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Comparative Analysis of the Use of Renewable Energy Sources in Selected Single-family Houses

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Abstract: Renewable energy sources play a substantial role in producing electricity and heat in single-family homes while becoming independent from external energy suppliers. This is primarily due to economic advantages, i.e., reducing electricity costs. This article aims to compare two single-family homes powered by photovoltaic systems and, additionally, a heat pump. Both buildings were located near each other in the same climate conditions (Swietokrzyskie Province, Poland). The analysis compared electricity production from the photovoltaic systems for two different module models with a maximum power of 280 W and 340 W for both buildings. Additionally, an analysis of electricity production was carried out for the monthly installation operation in the summer and autumn periods. The monthly electricity consumption from the heat pump in the autumn and winter periods was presented. In the last step, an economic analysis of the return on investment for both installations was presented. It turned out that despite the difference in investment costs, the payback period for both buildings is between 6-7 years.

Keywords: heat pump, photovoltaic system, renewable energy generation

1. Introduction

Renewable energy sources are playing an increasingly important role in the modern world. This is related to the production of clean energy (i.e., zero-emission production), independence from external energy suppliers, and financial and energy savings. Currently, many households decide to install photovoltaic systems and heat pumps to minimize electricity bills.

In Poland (Księżopolski et al. 2020), the focus has often been on buildings located in rural areas. As the authors pointed out, these houses were built between 1945 and 1970, and their energy efficiency is low, amounting to the final electricity consumption of 240 kWh/m^2/year. The analysis carried out by the authors, based on the two most common single-family buildings in villages, showed that thermal modernization and changing the heat source is key to reducing the energy costs of residents. With a similar intention, research conducted (Lee & McCuskey Shepley 2020) in South Korea focused on rented apartments (belonging to the city of Seoul) by low-income people who received a photovoltaic system from the government energy plan to save energy and reduce its costs – similarly to the research (Reames 2020) which examined homes in low-income and middle-income households and the possibilities of using solar systems. In Poland, the research (Dębska et al. 2024) focused on producing electricity from a photovoltaic installation and heat production and presenting the payback time of such an investment for a single-family house. As indicated by the analysis of the hybrid use, photovoltaic panels produced electricity in the range of 600 to 1200 kWh (April-October). The entire investment was to start paying off between the 9th and 10th year of using the installation. Contrary to the study (Rej Witt & Dębska 2022), where the return on investment would be from 4 to 5 years. Additionally, both analyses indicated that despite Poland's autumn and winter periods, energy production was unchanged – not as efficient as in the summer, but it was visible. This fact, as indicated, may be a positive argument for future investors. The authors claimed that the tenants of these apartments were satisfied with such a government solution. Data from other Polish experimental studies (Czajor & Amanowicz 2024, Dudkiewicz et al. 2022, Dudkiewicz & Fidorów-Kaprawy 2020, Stokowiec et al. 2023) confirm a positive impact of the modernization works on buildings, which aimed at increased thermal efficiency and reduced energy costs.

Due to its geographical location, the island nation of the Maldives is closely dependent on other countries, importing solid fossil fuels for electricity production. Considering the location of these islands in the Indian Ocean, a large potential for electricity production from the sun can be indicated. In connection with this, an analysis of the photovoltaic potential on the island of Hulhumale was carried out (Ali et al. 2018). It turned out that by using a photovoltaic installation, from 4.8 to 8.0 GWh of electricity can be generated (depending on the roof area), resulting in independence from imports of energy resources and reduced energy production costs. In Valencia, Spain (Gomez-Navaroo et al. 2021), the energy potential of photovoltaic systems installed on buildings was analyzed. It turned out that the amount of energy produced could cover Valencia's energy needs. Moreover, research conducted in Italy (Noro & Busato 2023) on energy savings using renewable energy sources for two selected types, an apartment, and a single-family house, showed that it is possible to save non-renewable primary energy by about 58% and save annual energy costs by 72%. Similarly to the research (Noro & Busato 2023), the research object in Canada (Abdolmalek & Berardi 2024) is a single-family house and an apartment. In this example, the authors try to propose an installation in which a photovoltaic installation is used together with hydrogen (similar to (Ostergaard et al. 2023)), which discusses hydrogen for energy storage purposes) and a battery bank. Such a solution may be an alternative to hybrid installations because, according to the data, adding such batteries may be crucial for storing energy when high overproduction occurs. The next study (Puranen et al. 2021) focuses on the use of photovoltaic installations and hydrogen (such as Ostergaard et al. 2023, Abdolmalek & Berardi 2024, Naumann et al. 2024) in Finland. For this purpose, a single-family house with a 21 kWp photovoltaic installation and a heat pump was selected. After analyzing documents related to energy import and export, a period was identified in which the highest energy demand occurs with the low-efficiency operation of photovoltaic panels, indicating the need to control such power intelligently. The authors noted that for the studied case, the capacity of such an energy storage battery would be about 20 kWh. Studies conducted in 13 regions of Chile (Ramirez-Sagner et al. 2017) have shown the country's great economic potential for investing in photovoltaic systems. The results provided by (Miravet et al. 2022) also confirm this with the extension of the research sample to other South American countries. The advantages of such investments in terms of improving the lives of residents, reducing CO_2 emissions or increasing the consumption of firewood were mainly indicated. In New Zealand (Emmanuel et al. 2017), 40 photovoltaic panels were installed on a school roof, and surplus energy was sold to the external grid. It was calculated that energy costs decreased by 32%, reducing the school's energy expenditure from the grid, and the time for the return on investment was estimated at about 6.5 years.

