ENERGETSKA EFIKASNOST U SEKTORU JAVNIH ZGRADA NA TERITORIJI GRADA KRAGUJEVCA – STUDIJA SLUČAJA OŠ „MILUTIN I DRAGINJA TODOROVIĆ“

ENERGY EFFICIENCY IN THE PUBLIC BUILDINGS SECTOR IN THE TERRITORY OF THE CITY OF KRAGUJEVAC – CASE STUDY OF "MILUTIN AND DRAGINJA TODOROVIĆ" ELEMENTARY SCHOOL

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Obrazovne ustanove (OU), sa udelom od oko 38%, predstavljaju najveću kategoriju objekata u sektoru javnih zgrada (SJZ) na teritoriji grada Kragujevca po pitanju potrošnje električne energije, koja na godišnjem nivou iznosi preko 10 GWh. Sprovođenjem odgovarajućih mera koje podrazumevaju obaveznu upotrebu obnovljivih izvora energije (OIE) u kombinaciji sa vodjenjem odgovorne energetske politike na gradskom nivou, potrošnja električne energije u navedenom sektoru može biti značajno redukovana, uz niz pozitivnih efekata, od energetskih i ekonomskih, do ekoloških. U ovom radu korišćeni su softverski paketi EnergyPlus i Google SketchUp kako bi se ispitala mogućnost postavljanja fotonaponskih (FN) panela na krov zgrade OŠ „Milutin i Draginja Todorović“, sa osnovnim ciljem da se u bližoj budućnosti ovaj model implementira i na ostale javne zgrade čime bi se obezbedila veća energetska nezavisnost i stabilnost čitavog sektora.

Ključne reči: *sektor javnih zgrada (SJZ); obrazovne ustanove (OU); osnovne škole (OŠ); fotonaponski (FN) paneli; EnergyPlus.*

Educational institutions (EI), with a share of approximately 38%, represent the largest category of facilities in the public buildings sector (PBS) in the City of Kragujevac when it comes to electric power consumption, which annually amounts to over 10 GWh. By implementing appropriate measures, including the mandatory use of renewable energy sources (RES) in combination with a responsible energy policy at the city level, electricity consumption in this sector can be significantly reduced, with a number of positive effects – from energy and economic to environmental ones. In this paper, the software packages EnergyPlus and Google SketchUp were used to examine the possibility of installing photovoltaic (PV) panels on the roof of "Milutin and Draginja Todorović" Elementary School (ES) building, with the main goal to implement this model in other public buildings in the near future, thus providing greater energy independence and stability of the whole sector.

Key words: *public buildings sector (PBS); educational institutions (EI); elementary schools (ES); photovoltaic (PV) panels; EnergyPlus.*

1 Introduction

According to the data available in the Energy Efficiency Program of the City of Kragujevac [1], the electric power consumption in PBS is 10089395.48 kWh/a (Fig. 1). EI contribute the most to this consumption with approximately 3857881.2 kWh (38%), followed by HI (1624609.61 kWh/a) and SO (1299957.83 kWh/a). Among EI in the city of Kragujevac, the ES are the most numerous (69 of them), which is why they have the highest consumption of electric power (1909274.03 kWh/a), while the second highest are HS with the consumption share of 12% (1223935.83 kWh/a).

In order to reduce the consumption of electricity in EI, and even in the entire PBS, the use of PV panels can play a key role, which has been tested and shown in a large number of papers around the world [2-7].

