

The use of a photovoltaic system in a single family house in Poland – case study

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Abstract. Renewable energy is becoming widely used all over the world nowadays. More single-family houses use such sources to generate heat and electricity. The article presents a case study of a house located in central Poland, in which a photovoltaic system was used, additionally with other renewable sources, such as a small wind turbine, biomass boiler and solar panels. The article describes the advantages of using renewable energy sources in the building sector considered and presents the results of experimental studies of electricity generation in a given period of time with their analysis. It turned out that the production of electricity using photovoltaic panels in autumn can support high electricity demand at this time.

1 Introduction

Renewable energy sources are the fastest growing energy sector in the world. Its main purpose is to obtain energy from the sun, wind, water, biomass or earth heat and convert it into electricity or heat that is used in households, at work or in public buildings. The most important advantage of using and installing such devices and installations is the fact that it contributes to the reduction of air pollution and has a positive impact on the environment.

Rieck et al. [1] conducted an analysis of single-family houses in Germany, where wind turbines and photovoltaic panels powering the work of heat pumps were installed. The main purpose was to obtain information's on the amount of electricity and heat produced for a single-family house. The analysis concluded that it is profitable to install home wind turbines because it is able to cover the demand for electricity in various weather conditions. Another example of research is a study by Laib et al. [2] in an apartment house in the north of Algeria. The study covered a household where photovoltaic panels produce electricity on sunny days, and when the weather conditions are unfavourable, energy is taken from the grid. The installed photovoltaic panels generated 67.6% of the total energy. The rest of the required energy was taken from the grid in the amount of 33.4%. Wherefore, Ali et al. [3] conducted research on the island of Hulhumale in the Maldives of the potential for energy production with solar panels. The research showed that on the roofs of residential houses, depending on their surface area, approximately 4.8-8.0 GWh of electricity could be generated within a year. Furthermore, Gonzalez et al. [4] proposed the design of a hybrid system that uses wind, solar and biomass energy to produce electricity in central Catalonia. The authors

concluded that wind energy has a lower environmental impact than solar energy or biomass. Moreover, Ramirez-Sagner et al. [5] conducted a study in Chilean regions on the electricity production potential of solar PV systems divided into residential and commercial systems. According to the analysis, Chile, and in particular its central and northern part, has a huge energy potential, and thus the possibility of applying electricity tariffs in the form of clusters. For instance, Chwieduk and Chwieduk [6] analysed an example of a photovoltaic system for a low-energy house in Poland, which supplies a heat pump in winter. This was to check whether the number of hours of operation of the PV system and energy production will be sufficient to supply it all year round to the heat pump, so as to maintain the air parameters in the building at a similar level. Energy consumption and the work of photovoltaic panels by the authors were in terms of the Polish energy law. Boarin et al. [7] analysed Australian rural areas, in this case Cape York, Queensland, where there is an electricity problem. According to the authors, off-grid photovoltaic installations are an ideal solution. The obtained results suggested that in economic terms such a photovoltaic system is profitable, what is more, the produced energy is cheaper than from other unconventional sources. Emmanuel et al. [8] conducted a study at the Wellington School in New Zealand based on 40 solar panels. During the holiday season, the produced energy is fed into the grid. Electricity consumption at school decreased by 32% and the cost of bills decreased by 45%. It is also worth noting that thermal environment in modern, often intelligent buildings, which are commonly supplied with renewable energy sources, might be different as investigated by the author and other co-workers at Kielce University of Technology [9 - 11]. An additional research proposal on the energy and economic analysis

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of a 5 MW photovoltaic system was presented by Alshare et al. [12]. The authors examined the work of photovoltaic cells on the campus of the University of Science and Technology of Jordan. The cells were tilted by 15, with an azimuth of 0. Analysis showed that the payback period is 4.32 years. Similar research was carried out by Duman and Guler [13]. The authors also undertook the analysis of a photovoltaic system with a power of 5 kW, located on the roofs of houses in several selected provinces in Turkey. All the obtained results turned out to be in the standard with recommendations and only two provinces showed the greatest potential for the use of photovoltaics - one in the southern part and the other in the northern part of the country.

