unfortunately, auditors often forget about a very important remark contained in this regulation, that the surface illuminance, measured [lm/m^2] after modernization, meets the requirements of Polish Standards, including [16].

In the analyzed case of a road lighting installation, we are dealing with a road with medium traffic intensity M5. The proposal for modernization is to replace the luminaires with LED luminaires with a nominal power of 72 W, the luminous flux of the luminaire 7221 lm and the luminous flux of the LED lamp 8700 lm. The amount that can be saved was calculated from the relationship (1) given in [9]:

$$\Delta Q_0 = T_U (M_0 - M_1)/1000 \quad (1)$$

ΔQ_0 [kWh/year] – amount of energy saved, T_U [h/year] – lifetime of light sources, M_0 [W] – total power rating of luminaires or light sources before replacement, M_1 [W] –

total power rating of new luminaires or light sources after replacement.

The analyzes assume that the lighting time of the luminaires is 4150 h per year [9], the cost of energy PLN 0.70 per kWh, the cost of luminaire maintenance: PLN 8 net per month, the cost of replacing the light source over a period of 7 years (PLN 165 net, three group), annual cost PLN 23.50, binding cost about PLN 1800. The results of the analyzes are presented in Table 3.

Table 3. Analysis of operating costs before and after modernization. Source: Own study

PARAMETERS	SODIUM LUMINAIRE	LED LUMINAIRE
Power	290 W (250W+40W ballast power)	72 W
Annual energy consumption	1203.5 kWh	299 kWh
CO2 emission (9 luminaires)	7.7 tons	1.9 tons
Energy cost per luminaire per year	842.5 PLN	209 PLN
The cost of replacing light sources for a period of 7 years for one luminaire	23.50 PLN/year	no cost
Luminaire maintenance cost	96 PLN/year	48 PLN/year
Annual cost of one luminaire	962 PLN	257 PLN
Payback time in years		2.5 years

Conclusions

- Road with medium traffic. The lighting does not meet all the parameters and is inappropriate for this class of street. Light sources with disproportionately high power as for this class of street were used. Energy-intensive effect, uneconomical. Can be replaced with 72W LED luminaires. The amount of saved final energy determined in accordance with equation (1) is 6391 kWh/year.
- Analysis of the profitability of lighting modernization:
  - the existing sodium lighting generates high electricity consumption, which significantly burdens the city budget in terms of electricity charges. High energy consumption also means high CO_2 emission.
- Thanks to the modernization we gain:
  - decrease in charges for electricity consumption by 75%. Such a significant decrease is possible thanks to the use of 72 W LED luminaires, which meet the same parameters as the existing sodium luminaires.
  - energy efficiency of the new installation - electricity consumption is significantly lower by 75%;
  - reduced CO_2 emissions by 5.8 tons - a significant ecological effect in the residential area.

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