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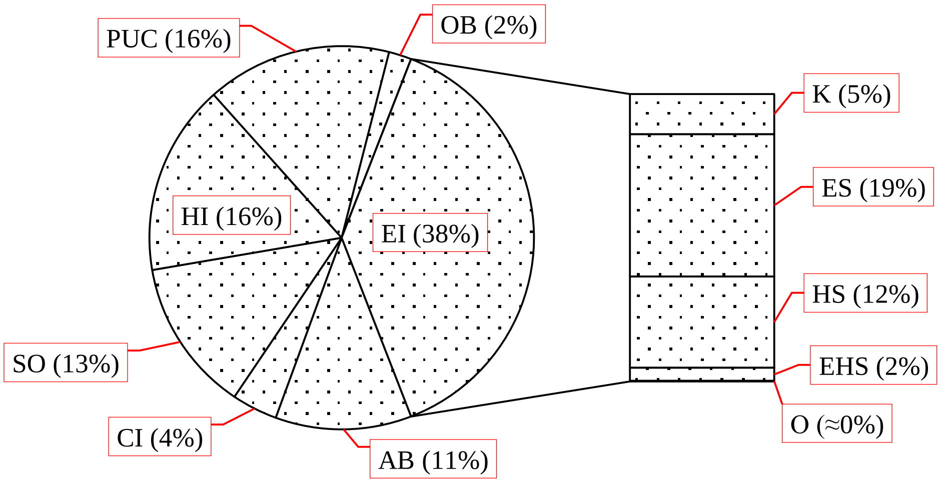

Fig. 1. The electric power consumption in PBS in the City of Kragujevac according to the facility structure [1]
EI – Educational Institutions; AB – Administrative Buildings; CI – Cultural Institutions; SF – Sports Objects; HI – Health Institutions; PUC – Public Utility Companies; OB – Other Buildings; K – Kindergarten; ES – Elementary School; HS – High School; EHS – Elementary and High School; O – Other

The study conducted in Portugal [8] dealt with the implementation of PV panels on the roofs of school buildings, taking into account the following: the potential of use of the roofs of school buildings, investment costs, return of investment period, reduction of greenhouse gases. *Shaari and Bowman* simulated the operation of BIPV applications on a standard school building in Malaysia, showing that the potential for using PV technologies is much higher [9]. A study conducted on a school building in Turkey [10] showed that the use of PV panels can cover 28-80% of electricity needs, depending on the month of the year. In [11] 265 PV panels were used on the roof of the school in Izmir to meet 65% of its own electricity needs. In one school building in the United Arab Emirates [12], 62 PV panels (total installation power of 7936 W) were used in conjunction with 62 batteries (each 12 V), which proved that the produced electricity can be used for an in-school water treatment plant and night decorative lighting. *Leena Cholakkal* took a specific example of a school building in Blacksburg (Virginia) and used multiple linear regression in order to develop a model that would be used to assess the cost-effectiveness of a structurally integrated PV roof system connected to a electric power grid [13]. In [14] eQUEST software package was used to (among other things) examine the production of electricity from the PV system in a school building located in a humid climate, in Hong Kong. By using BIPV for facades, 97.5% of electricity needs can be met, and by installing PV panels on the roof, complete energy independence of the building can be ensured.

In Serbia, the use of PV panels is still very low, although the potential for using solar energy is higher than the European average. One of the main reasons is that there are no legal regulations for the return of "surplus" electricity produced into the power grid, free of charge, which is why solar systems are sized according to the needs of the users in the building (regardless of its purpose).

In this research, the roof of the "Milutin and Draginja Todorović" Elementary School building is used for the installation of PV panels in order to reduce the consumption of electricity in it. The goal is to accelerate the use of solar energy through greater implementation of PV systems in PBS, which would ensure energy and environmental stability of the City of Kragujevac.

2 Materials and methods

The subject of the research is the "Milutin and Draginja Todorović" Elementary School building (Fig. 2). The building has four floors with a total area of 4424.74 m^2, as follows: basement (683.3 m^2), ground floor (1986.94 m^2), first floor (823.55 m^2) and second floor (930.95 m^2). The main entrance is oriented to the southwest (SW).