The topic of renewable energy sources is interesting because of the possibility of becoming independent in terms of energy from other energy suppliers. Many countries use them as the first energy source in the country. Therefore, the undertaken research topic aimed at checking whether photovoltaic cells, even in the autumn period, will be able to enable the production of energy that the household members will be able to use at a later time. In addition, an economic analysis of the return of such an investment was carried out, assessing whether it is profitable enough to invest in it.

2 Methods

The research covered a single-family building located in central Poland, in the village of Rzymysko BG, in which 17 photovoltaic panels were installed on the ground. Additionally, the facility has solar panels, a pellet boiler, a fireplace with a water jacket and a wind turbine for the production of domestic hot water and central heating. Figure 1 and Figure 2 presents the photos of the analysed single family house.



Fig. 1. Investigated building- Eastern façade.



Fig. 2. Investigated building- Western façade.

The photovoltaic installation has been embedded on the ground next to the building (Fig.3.), facing south. The entire installation has a power output of 5.1 kW. It consists of 17 panels with a unit capacity of 300 Wp. As a result of solar radiation falling on the surface of photovoltaic panels, the energy from this radiation is converted into electricity. Then by means of an inverter, electric energy with direct voltage is converted into energy with alternating voltage, such as is found in the building's network. The power of the inverter was determined at 5800 W. The main assumption of this investment was to produce enough electricity to meet the demand of the entire building as much as possible. The operation of this installation is estimated at 25 years, and it's operation itself is to reduce unwanted pollutants in the environment.



Fig. 3. Ground level PV system.

Table 1 below presents selected technical data of modules installed in the single-family house [14].

Table 1. Font styles for a reference.

Parameter	Dana	Units
Max. power of the module	300	W
Efficiency of the module	18.3	%
Cell type	Monocrystalline	-
Number of cells	60	pcs
Module surface	1650x991x40	mm
Unit weight	18.2	kg

From a technical point of view, the selected photovoltaic panels are monocrystalline, with high module efficiency, but not necessarily high maximum module power, which can be found in other modules.

Additionally, two solar panels were installed on the roof of a single-family house, located on the south side. As the fluid in the pipes is heated with the polypropylene glycol heating medium heated by the sun, energy will be generated, which in turn will turn into heat. The generated heat is then transferred to the boiler room, where there is a water tank. By convection, the water is heated and the liquid itself is cooled and drained back to the collectors. The whole process is carried out using a controller that allows you to read the current temperature measurements of solar collectors as well as in tanks with water and central heating, and allows you to plan the temperature for buffers. The first water tank has a capacity of 200 litres, the second one has a capacity of 1000 litres. If solar collectors do not produce the right amount of heat to heat water, the water is heated in a hybrid way by energy generated from wind or a pellet boiler. Another system supporting central heating is a fireplace with a water jacket with a thermal power of 14 kW. The fireplace is powered by wood from deciduous trees. In turn, the water that is heated is transported to the central heating tank. Another device responsible for supporting domestic water heating is a 2 kW home wind turbine. The tree-blade rotor is mounted on a 12-meter mast. Electricity is generated in a generator which is powered by the rotor blades. Then, the resulting energy supports the electric heater, which is located in the domestic hot water tank. The pellet boiler is responsible for supplying the central heating and domestic hot water tanks. It is one of the main heating sources in the building. Its nominal power was determined at 16 kW, and the optimal one at 9.9 kW

3 Test results and discussion

This chapter will discuss the results of the energy produced by the tested photovoltaic panels and the economic assessment of investments in this type of renewable energy.

