IMPLEMENTACIJA SOLARNIH SISTEMA U POSTROJENJIMA PREHRAMBENE INDUSTRIJE – STUDIJA SLUČAJA KRAGUJEVAC

IMPLEMENTATION OF SOLAR SYSTEMS IN FOOF INDUSTRIES - CASE STUDY KRAGUJEVAC

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Upravljanje energijom u industriji hrane je neprekidan proces, koji obuhvata praćenje energetskog učinka preduzeća i neprestano pronalaženje načina da se isti održi i poboljša. Na konkretnom preduzeću lociranom u Kragujevcu, sprovedena je studija slučaja u kojoj je razmatrano postavljanje ravnih solarnih kolektora (RSK) i fotonaponskih panela (FNP) na ravan krov postrojenja, sa ciljem povećanja energo-eko efikasnosti (EEE). Kompletno istraživanje je sprovedeno numerički, pomoću EnergyPlus softvera. Rezultati pokazuju da se FNP godišnje može zadovoljiti 3,65% potreba preduzeća za električnom energijom, uz period otplate od 22,6 godina, dok se primenom RSK potrošnja prirodog gasa na godišnjem nivou redukuje za 14,64%, uz dosta kraći period povraćaja uloženih sredstava (12,05 godina).

Ključne reči: *EEE; prehrambena industrija; FNP; RSK; EnergyPlus; simulacija, period otplate*

Energy management in the food industry is a continuous process, which includes monitoring the energy performance of the company and continually finding ways to sustain and improve it. At a concrete company located in Kragujevac, the installation of flat plate solar collectors (FPSC) and photovoltaic panels (PVP) on flat roofs of the plant was discussed with the aim of increasing the energy-eco efficiency (EEE). Complete research was conducted numerically, using the EnergyPlus software. The results show that PVP annually can meet 3.65% of the electricity needs of the company, with a payback period of 22.6 years, while using the FPSC consumption of natural gas annually reduces by 14.64%, with a much shorter return on investment (12.05 years).

Key words: *EEE; food industry; PVP; FPSC; EnergyPlus; simulation, payback period*

1 Introduction

According to the Energy Information Administration (EIA), final energy consumption is the highest in the industrial sector (32%). The food industry contributes 1.6% to this sector [1].

Although the food industry (as a percentage) is not a major consumer of final energy, the potential for energy savings in this branch of the food industry is high [2]. Therefore, in the literature, various measures can be found to achieve this:

- Purchasing new and replacement of old equipment [3-6];
- Optimization of production processes and lines [3-6];
- Adequate maintenance and management of production processes and lines [3-6];
- Training of employees [7];
- Recovery of waste heat where the technological and sanitary conditions allow it [8-14];
- Use of renewable energy sources (solar, geothermal and biomass energy) [15-18].

In order to increase energy-eco efficiency in the food industry, in the case of a plant located in Kragujevac, a numerical survey was conducted using EnergyPlus software to consider the possibility of using solar energy through FPSC and PVP.

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2 Description of the plant

The subject of research is the company within the food industry (Figure 1). The plant is located in Kragujevac and WeatherFile [19] for this city was used within the EnergyPlus software. The green arrow determines the direction of the north, and it can be concluded that the building is oriented towards NE-SW.