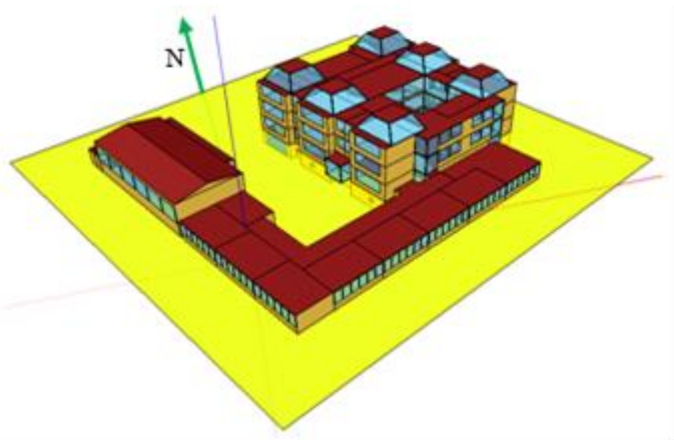

Fig. 2. Isometric view of the ES "Milutin and Draginja Todorović"

Kragujevac (located in GMT+1 h time zone) is characterized by a moderate continental climate with distinct seasons. Summers are hot and humid, with temperatures reaching +37°C. On the other hand, winters are cold (temperatures drop to -12°C) with snow. The city is located at 44°02′ N and 20°92′ E, at the altitude of 209 m [15]. Meteorological data for the city of Kragujevac are given in Tab. 1.

Tab. 1. Meteorological data for the city of Kragujevac [15]

Month	t_D [°C]	t_W [°C]	I_{DIFF} [W/m^2]	I_{DIR} [W/m^2]	φ [%]	a [deg]	c [m/s]
January	-0.24	-1.44	33.30	63.63	79.92	213.17	2.01
February	0.88	-0.46	49.39	86.66	79.82	210.60	2.02
March	5.57	3.29	77.08	106.12	72.06	207.98	2.35
April	10.87	7.74	92.65	149.02	67.92	209.06	2.27
May	16.06	12.18	113.30	176.45	66.57	210.08	1.77
June	18.85	14.99	109.50	208.94	69.42	209.51	1.69
July	20.78	16.04	110.60	228.12	64.49	198.04	1.62
August	20.38	15.69	96.25	215.40	64.05	211.45	1.51
September	16.68	13.30	75.54	166.92	71.21	203.79	1.68
October	11.18	8.83	57.34	119.43	76.40	222.28	1.69
November	6.08	4.45	39.83	64.51	79.80	210.38	2.06
December	1.13	0.09	28.66	58.86	83.51	208.33	1.87

t_D – Dry bulb temperature; t_W – Wet bulb temperature; I_{DIFF} – Diffuse solar radiation;
I_{DIR} – Direct solar radiation; φ – Relative humidity; a – Wind Direction; c – Wind speed

Taking into account the specific factor of the building shape and orientation, the Fig. 3. shows potential roof surfaces for the installation of PV panels. The characteristics of the listed roof surfaces are given in Tab. 2.

It is possible to install 72 monocrystalline PV panels, measuring 1940×990×40 mm in size, with the total installed (maximum) power of 24480 W [16] on the Roof 1. Taking into account the optimal angle of inclination of the PV panels, which is 37.5° for the city of Kragujevac [17], the recommendations from [18] related to the method of assembly and installation of PV panels, the impact of shadow due to the factor of orientation and shape of the building (Fig. 4), as well as the formula (Eq.1 [19]) for determining the optimal distance between the rows of PV panels (Fig. 5), it is possible to place a total of 88 monocrystalline PV panels (of same dimensions) with the total installed (maximum) power of 29920 W on the Roof 3.