3.1 Electricity production using photovoltaic panels

The aim of the photovoltaic installation is to generate as much electricity as possible on sunny days, but also on cloudy days. Figure 4 shows the data obtained from the Konin Meteo station [15] informing about solar radiation for three selected days - October 24, on a sunny day, November 8, when it was cloudy, and December 10, when it was completely cloudy. In addition, an important issue that will be checked here is the impact of solar radiation on increasing the power of photovoltaic panels and thus on the production of electricity for a small-scale PV system used in a single-family house.

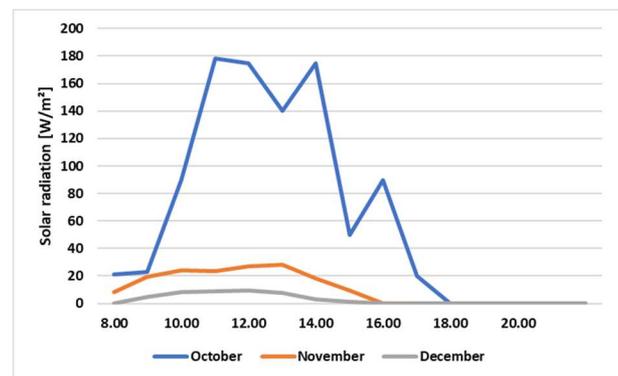


Fig. 4. Solar radiation measurement data for October 24 (blue line), November 8 (orange line) and December 10 (grey line) obtained from the Meteo station in Konin [15].

Out of the three selected days, the highest solar radiation fell on October 24 - from 8:00 a.m. it was 21 W / m² and gradually increased, reaching the highest value at 11:00 a.m. - 178 W/m². From 6:00 p.m., the measurements were 0 W/m². In the case of November 8 at 8:00 a.m. solar radiation was 8.1 W/m², and the highest value was 28.2 W/m² at 1:00 p.m. On this day, you can already see the shortening of the measurements taken from 4:00 p.m. On December 10, at 8:00 a.m. no measurement was recorded, the highest data received was 9.5 W/m² at 12 o'clock. Comparing three different months, on three different days, you can see that with the arrival of autumn and winter the radiation weakens, but still occurs in small amounts. Figures 5, 6, 7 below show the current power of the photovoltaic panels device and the energy that has been produced, in the hourly range from 8:00 to 22:00, separately for each tested day.

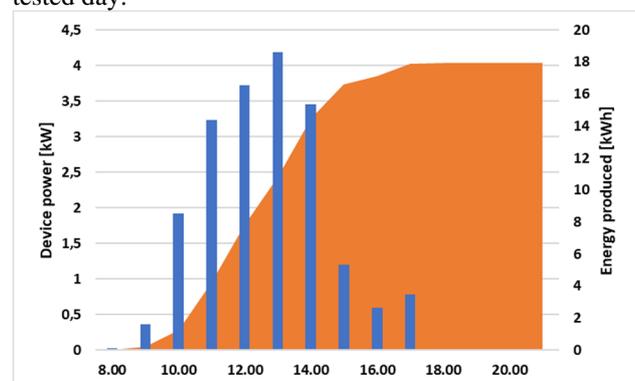


Fig. 5. The cumulative amount of energy produced on October 24, 2020 by photovoltaic panels (orange colour) and device power (blue colour).

Based on Figure 4, on October 24 at 8:00 a.m. on a sunny day, the amount of solar radiation was 21 W/m², which translates into the commenced operation of photovoltaic panels of 0.023 kW (Figure 5). With such a low power of the device, energy production of 0.011 kWh was achieved. The greatest power of the device was noticed between 11:00 and 14:00. The average power of the device for this hourly interval is 3.54 kW. Since then, there has been an increase in electricity production from 4,191 kWh until 4 p.m. where electricity production started to stabilize at 17.96 kWh by 9 p.m.