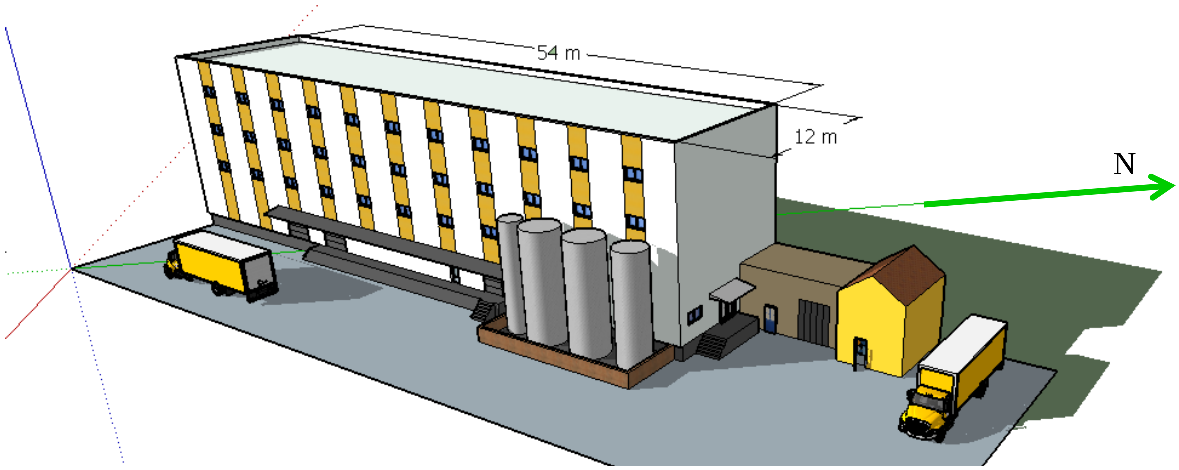

Figure 1 – Subject of research

The specific consumption of natural gas, electricity and water, depending on the volume of production, is shown in Table 1.

Table 1 – Specific energy consumption depending on production volume

Year	*Specific consumption*		
	Natural gas [Sm^3/t]	*Electricity* [kWh/t]	*Water* [m^3/t]
2015	14.76	124.48	1.16
2016	13.80	112.60	0.70
2017	14.71	119.07	0.81
2018	14.31	117.46	0.54

Table 1 shows that energy consumption does not follow the production volume. Specific energy consumption in the food industry (in general) depends on the range of products, the technological process of production, the age and maintenance of equipment, the amount of generated waste, as well as the skills and level of employee training. On the other hand, the specific energy consumption impacts have weather conditions because they depend on the required amount of heat and cooling energy during the year.

3 Thermotechnical systems

3.1 PVP

Within the EnergyPlus software, three different PV modules are implemented: Simple, Equivalent One-Diode and Sandia. In this paper, a Simple Module was used which calculates the amount of generated (produced) PVP electricity from the following form [20]:

$$P_{PVP} = A_{PVP} \cdot f_{ACTIVE} \cdot I_{TOTAL} \cdot \eta_{CELL} \cdot \eta_{INVERTER} \tag{1}$$

Where are: P_{PVP} - electricity produced from PVP [kWh/month], A_{PVP} - area occupied by PVP [m^2], f_{ACTIVE} - fraction of surface area with active PV cells [-], I_{TOTAL} - total solar radiation incident on PVP array [kWh/m^2/month], η_{CELL} - module conversion efficiency [-], $\eta_{INVERTER}$ - DC to AC conversion efficiency [-].

Taking into account the orientation of the building (Figure 1), the optimal angle of inclination of solar systems (for the city of Kragujevac this angle is 37.5° [21]) and recommendations related to the installation of solar systems (Figure 2), a flat roof can be covered with 90 polycrystalline PVP (Figure 3) measuring 1.64×0.99 m [22], which means that the total area for collecting solar energy is 146.12 m^2. Solar cells cover 89.21% of solar panels (the number of solar cells per panel is 60, the dimension is 0.156×0.156 m). The efficiency of solar cells is 18.48%, and the inverter is 75% [20].

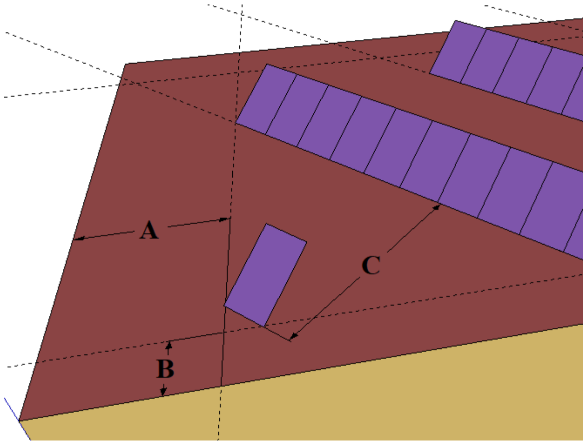

Figure 2 – Recommendations for installation PVP [23]
(A=3 m; B=1.2 m; C=4.5 m)