It is also impossible not to discuss solutions for using heat pumps as a heating energy source. An example of such work is (Tihana et al. 2023), where the operation of an air heat pump was combined with a condensing gas boiler. The authors indicated differences between the manufacturer's and actual energy consumption data and the same in energy production, where these differences were about 15% and 25%. Another example of using an air heat pump with a photovoltaic installation was discussed in the work (Pater 2023) in Krakow (Poland). The author mainly focused on assessing the year-round operation of such an installation.

On the other hand, (Chwieduk & Chwieduk 2023) proposed a solution for housing estates in which a central heat pump would be installed, supported by electricity from photovoltaics, showing greater efficiency of such a solution than in the case of stand-alone installations in individual buildings. The use of photovoltaic panels and a heat pump was also presented in the work (Schreurs et al. 2021, Nordgard-Hansen et al. 2022), where the positive aspect of their use was indicated as profitable. On the other hand, (Dermentzis et al. 2021) compared two zero-energy buildings. The results showed that the production of electricity from photovoltaic panels was 6% higher than the value consumed by the heat pump, which is generally good news for people considering investing in hybrid solutions. Another aspect of heat pumps that is not often discussed in the literature is their proper design, which could increase efficiency. Especially vital is the use of effective phase-change heat exchangers (Pavlenko & Basok 2005, Pavlenko et al. 2014). Their improved design through, e.g., surface modifications (Chatys & Orman 2017, Kaniowski & Pastuszko 2021, Orman & Chatys 2011) could increase such devices' overall efficiencies.

It should be added, however, that the problem of a sick building is increasingly common, which harms people's well-being through the appearance of unwanted ailments, as in the works (Krawczyk et al. 2023, Sarkhosh et al. 2021). Proper ventilation and using renewable energy, i.e., using hybrid solutions in combination with intelligent energy and heat management, can improve internal environmental conditions in single-family or public buildings (Ratajczak et al. 2023).

This paper compares two modernized buildings constructed at the turn of the 60s and 70s. Both of them are equipped with photovoltaic systems, while one of them is also equipped with a heat pump. No similar comparative study of two such buildings located in the Swietokrzyskie Province has been found in the literature. Moreover, the paper compares electricity production from photovoltaic installations and the sale or purchase of energy to/from an external energy distribution network. The monthly operating time of the heat pump and the energy consumption for its needs are presented. Finally, the payback time of both investments is discussed.

2. Experimental Set-up and Testing Method

2.1. Characteristics of the buildings examined

Typically, houses in Polish villages use fossil fuels as their energy source. The combustion process in small-scale boilers is quite challenging (Papučík et al. 2016, Patsch & Pilát 2018) and generates unwanted environmental burdens. Thus, renewables could be an ideal solution. Naturally, proper thermal insulation of buildings is also important to keep thermal energy demand to a minimum. Thus, the thermophysical properties of building partitions should ensure their high thermal resistance (Basok et al. 2021). Equally important is adequate heat sources in individual rooms – mostly radiators (Kotrys-Działak & Stokowiec 2023).

The single-family houses included in the analysis are located in the Swiętokrzyskie Province (Poland), only about 4 km from each other. The first building was built in 1969 and insulated in 1998, while the second house was built in 1971, and its thermal modernization took place in 2016. Both buildings have a ground floor and a first floor and contain a living room, kitchen, bedrooms, bathrooms, etc. Figure 1 compares both buildings, and Table 1 compares the square footage.