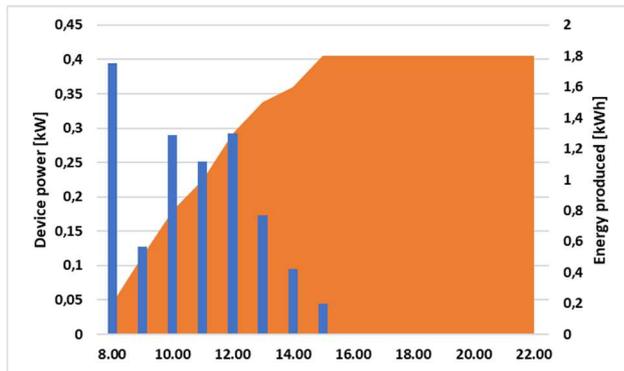


Fig. 6. The cumulative amount of energy produced on November 8, 2020 by photovoltaic panels (orange colour) and device power (blue colour).

In November, a significant decrease in solar radiation was noticed (Fig. 4) in contrast to the measurements from October. The highest power of the device was registered from 8:00 to 9:00 and amounted to 0.395 kW. Between 10:00 a.m. and 1:00 p.m. Electricity production started at 8:00 a.m. with a value of 0.2 kWh and increased until 3:00 p.m., reaching a steady production level of 1.8 kWh.

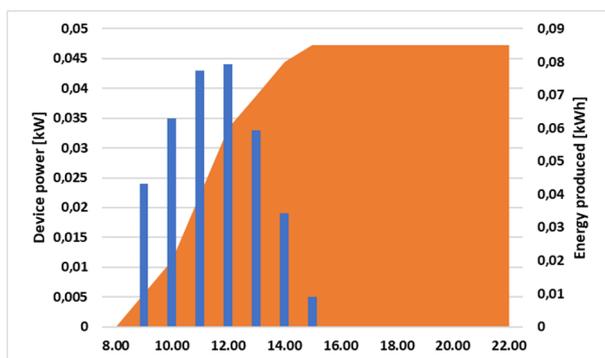


Fig. 7. The cumulative amount of energy produced on December 10, 2020 by photovoltaic panels (orange colour) and device power (blue colour).

Due to the fact that the solar radiation on December 10 from 8:00 to 9:00 was 0 W/m², the power of the device and produced energy were respectively 0 kW and 0 kWh. From 9:00 a.m., the device started producing electricity with a value of 0.01 kWh, with a device power of 0.024 kW and solar radiation of 5 W/m². From then on, the power of the device increased, reaching a maximum of 0.044 kW at 12:00. From 15:00, the level of electricity production was 0.085 kWh and remained constant until 22:00. Despite the clouds on November 8 and December 10, energy production took place, even with such low solar radiation. Figure 8 below shows the annual operation time of the photovoltaic installation and the amount of energy it produced for the whole year 2020, reported monthly.

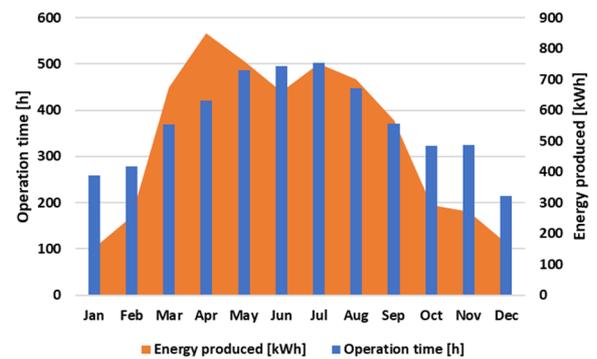


Fig. 8. Annual summary of the operation time of the photovoltaic installation and electricity production for 2020.

In January and February the machine ran for 259 and 278 hours consecutively, taking into account the winter period. During this time, 154.2 kWh and 256 kWh were produced. From March and July, the number of hours of operation of the device increased as the day got longer. In July, the machine achieved the highest number of hours worked, equal to 502 hours. Contrary to appearances, despite the large number of hours of operation of the photovoltaic installation in July, the highest energy production was recorded in April in the amount of 850.9 kWh. From August the plant's operating time and energy production began to decline due to shorter days and longer nights. The lowest value of the device operation was noticed in December amounting to 214 hours and energy produced amounting to 171 kWh. Definitely, despite to the lower number of operating hours, the energy produced was still higher than in the case of the greater number of operating hours of the device in January with the production of electricity equal to 154.2 kWh. From March to November, energy was greater than 500 kWh as opposed to January, February and December. During the year, the device worked 4491 hours and produced 6109.8 kWh of electricity.