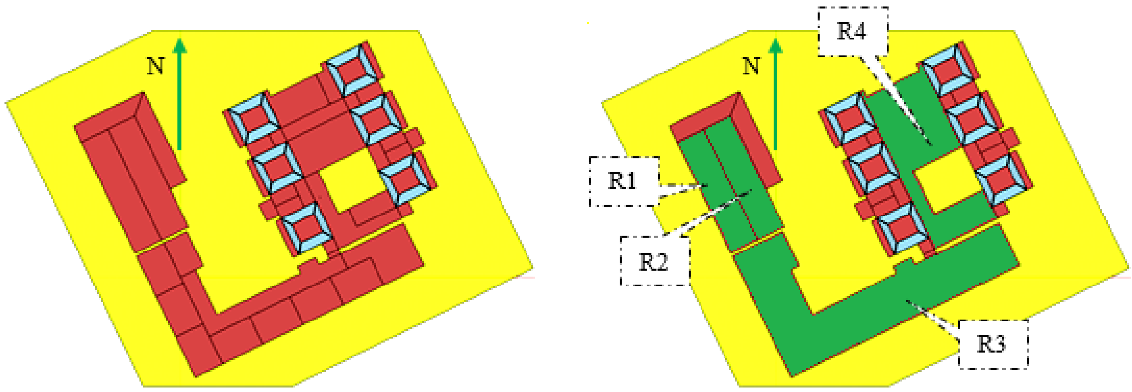

Fig. 3. View of the roof flats of the ES "Milutin and Draginja Todorović"

Tab. 2. Characteristics of potential roof surfaces for installing PV panels

Name	Designation	P [m^2]	Characteristic	I_{TOT} [kWh/m^2/a]	Conclusion
Roof 1	R1	145.24	Hip roof (≈9.6° to SW)	1367.52	Suitable for installing PV panels
Roof 2	R2	145.24	Hip roof (≈9.6° to NE)	1247.63	Not suitable for installing PV panels
Roof 3	R3	647.95	Flat roof	1278.14	Suitable for installing PV panels
Roof 4	R4	366.35	Flat roof	1242.86	Not suitable for installing PV panels

P – Roof area; I_{TOT} – Total solar radiation incident on roof area

$$Z = H \cdot \frac{\sin\left(180^\circ - (\alpha + \beta)\right)}{\sin \beta} = 1.94m \cdot \frac{\sin\left(180^\circ - \left(37.5^\circ + 22.5^\circ\right)\right)}{\sin 22.5^\circ} = 2.24m \qquad \text{(Eq. 1)}$$

The impact of the shadow (the so-called shadow line) is determined for the spring (March 21) and autumn (September 23) equinox, when the length of the day and night is 12 hours each.

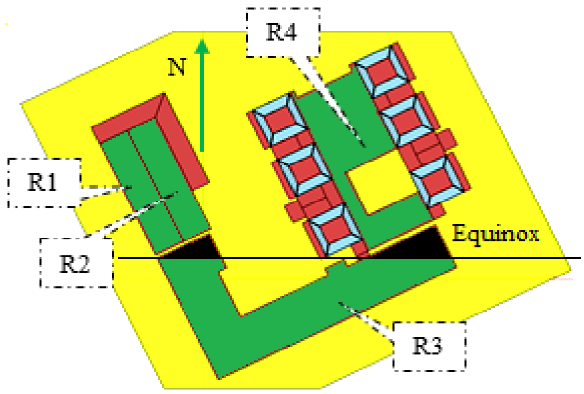

Fig. 4. Net roof surface for PV panel installation on the Roof 3

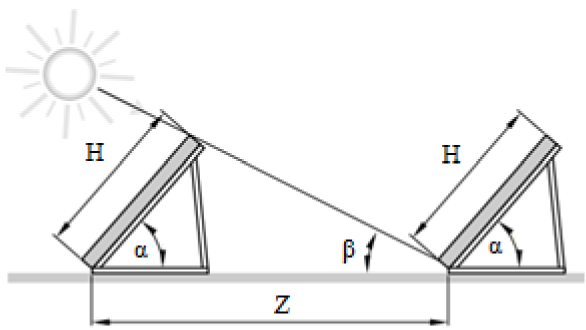

Fig. 5. Optimal distance between the rows of PV panels

Isometric view of the conceptual design of the solar power plant on the roof of the "Milutin and Draginja Todorović" Elementary School building with a total installed (maximum) power of 54400 W is shown in Fig. 6.