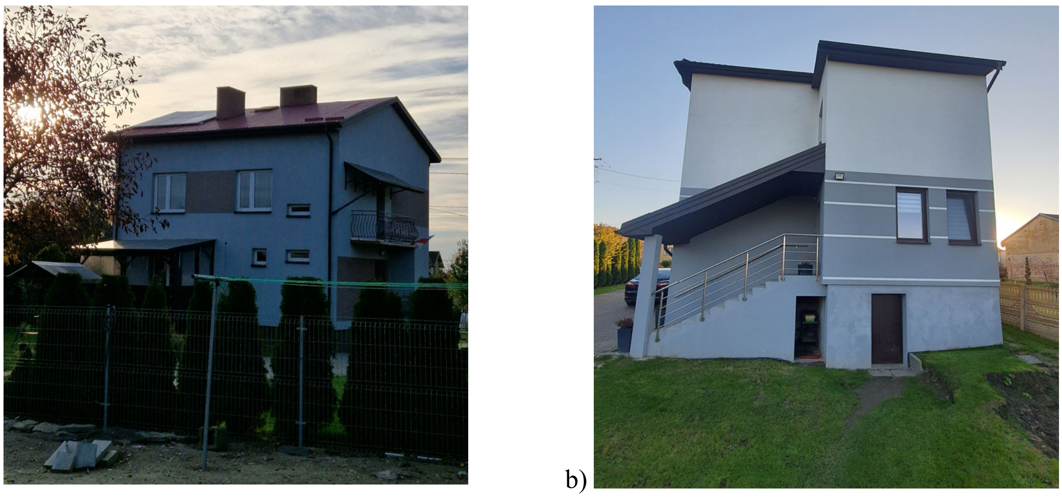

a) b)

Fig. 1. Comparison of examined buildings a) building no. 1 b) building no. 2

Table 1. Comparison of building areas

	Building no. 1	Building no. 2
Ground floor	54.68 m^2	54.80 m^2
I floor	55.46 m^2	54.80 m^2
Usable area	110.14 m^2	109.6 m^2
Volume of the building	632.15 m^3	814.0 m^3

It should be noted that the usable area is comparable (difference of 0.54 m^2). However, the visible difference is noticeable in the volume of the buildings. This is related to the fact that in building no. 2, in addition to the ground floor and first floor, there is also a basement with a boiler room and two technical rooms. In building no. 1, on the other hand, there is no basement, but the volume includes a garage.

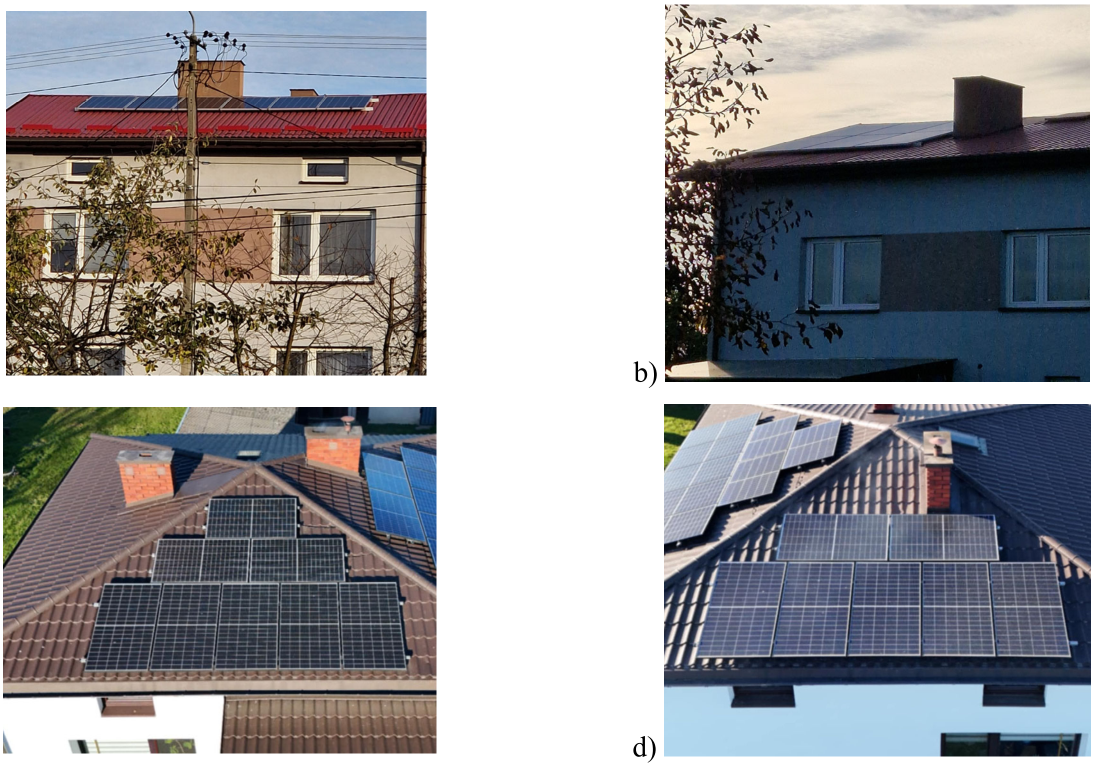
Both buildings have natural ventilation and are inhabited by families of four people. Table 2 provides data on the U-values of the partitions in each building.