3.2 Economic cost of returning the installed photovoltaic system

The total cost of the installation was PLN 35670 gross (which is about 8000 Euro). Due to the possibility of using co-financing from the European Union for the purchase of a photovoltaic installation, the own contribution amounted to PLN 7134 gross (about 1600 Euro). The monthly amount spent on electricity is PLN 140 (about 31 Euro). Therefore, the total annual cost of electricity bills is PLN 1680 (about 373 Euro). In order to calculate the return of investment costs, the own contribution had to be divided into the cost of the annual electricity bill. Thus, the investment will start to pay off between the fourth and fifth year of the investment. Figure 9 below shows the period after which the investment costs of the photovoltaic system will pay off.

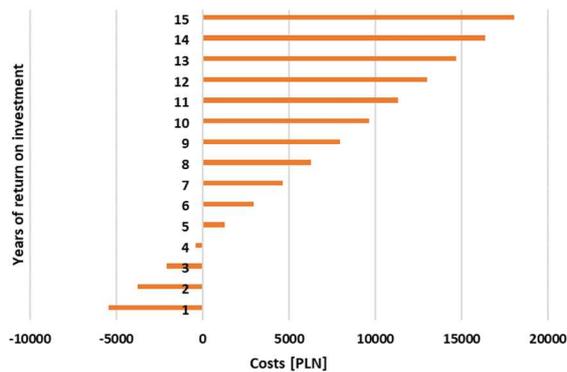


Fig. 9. Payback time of the investment costs of the PV system installed in the single family house.

In the first 4 years the investment the return amounts will be negative. A significant change can be noticed between the 4th and 5th year, where the positive amount will already amount to PLN 1266 (about 280 Euro). It is at this time that the first return on investment costs will take place and it will gradually increase in the following years.

It should be mentioned, however, that from time to time the system will short-circuit, i.e. a fire. Nevertheless, this is not the cause of the cells themselves, but of poorly connected wiring. Therefore, when installing the cells, make sure that everything is properly connected to the inverter. An additional disadvantage is the frequent cleaning of such cells, because all dust and dirt settle on their surface. This may contribute to a reduction in the efficiency of energy collection from solar radiation. Which results in less electricity production. Nevertheless, studies have shown that using photovoltaic cells to generate clean energy is the most appropriate solution, as energy production lasts all year round. This is especially important in the winter season, when it is already dark in Poland at 4 p.m. and energy consumption is high, such support from photovoltaic panels will enable the comfort of the building's residents.

4 Conclusions

The use of renewable energy sources can be very efficient in single family houses in central and eastern Europe. It might be especially profitable and advantageous if European Union funding for such "green" energy systems can be obtained. The number of operating hours of the installation is not an indicator of the energy produced. In this case, only 421 hours of operation of the device was enough for the energy produced to be 850.9 kWh, compared to July, where the operating hours were 502 kW and the electricity produced was only 751 kWh. This proves that the weather conditions in April were the best, and not necessarily the summer period as the most favourable for obtaining the greatest possible electricity. In economic terms, the period of 4 years of return on investment costs is a small period of waiting for the first noticeable financial results. However, it should be remembered that the own contribution was not high in

compared to the cost of the entire investment, hence the quick payback period. Despite the cloud cover and the autumn period in which the research was carried out, photovoltaic panels produced, depending on the month, a greater or a small amount of electricity. The difference can be noticed in October, where the solar radiation ended at 6:00 p.m., and in November with moderate cloudiness already at 4:00 p.m., similarly to December with total cloudiness. However, from 8:00 in October, solar radiation was 21 W/m², in November, solar radiation was 8.1 W / m², and in December only 0 W/m². This is a confirmation that it is worth investing in renewable sources for financial as well as environmental reasons. Each type of renewable energy sources has potential, especially photovoltaics, due to the benefits of installing it and its availability. It is much easier to place panels on the roof or the ground than to use geothermal energy in Poland (due to the geographical arrangement of the country). Therefore, the prospect for the development of photovoltaics in the future will gain momentum not only in Poland but also in many countries around the world.