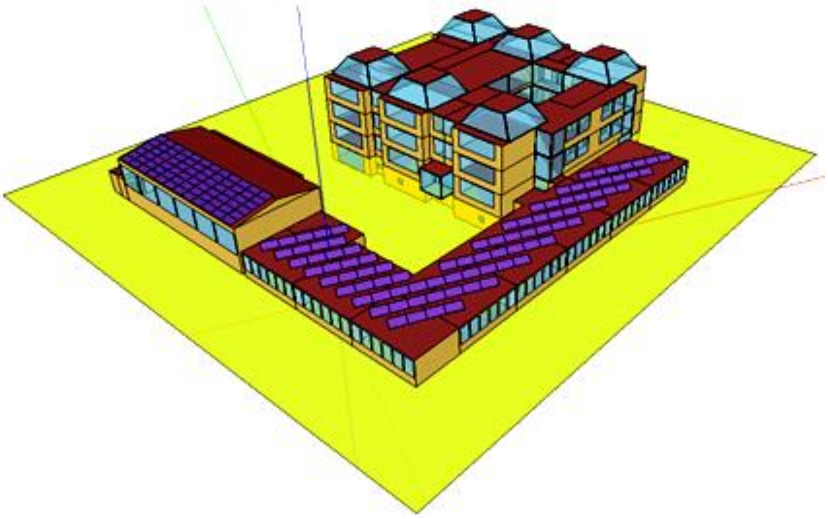

Fig. 6. Isometric view of the conceptual design of the solar power plant on the roof of the "Milutin and Draginja Todorović" ES building

3 Research results

Electric power consumption in the "Milutin and Draginja Todorović" Elementary School building, by months, for the period 2015-2019, is shown in Fig. 7.

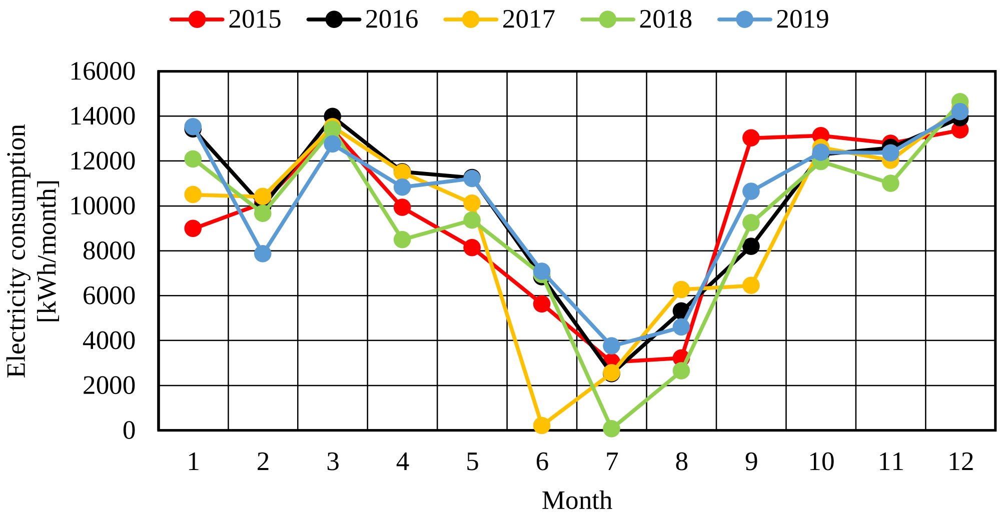

Fig. 7. Monthly consumption of electricity in "Milutin and Draginja Todorović" ES building (2015-2019)

Fig. 7. shows that consumption of electric power is very uneven if the same months are observed during the analyzed period. It can also be noticed that electricity consumption during the summer season is much lower (from March to October) compared to electricity consumption during the heating season. The reason lies in the school calendar that includes summer vacation, but also in lowerusage of air-conditioning split systems that are utilized as a supplementary heating sourceduring the winter season.