Table 2. U-values of building partitions

Partition	Building no. 1	Building no. 2
External walls	0.26 W/(m^{2}K)	0.19 W/(m^{2}K)
Internal walls	1.81-2.22 W/(m^{2}K)	1.55-1.92 W/(m^{2}K)
Windows	1.7 W/(m^{2}K)	1.30 W/(m^{2}K)
External doors	2.3 W/(m^{2}K)	1.70 W/(m^{2}K)

2.2. Description of the renewable energy sources used in the studied cases

A photovoltaic installation was installed in the first building in 2018/2019. The total number of monocrystalline modules is 12 (six placed on the western part of the roof and another six on the eastern part). Energy production began in February 2019 in cooperation with a Solaredge inverter. In the second building, eight monocrystalline modules were installed on the northern side of the roof and seven on the eastern side of the roof (a total of 15 photovoltaic panels). The installation was completed in 2020. The photovoltaic installation began working in cooperation with a Huawei inverter. Figure 2 shows the location of photovoltaic panels in both buildings, while Table 3 presents the technical parameters of the photovoltaic modules.



a) b) c) d)

Fig. 2. Distribution of photovoltaic modules for the first building: a) western part of the roof, b) eastern part of the roof, and for the second building: c) northern part of the roof, d) eastern part of the roof

Table 3. Comparison of technical data of the photovoltaic installation used for both buildings

Technical data	Building no. 1	Building no. 2
Nominal max. power	280 W	340 W
Total maximum power	3.36 kW	5.1 kW
Cell type	monocrystalline –	monocrystalline –

It should be added that when electricity production exceeds its consumption, this energy is sold to the power grid (most often in the summer). However, when the building lacks electricity, it is drawn from the external network to supplement this energy deficit (autumn-winter period).

Additionally, it is worth mentioning that in the first building in 1969, in addition to installing a photovoltaic system, an air-source heat pump was purchased and installed, and it was used for central heating and domestic hot water systems. The maximum thermal power of this pump is 11.0 kW, and the rated thermal power is 0.9 kW. The buffer tank has a volume of 250 l. No floor heating is used – heat is provided to the individual rooms with traditional radiators.

3. Results and Discussion

3.1. Photovoltaic systems

As mentioned, both buildings under study are located at a short distance from each other. What is more, they are located in the same commune. Therefore, the solar radiation in this area is the same. This area is characterized by good solar radiation and, at the same time, strong gusty winds. Based on the collected measurement data, Table 4 presents the average, highest, and lowest solar radiation for the four seasons for the commune area.

Table 4. Comparison of solar radiation in the considered commune area, taking into account the season (https://ongeo.pl/geoportal/gmina-mirzec/fotowoltaika 2024)

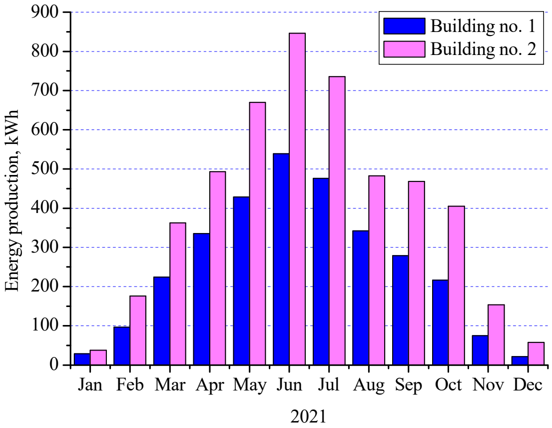
	Solar radiation			
Season	Average	Maximum	Minimum	Unit
Spring / Autumn	2283.48	2494.45	1157.18	$kWh/m^2/day$
Summer	5569.65	5817.02	4313.25	
Winter	159.42	287.37	58.80	

As expected, summer has very high solar radiation, which is twice as high as in spring/autumn. Nevertheless, future investors need to know that the highest energy is obtained in these three seasons. On the other hand, the winter period, despite difficult weather conditions (in Poland, the day is short, the night is long, the sky is often cloudy, and it rains/snows), allows for the production of electricity, but unfortunately, in insufficient quantities to meet the energy needs of the building at that time. The average solar radiation for winter is about 35 times lower than summer.

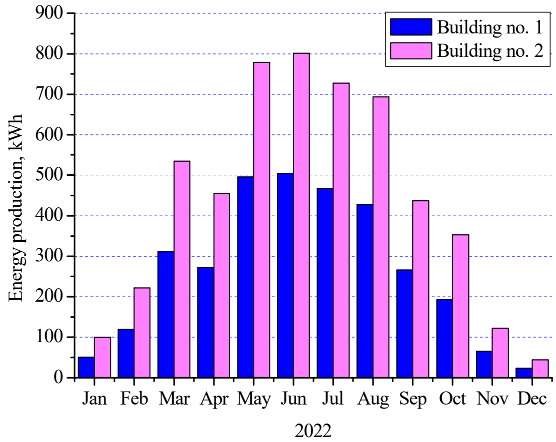
Figure 3 presents a three-year monthly comparison of the electricity produced by the photovoltaic installation in building no. 1 (i.e., photovoltaic panels with a maximum power of 280 W) and in building no. 2 (i.e., photovoltaic panels with a maximum power of 340 W).