References

1. J. Rieck, L. Taube, F. Behrendt, RE, **162** (2020), 1104-1112. <https://doi.org/10.1016/j.renene.2020.07.011>
2. I. Laib, A., Hamidat, M. Haddadi, N. Ramzan, A.G. Olabi, Ener. **152** (2018), 445-454. <https://doi.org/10.1016/j.energy.2018.03.157>
3. I. Ali, GM. Shafiullah, T. Urmee, R&SER, **83** (2018), 18-32. <https://doi.org/10.1016/j.rser.2017.10.019>
4. A. Gonzalez, J.-R. Riba, B. Esteban, A. Rius, RE, **126** (2018), 420-430. <https://doi.org/10.1016/j.renene.2018.03.062>
5. G. Ramirez-Sagner, C. Mata-Torres, A. Pino, R. A. Escobar, RE, **111** (2017), 332-343. <https://doi.org/10.1016/j.renene.2017.04.011>
6. B. Chwieduk, D. Chwieduk, RE, **165** (2021), 117-126. <https://doi.org/10.1016/j.renene.2020.11.026>
7. P. Boarin, E. Haarhoff, M. Manfredini, M. Mohammadzadeh, A. Premier, *Techno-economic analysis of PV-based power systems for Cape York, Australia. Rethinking Sustainable Pacific Rim Territories*. Proceedings of the 2020 APRU Sustainable Cities and Landscapes Hub PhD Symposium, Future Cities Research Hub, School of Architecture and Planning of the University Of Auckland.
8. M. Emmanuel, A. Akinyele, R. Rayudu, Ener. **120** (2017), 573-583. <https://doi.org/10.1016/j.energy.2016.11.107>
9. J.Zb. Piotrowski, Ł.J. Orman, X. Lucas, E. Zender – Świercz, M. Telejko, D. Koruba, Tests of thermal resistance of simulated walls with the reflective insulation, Proc. of Int. Conf. "Experimental Fluid Mechanics 2013", Czech Republic, EPJ Web of

- Conferences, **67**, 02095, 2014.
<https://doi.org/10.1051/epjconf/20146702095>
10. G. Majewski, M. Telejko, Ł.J. Orman, Preliminary results of thermal comfort analysis in selected buildings, Proc. of Conf. on Interdisciplinary Problems in Environmental Protection and Engineering (EKO-DOK), Poland, E3S Web of Conferences, **17**, 00056, 2017.
<https://doi.org/10.1051/e3sconf/20171700056>
 11. Dębska L., Krakowiak J., Kapjor A., Modern methods of thermal comfort measurements, SAE, **4** (2020).
 12. A. Alshare, B Tashtoush, S. Altarazi, A. El-Khalil, CSiTE, **21** (2020).
<https://doi.org/10.1016/j.csite.2020.100722>
 13. A. C. Duman, Ö. Güler, RE, **148** (2020), 697-711.
<https://doi.org/10.1016/j.renene.2019.10.157>
 14. https://columbusenergy.pl/blog/panele-longi-solar-technologie-jakosc-i-odpowiedzialnosc/?zrodlo=google-ads&medium=search&IDkampanii=1509955182&kampania=fotowoltaika-search-1&gclid=Cj0KCQiA-K2MBhC-ARIsAMtLKRtNeyBC3Gty0gTDE0mqkHYe2wMVqn6QA5jSarzOIweRbE3qHJ5VTocaAiJcEALw_wcB
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