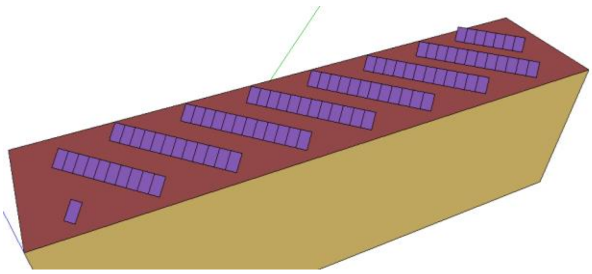

Figure 3 – Flat roof covered with PVP

3.2 FPSC

A simplified thermal calculation of the FPSC in the EnergyPlus software is based on the application of the following form [20]:

$$P_{FPSC} = A_{FPSC} \cdot I_{TOTAL} \cdot \eta_{FPSC} \quad (2)$$

Where are: P_{FPSC} - heat energy produced from FPSC [kWh/month], A_{FPSC} - area occupied by FPSC [m^2], I_{TOTAL} - total solar radiation incident on FPSC array [kWh/m^2/month], η_{FPSC} - FPSC efficiency [-].

Taking into account the constraints that applied to PVP (orientation, inclination, recommendations for installation), in this case, the total area for collecting solar energy is 142.62 m^2 (adopted 56 FPSC dimensions 2.356×1.081 m [24]). For the efficiency of FPSC, the value was 0.44 [21]. Recommendations for mounting the FPSC date sun in Figure 4, and the roof covered with FPSC is shown in Figure 5.

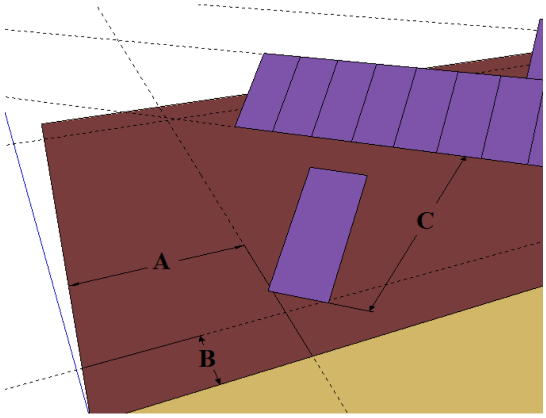

Figure 4 – Recommendations for installation FPSC [23]
(A=3 m; B=1.2 m; C=6.5 m)

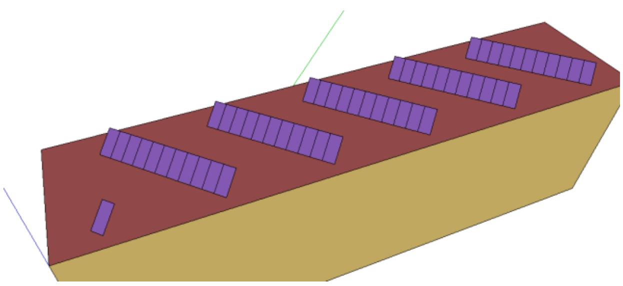

Figure 5 – Flat roof covered with FPSC

The amount of natural gas that is required for a gas boiler (GB) to produce the same amount of heat as FPSC can be determined as follows:

$$\dot{m}_G = \frac{P_{FPSC}}{\eta_G \cdot H_{DG}} \quad (3)$$

Where are: $\dot{m}_G$ - mass flow of natural gas [Sm^3/month], H_{DG} - lower thermal power of natural gas [kWh/Sm^3], η_{GB} - overall efficiency of the system with GB [-].

For thermal power of natural gas, the value of 9.261 kWh / Sm^3 [25] was adopted. Taking into account GB efficiency, pipe network efficiency and efficiency of the control system, the total efficiency of the system with GB is 0.77 [26].

4 Research results

Power generation from PVP (Figure 6) varies over the course of the year and depends on weather conditions (time of day, season, amount of precipitation, cloudiness). From the picture it can be seen that the largest electricity generation in the summer period: June (2,747 kWh), July (2,775 kWh), August (3,097 kWh), September (2,996 kWh), and during the winter months the smallest: November (1,117 kWh) December (891 kWh), January (1,092 kWh), February (1,371 kWh). In this case PVP system can produce 24,811.93 kWh/a, which means that one PVP produces 275.69 kWh/a.