The first thing that could be noticed is that electricity production, regardless of the year, is definitely higher in building no. 2 than in building no. 1. This is due to the difference in the maximum power of the installed modules. In 2021, energy production increased systematically in both cases from January to June and decreased from July to December. The highest month in terms of energy production is in June for both buildings – for the first, it was about 540 kWh, and for the second, 846 kWh. For 2022, it can be seen that insolation in March was better than in April, where a slight decrease was noted. However, comparing the summer period to 2021, from May to August, energy production from photovoltaic panels remained at a similar level between 700-800 kWh for building no. 2 and between 400-500 kWh for building no. 1, while for 2021, range between 700 and 800 kWh only concerned the months of June and July (building no. 2), while the range between 400 and 500 kWh concerned the period from May to July. In 2023, as in the case of 2022, the period of the highest production for house 2 fell from May to July (production between 700-800 kWh). However, energy production in September cannot be overlooked because only for this year and this month was 560 kWh produced, while for 2021 and 2022, the energy production in this month was below 500 kWh. The first house recorded an energy yield of between 400 and 500 kWh from May to July (similar to 2021). The annual energy summary for both buildings cannot be omitted either. In both cases, the highest annual energy yield was recorded for 2022. Interestingly, 2021 is better in terms of energy production for house 1 compared to 2023, while the opposite is true for building 2 because 2021 was the weakest year in terms of production and better in 2023. It should also be added that in the authors' research (Dębska et al. 2024), theproduction of electricity from a photovoltaic installation containing 21 monocrystalline modules with a maximum power of 300 W was examined (the difference in the number of modules for first building is 9 modules and for the second 6 modules). Considering the annual energy yield for the same years 2021-2023, energy production was between 7100-8200 kWh. It may be important to note that in addition to sunny days, the role of power and the number of modules has a real impact on the electricity yield for own use. The conclusion that emerges from the analysis is that energy production from weaker panels is about 40% lower per year compared to stronger modules. The next analysis will cover two months, June and November of 2023, along with their daily energy production. Figure 4 shows the monthly distribution of kWh energy production for the months a) June and b) November.

It is again noticeable that the energy production from higher power panels is larger than that of weaker modules. Moreover, it can be seen that the energy production in June ranges from about 7-35 kWh, while for November, this range ranges from below 1 kWh to about 14 kWh. Nevertheless, it is good news for investors that despite worse weather conditions, energy production takes place (this was also confirmed by studies (Dębska et al. 2024, Rej-Witt & Dębska 2022). Weather conditions mainly cause such fluctuations. On days when the sun shone intensely, in both cases, the energy yield was high, while when the sky was cloudy or it rained, there was a noticeable decrease in this production. Similarly, in the case of November, when there are few sunny days and the day is short (only about 7-8h), the operation of photovoltaic modules is observed between the 1st and 16th day. From the 17th day to the end of the month, these yields were very low at up to 3 kWh. The next summary presented in Figure 5 focuses mainly on energy fed into the grid and energy purchased from the grid during intensive production (energy sale) and energy shortages (energy purchase) for 2022 and 2023.



a)



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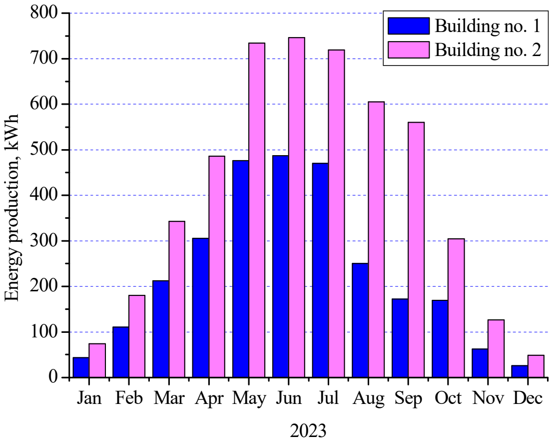

c)

	Total energy production, kWh	
Year	Building no. 1	Building no. 2
2021	3060.01	4888.4
2022	3194.71	5269.89
2023	2782.91	5028.26

d)

Fig. 3. Summary of annual energy production from photovoltaic panels for building no. 1 (blue colour) and building no. 2 (pink colour) in the year: a) 2021, b) 2022, c) 2023 and d) total energy production