Fig. 8. shows the relationship between the monthly production of electricity from the solar power plant and its average consumption in the period from 2015 to 2019 in the analyzed building.

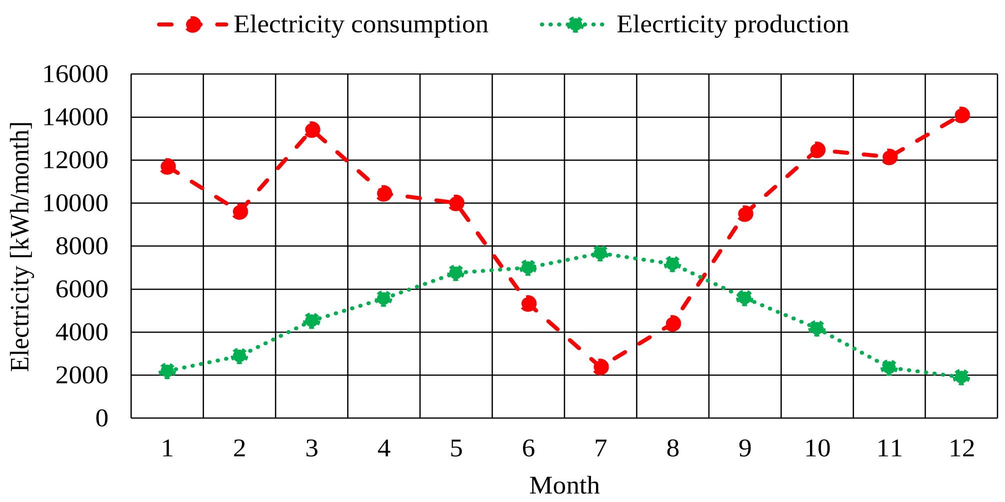

Fig. 8. Relationship between the monthly production of electricity and its average consumption in "Milutin and Draginja Todorović" ES building

The first thing to be noticed is that the solar power plant is not able to fully compensate for the school's needs for electric power from September to May, that is, school's electricity needs are much higher than the solar power plant potentials. It can also be noticed that the production of electricity is the highest in June, July and August, when the needs are the least (the production of electricity exceeds the needs of the building). As the legislation in Serbia is still not on the side of the privileged producers of electricity, the surplus electricity can be stored and then used depending on the needs of the building. This would give much more even production and consumption curves (Fig. 9).

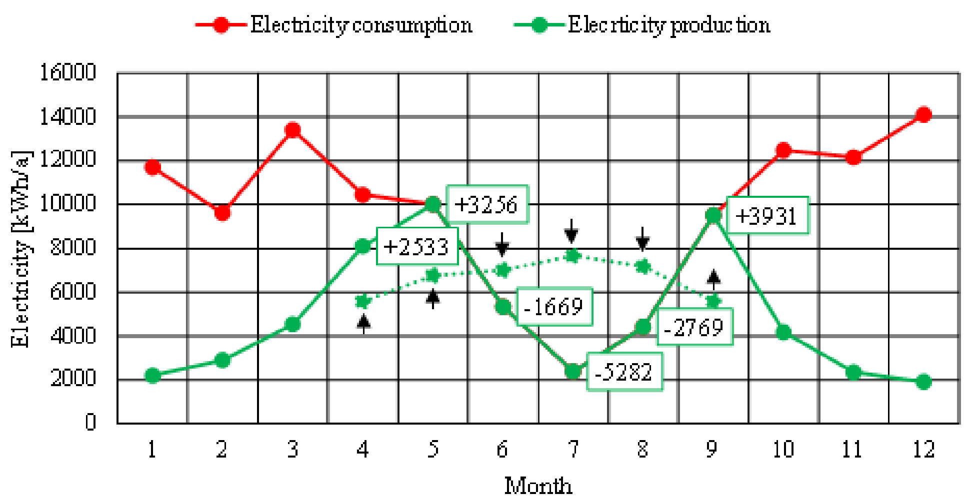

Fig. 9. Balancing of electricity consumption in "Milutin and Draginja Todorović" ES building

As the average annual electricity consumption in the analyzed period is around 115558 kWh/a, and the average electricity production is 57795 kWh/a (with a system efficiency of 90% during the first 15 years), it can easily be concluded that, by installing a solar power plant on the roof of the "Milutin and Draginja Todorović" Elementary School building, savings in consumption of about 50% can be achieved, which means that a significant reduction in CO_2 emissions and primary energy consumptioncan be achieved as well (Fig. 10, Fig. 11).