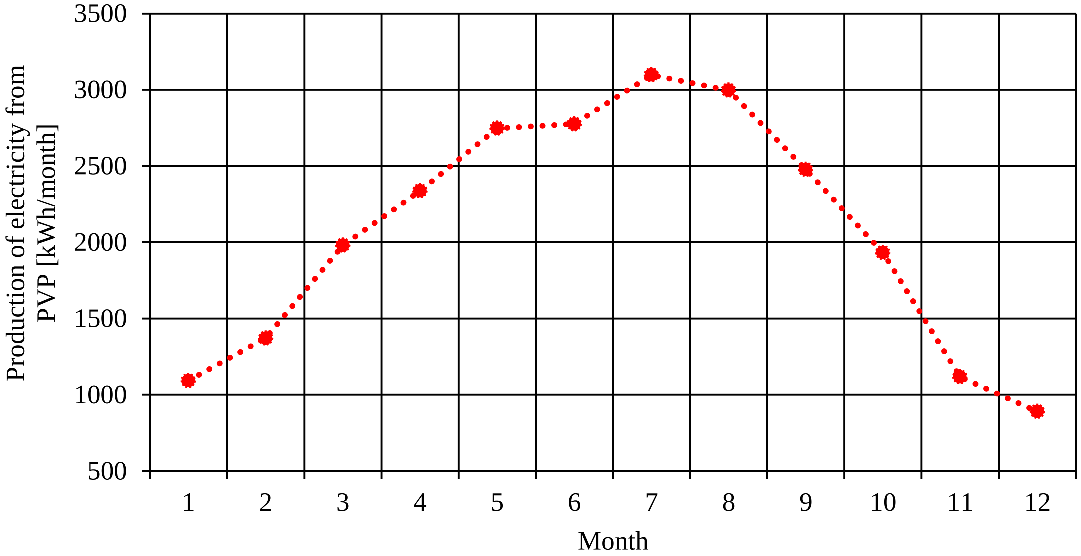

Figure 6 – Production electricity from PVP

Based on a four-year data collection, the average annual needs of the power plant are 679,180.5 kWh (Figure 7). By installing a PVP system, in analogy to Figure 6, the highest savings are achieved during the summer, and at least during the winter. Annually, this one system can achieve savings of 3.65%.

Figure 8 shows that during the year, 86,179.5 kWh of heat can be produced from the FPSC for the needs of the plant (one FPSL produces 1,538.92 kWh/a). The consumption of natural gas can be reduced from 82,561.75 to 70,475.93 Sm^3 at the annual level by the indicated solar system. In other words, natural gas consumption is reduced by 14.64% (Figure 9).

The investment costs of PVP installation are € 29,160 (1.2 €/W). Taking into account the average electricity price for the analyzed period (Table 1) amounting to 0.052 €/kWh (payment invoices) and the amount of electricity produced (24,811.93 kWh/a), the payback period was estimated at 22.6 years (Figure 10).

For the installation of FPSC, a cash investment of € 39,900 (2.85 €/W) is required. If the price of natural gas during the period was 0.274 €/Sm^3, and the estimate of its consumption savings of 12,085.82 Sm^3/a, this investment would be payable after 12.05 years (Figure 10).