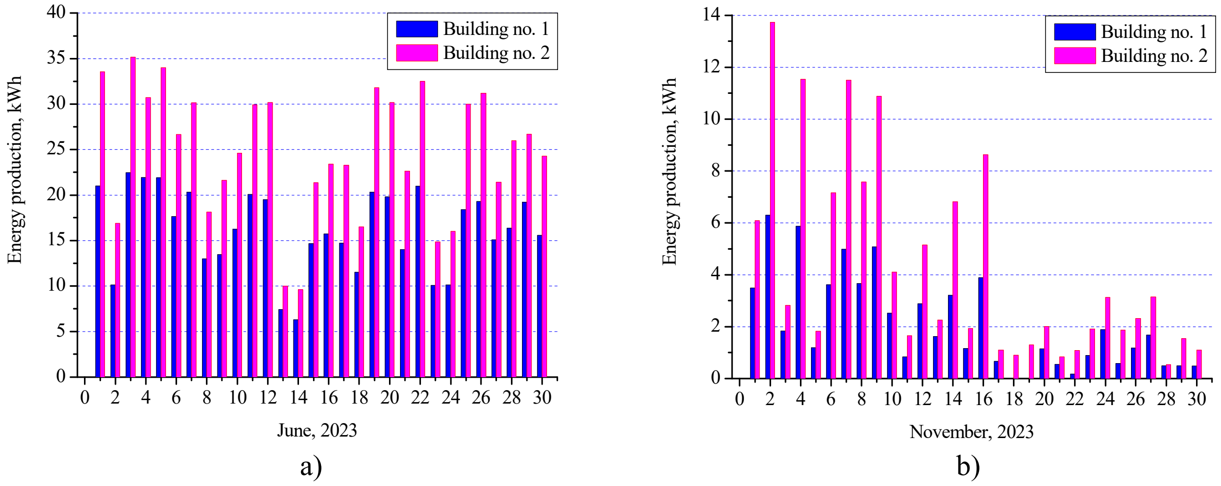

Fig. 4. Comparison of monthly energy production for the first (blue colour) and second (pink colour) building in 2023 for the months a) June and b) November

Figure 5 shows the trend of electricity consumption from the external power grid, mainly visible in the autumn-winter period when production from photovoltaic panels is low. For 2022 (building 1), it lasted from January to May and then from August to December, while overproduced energy was returned to the grid from May to August. A visible change occurs in 2023, where energy consumption takes place similarly to 2022 from January to May and then from mid-September to December, and the return of overproduced energy in 2023 occurred in the period from May to mid-September, which is almost a month more than in 2022. However, considering house no. 2 has stronger modules, the energy consumption and return distribution is different than that of the building with weaker modules. In 2022, the period of obtaining energy from the external network in building no. 2 fell in January and February and then from October to December. In the meantime, i.e., from mid-February to October, the surplus energy production was sent to the network. In 2023, energy consumption lasted from January to March and, like in 2022, from October to December. The surplus energy from March to October was sold to the external network. As shown in Figure 3, the annual summary of energy production for 2021-2023 is strongly related to Figure 5. It is also a confirmation because, according to the data from Figure 5, more favorable weather conditions can be seen in 2022 than in 2023 (confirmed by the data from the table).

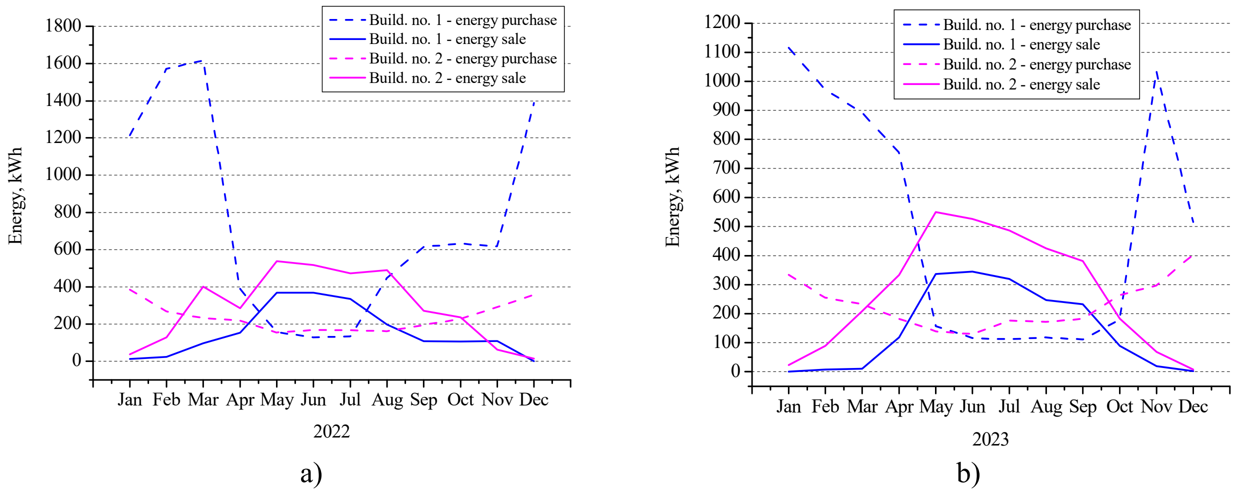

Fig. 5. Transfer of produced energy to the external power grid and collection of energy from the external grid for the year a) 2022 and b) for the year 2023

Undoubtedly, the benefits of using photovoltaic systems in single-family houses are clear and confirm the findings in the literature (Dębska et al. 2024, Emmanuel et al. 2017, Noro & Busato 2023). However, precise energy generation depends on many factors (solar insolation of a specific area, power rating of the pv systems, etc.).