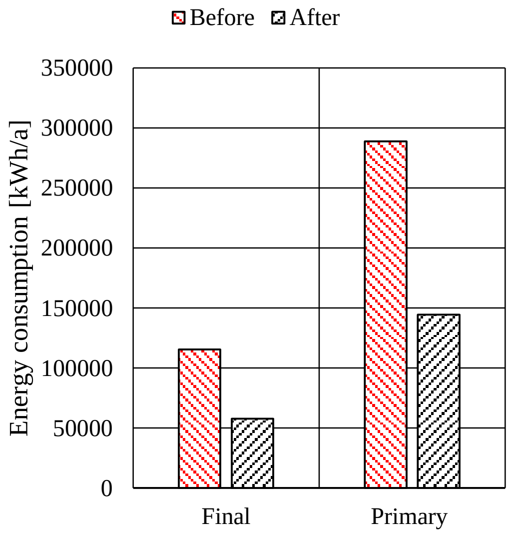

Fig. 10. Final and primary energy consumption in "Milutin and Draginja Todorović" ES building before and after energy efficiency measures [20]

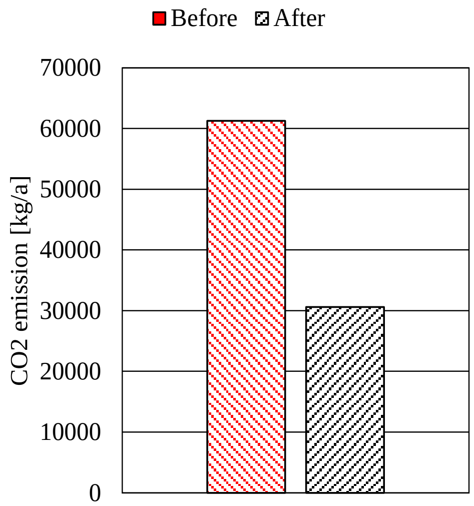

Fig. 11. CO_2 *emissions in "Milutin and Draginja Todorović" ES building before and after energy efficiency measures* [20]

4 Conclusion

Educational institutions (EI), with a share of approximately 38%, represent the largest category of facilities in the public buildings sector (PBS) in the City of Kragujevac when it comes to electric power consumption, which annually amounts to over 10 GWh. By implementing appropriate measures, including the mandatory use of renewable energy sources (RES) in combination with a responsible energy policy at the city level, electricity consumption in this sector can be significantly reduced, with a number of positive effects – from energy and economic to environmental ones.

In order to reduce electricity consumption in EI, and even in the entire PBS, the use of PV panels can play a key role, which has been tested and shown in a number of papers around the world. It is possible to install a solar power plant with a total installed (maximum) power of 54400 W on the roof of the "Milutin and Draginja Todorović" Elementary School building in Kragujevac.

The solar power plant is not able to fully compensate for the school's needs for electric power from September to May, that is, school's electricity needs are much higher than the solar power plant potentials. The production of electricity is the highest in June, July and August, when the needs are the least (the production of electricity exceeds the needs of the building).

By installing a solar power plant on the roof of the "Milutin and Draginja Todorović" Elementary School building, savings in consumption of about 50% can be achieved, which means that a significant reduction in CO2 emissions and primary energy consumption can be achieved as well. As the legislation in Serbia is still not on the side of the privileged producers of electricity, the surplus electricity can be stored and then used depending on the needs of the building.

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