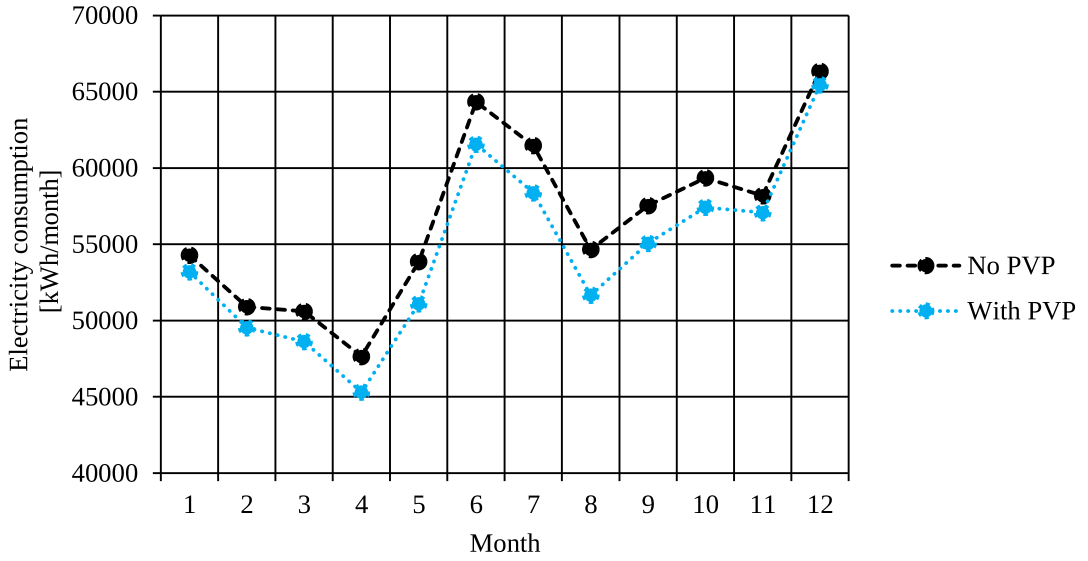

Figure 7 – Electricity consumption before and after placement of PVP

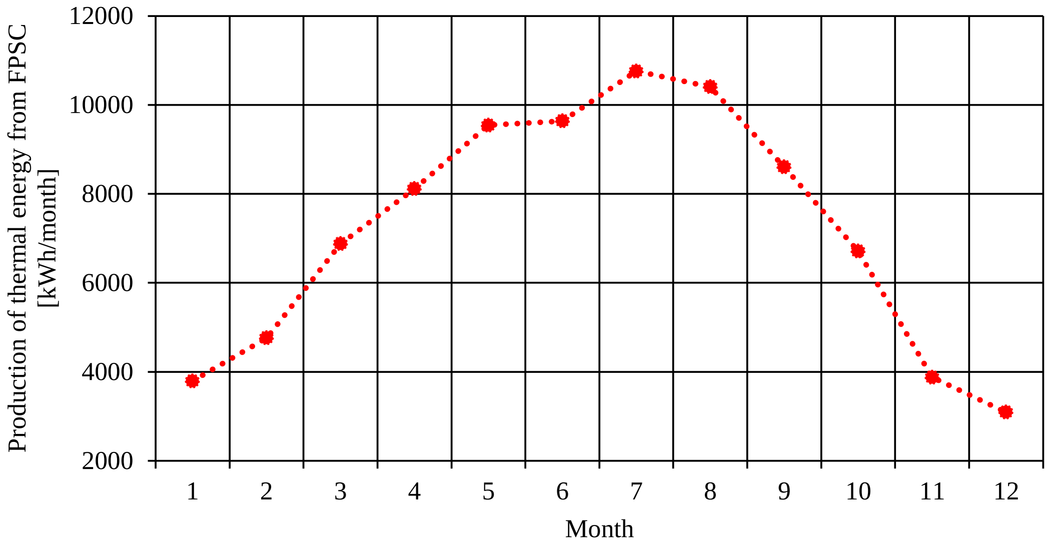

Figure 8 – Thermal energy production from FPSC

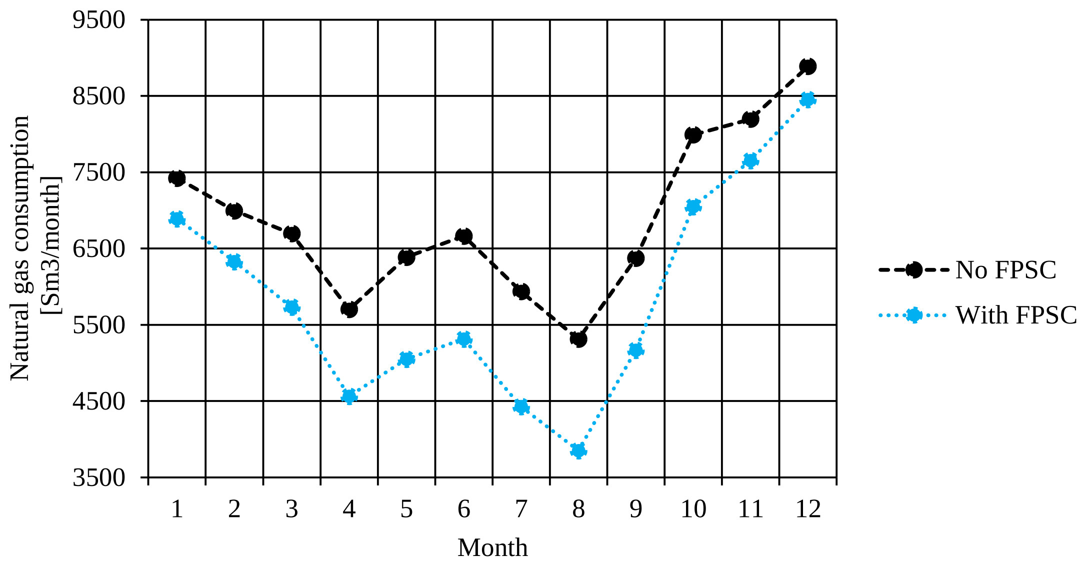

Figure 9 – Natural gas consumption before and after installation of FPSC

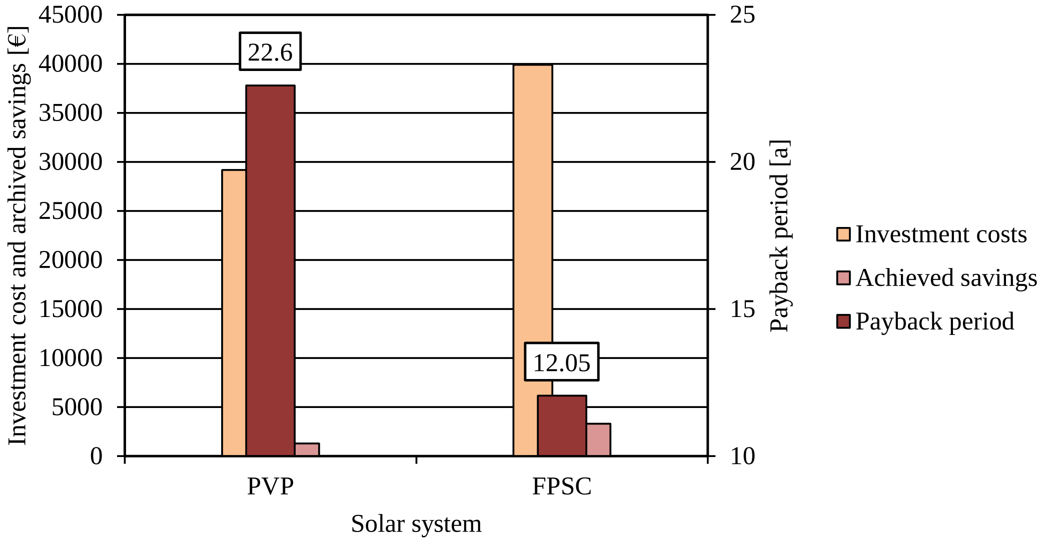

Figure 10 –Economic indicators for the installation of PVP and FPSC

5 Conclusion

The food industry is very sensitive in terms of final energy consumption. Therefore, various measures are being taken to increase EEE in food production plants. In this way, money savings are achieved, while at the same time the environment is protected. Using renewable energy sources, all negative consequences can be reduced considerably. The disadvantages of using renewable energy sources in order to achieve the EEE are reflected in the fact that initial investments can sometimes be quite high, which affects the payback period of the invested funds.

This article discusses the possibility of implementing the active solar systems in order to reduce the final energy consumption which can result in cost savings and saves the environment. The installation of PVP and FPSC on a flat roof of an industrial plant in the territory of Kragujevac was considered. The results showed that using PVP annual electricity consumption is reduced by 3.65%. Natural gas consumption is reduced by 14.64% using FPSC.

Economic analysis shows that the payback period is shorter (12.05 year) when FPSC is set.

6 Acknowledgments

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