3.2. Heat pump

Heat pumps can be a very effective heating energy source in mild climates (Berardi & Jones 2022). Figure 6 shows the electricity consumption for the operation of the heat pump for building 1 for the winter period – from November 2023 to January 2024.

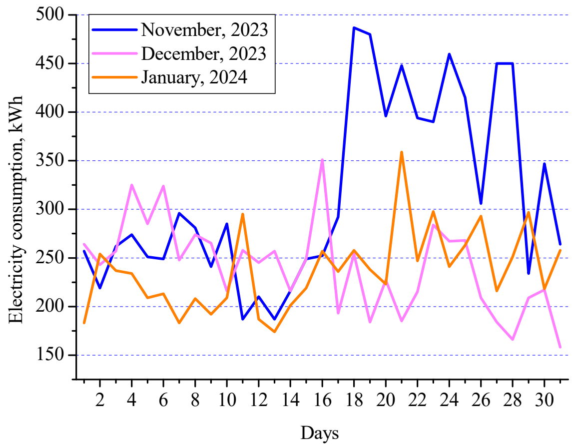

Fig. 6. Electricity consumption to power the heat pump from November 2023 to January 2024

The heat pump's electricity consumption ranges from 150 to 500 kWh. However, two months – December and January are in the range between about 150 and about 350 kWh, while November, between the 18th and 28th day of the month, indicates a very high electricity consumption because it exceeds the value of 350 kWh, reaching a maximum value of almost 500 kWh. Such uneven energy consumption indicates that the heat pump worked intensively, producing thermal energy to meet the needs of the residents. This was due to the prevailing external conditions, which were not favorable in November, and the pump's operating time on these days was higher than on the same days for December and January or for other days except for the 18th-28th day of the month. What is more interesting in the research (Dębska et al. 2024) the heat pump needed between about 500 and 1000 kWh for the same months (November-January). Such a discrepancy is influenced by the type of pump, external conditions, the amount of heat needed, etc. Figure 7 below shows the daily meter readings (cumulative) for three months, in reference to Figure 6, November and December 2023 and January 2024.

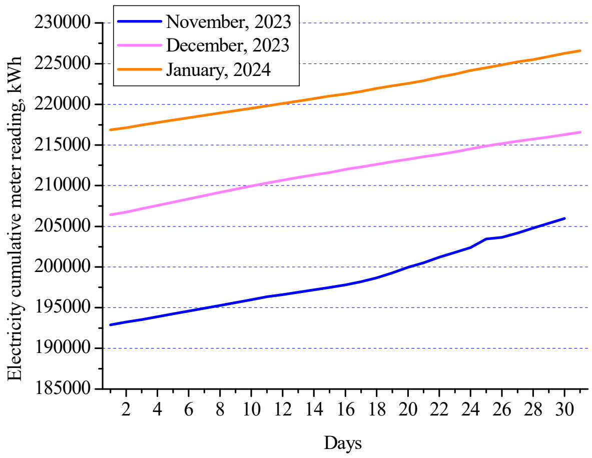

Fig. 7. Electricity cumulative meter reading for three months – for November, December 2023 and January 2024

As can be seen, the three lines indicate that the heat pump was working continuously and the energy consumption was at a constant level. However, in reference to Figure 6, it should be noted that the meter reading in November from day 18 to day 28 suddenly increased, which shows in Figure 6 that on these days, the heat pump needed more electricity to be able to work. In addition, the meter readings match the energy consumption by the heat pump.

3.3. Economic analysis of the investment for both buildings

Investors of the above-mentioned installations received the possibility of co-financing this investment in renewable energy sources. For the first house, where 280 W modules were used, the value of photovoltaic modules and devices cooperating with this installation amounted to 19478.13 PLN (4445.19 EUR). In this case, the analyses did not consider the costs related to installing the heat pump. The investment for the second building amounted to 23000 PLN (4989.15 EUR) for the installation and supporting devices. As also mentioned, investors took advantage of the possibility of co-financing. Therefore, 7867.13 PLN (1706.54 EUR – building no. 1) and 18000 PLN (3904.56 EUR – building no. 2) were finally paid. However, if such funding had not been received, the entire payback period for the first building would have been 16 years, and for the second building, approximately 8-9 years. Considering this, the payback period was shortened by 10 years for the first case, while for the second case, the payback period was shortened by about 2-3 years. It needs to be noted that both buildings used the G11 electricity tariff, while the price of 1 kWh was considered to be 0.68 PLN. The yearly savings were validated against the invoices received. Figure 8 presents the return on financial investment in the photovoltaic systems.

Despite the high investment costs for building 2, it should be noted that the return on investment will be between the 6th and 7th year of using the discussed installations – as in the case of building no. 1. After the 6th year, a financial benefit will be noticeable in the range of PLN 500 to 1000 (EUR 108-216) in savings related to the production and use of electricity.

In the case of the study (Rej-Witt & Dębska 2022), the return on investment ranged between 4 and 5 years, while in the studies (Dębska et al. 2024), the return on investment will occur between 9 and 10 years of using the installation. The return on a similar investment in New Zealand was after 6.5 years (Emmanuel et al. 2017), while better results can be obtained in Italy due to higher solar radiation (Noro & Busato 2023).

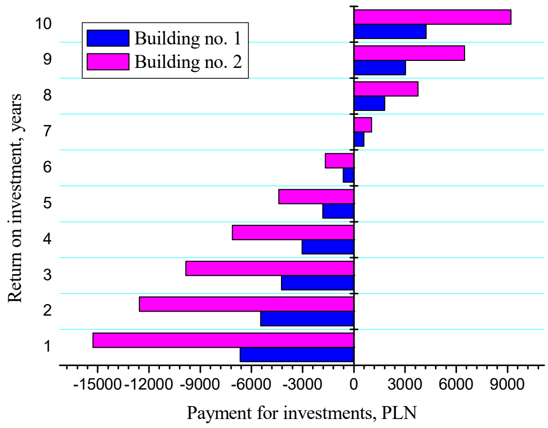

Fig. 8. Return on investment of the total investment for building 1 (blue color) and 2 (pink color)

However, it should be noted that everything depends on the number of house users, the amount of energy used for the building's needs, weather conditions, investment costs, and the type of renewable energy sources (single or hybrid system). All these factors are interdependent and determine the real return on investment. Despite this, it should be stated that installing installations working with renewable energy sources is profitable because the financial benefits are visible in this case after 6 years, and energy production takes place all year round. Additionally, financial benefits are obtained for the sale of electricity to the external network of the energy distributor.

The houses could be even more eco-friendly and self-reliant if energy storage systems were installed together with the extension of the photovoltaic systems (for example, through their integration in various elements of the building (Nešović et al. 2024) and/or its surroundings, e.g., the fence). Moreover, micro-cogeneration units could be used as part of the energy generation systems of the houses. Their application was proven useful in single-family homes (Patsch & Čaja 2015) as thermal and electrical energy sources utilizing natural gas in the fuel cell unit. Due to their location in the villages, other renewable energy sources could be used in the analysed houses, such as wind turbines.

The energy needed to prepare domestic hot water can be significant. These needs are met by a heat pump in building no 1. In Polish conditions, according to (Ratajczak et al. 2021), each person requires 27.4 +/- 1.4 dm^3/day of hot water, while (Szulgowska-Zgrzywa et al. 2021) provides a higher value of over 40 dm^3/day (as the mean value calculated for fifteen apartments). Naturally, this requires thermal energy to heat up the necessary mass flow of water. The problem is especially vital in cold regions, where gas boilers seem more economically attractive than heat pumps (Sarabia-Escriva et al. 2023).

The energy performance of both buildings differs. The values of EU, EK, and EP for the first building are currently estimated at the level of about 61.1 kWh/(m^2year), 29.5 kWh/(m^2year), and 26.8 kWh/(m^2year), respectively. These values for the second building are as follows: 55.6 kWh/(m^2year), 90.5 kWh/(m^2year), 91.4 kWh/(m^2year).

The most significant limitation of the study is the location of the considered houses. They are situated in one region (Świętokrzyskie province), of certain climate features and weather patterns. Thus, the results could be most accurate in the case of central Poland. Moreover, the analysis covered a certain period (three years), which seems quite large. However, analyzing the technical and economic performance of renewable energy systems could be more thorough if a larger data set for a longer duration could be considered. Additionally, a detailed comparison between the hot water systems in both buildings is difficult because only one is equipped with a heat pump. However, the hot water consumption in both buildings is similar because they are inhabited by four people each.

4. Summary and Conclusions

The analysis of the research results confirmed the validity of installing renewable energy sources for own use in single-family homes. Despite the different maximum power values, the production capabilities of both types of panels showed sufficient electricity production (considering Poland's climate – in particular, the autumn and winter periods). Depending on the year, the best period for the operation of the photovoltaic installation was May to August. However, from September to March, the energy yield, depending on the month, ranged from about 50 kWh to 600 kWh. This is positive information for future investors regarding such solutions, that even when there is not much insulation, the installation can produce electricity. The summer period turns out to be when surplus energy is sold to the power grid and purchased in the autumn and winter, depending on the demand of the building's users. The tested heat pump, apart from the days from 18 to 28 October, indicated stable operation and, at the same time, stable electricity consumption. Moreover, the economic analysis (focused on the photovoltaic systems only) showed that the first visible return on investment cost for both considered installations will appear between the 6th and 7th years of their use.

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