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Performance of the Heat Pump and Photovoltaic Systems Installed in the Single-family House

Luiza Dębska[1], Stanislav Honus[2], Lidia Dąbek[3], Aleksandra Nowak[4]*

[1]*Faculty of Environmental Engineering, Geodesy and Renewable Energy, Kielce University of Technology, Kielce, Poland*
https://orcid.org/0000-0001-7254-278X

[2]*Faculty of Mechanical Engineering, VSB – Technical University of Ostrava, Ostrava-Poruba, Czech Republic*

[3]*Faculty of Environmental Engineering, Geodesy and Renewable Energy, Kielce University of Technology, Kielce, Poland*
https://orcid.org/0000-0002-1198-5445

[4]*Faculty of Environmental Engineering, Geodesy and Renewable Energy, Kielce University of Technology, Kielce, Poland*

[*]*corresponding author's e-mail: ldebska@tu.kielce.pl*

Abstract: Renewable energy sources are increasingly common in Poland, and a growing number of single-family houses are now equipped with such systems. The article presents the study of the performance of the heat pump and the photovoltaic system installed in a house in the Swietokrzyskie Province near the city of Kielce. The data related to thermal and electrical energy generation throughout three years has been analysed with a focus on the advantages offered by such systems in the climate conditions of Central Poland. It turned out that 2022 was the best year for electricity production because it exceeded the value of 8000 kWh, and in the winter period from November to February, energy production balances at 200-300 kWh, which proves the high efficiency of panels for electricity production even in unfavourable climatic conditions. The heat pump generates the smallest energy production to heat the house in the summer, while in the winter, this production increases intensively due to the heating season in Poland. These are values from 1500 kWh to values above 3000 kWh. Similarly, in the case of domestic hot water, these values are higher in winter than in summer. Additionally, the work includes electricity consumption before and after the installation of renewable energy sources. Simplified economic analysis has also been presented in the paper. The simple payback period is estimated at approximately 9 years.

Keywords: heat pump, photovoltaic system, renewable energy sources

1. Introduction

Currently, the energy plans of many countries in the European Union and beyond are based on using renewable sources. It applies in particular to single-family or multi-family houses. Installing photovoltaic panels, heat pumps, windmills, etc., allows you to become independent from energy suppliers. Household members can use as much energy and heat as they need at a given moment. At the same time, excess production is usually sold to the grid, classifying it as a financial advantage of using such an energy solution. An additional advantage that eagerly attracts such investors is the financial value of a quick investment turnaround and ecological values, i.e. zero emissions of pollutants.

Even though renewable energy sources are no longer a new concept, they are still an interesting subject for many studies and analyses. An interesting study turns out to be a research paper (Miravet-Sanchez et al. 2022) in which the authors indicate the growing interest of the local population of Latin America and the Caribbean in the use of renewable energy. Authors specify that countries such as Argentina, Chile, Brazil, Peru and Nicaragua surprisingly stand out in developing and installing PV in these provinces. Additionally, researchers point out many positives related to the electrification of these houses by improving the health of the population and their psyche and reducing carbon dioxide emissions. In (Ramirez-Sagner et al. 2017), the authors also present Chile's potential for electricity production using a PV system for single-family houses and commercial purposes. This study took into account 314 districts in 13 regions. The analysis of the results showed that the best conditions in this country will be located in the central and northern parts. Australia and New Zealand are the next continents analysed regarding photovoltaic (PV) systems. In New Zealand (Emanuel et al. 2017) they focused on 40 photovoltaic panels in the selected Maungaraki school in Wellington, where the surplus energy produced during the holidays was sold to the grid. The annual efficiency was determined at 78%, which made it possible to reduce energy purchases by 32%, thus reducing the school's expenses by 45%, achieving savings equal to approximately 4700 New Zealand currency. The payback time is shown to be 6.4 years.

It should be noted that the authors presented a financial analysis that indicates the profitability of investing in photovoltaic panels, whether it is a single-family building or a public building. However, in Australia (Al-Qudah et al. 2021), the issue of rural areas, which are often unable to provide their homes with energy, was raised. Hence, the authors selected residents of Cape York, Queensland, Australia, for a techno-economic analysis of the use of PV systems. It was found that the best solution would be to use solar energy, which would reduce the costs of energy production and the production of energy from conventional fuels. A single-family house with 17 photovoltaic panels was analysed (Rej-Witt & Dębska 2022) in the village of Rzymsko BG. The power of the installed installation was 5.1 kW, with a specific power output of 300 Wp. A 5800W inverter was selected for this purpose. The authors came to interesting conclusions because, in this tested example, the annual energy production showed that in April, there was the highest production of 850.9 kWh despite only about 400 hours of installation operation. However, during the holiday period, despite 450-500 hours of installation operation, it was noticed that the energy production was between 600 and 800 kWh. The study provided interesting information that more energy is not always generated in summer than in other months. The first signs of return on investment were shown between the 4th and 5th years.

In addition to PV systems, using heat pumps for energy purposes in farm homes is eagerly explored. An example of a study is the work (Marijanovic et al. 2022), in which the authors ensure that using a heat pump in cooperation with energy storage facilities is a beneficial economic advantage. In (Berardi & Jones 2022), an analysis of the performance of air source heat pumps in Canada was conducted. The research object chosen is single-family houses in a cold climate. The authors assessed whether such heat pumps could be efficient in Canada's mild, colder and very cold places. It turned out that they were best accepted in Vancouver, where the temperatures are mild, as opposed to Toronto and Quebec City, where they would not be sufficient, which would decrease the efficiency of such pumps due to lower temperatures than in Vancouver. An in-depth analysis of the benefits of using various heat pumps in the United States for residential homes was conducted by (Lu & Ziviani 2022). They showed that climate zones are important to selecting the appropriate heat pump, such as a two-stage heat pump in cold climates, which allows cost savings of 10-20% than a single-stage heat pump for these specific conditions, a membrane evaporative cooler was selected for eight time zones. Similar analyses and efficiency of using and installing heat pumps for residential buildings can be found in works, e.g. (Vering et al. 2022, Yang et al. 2022, Shah et al. 2022).

Despite this, many energy experts recommend combining different renewable energy installations to complement each other in heat and energy production. An example of such a solution can be found in the work (Niekurzak et al. 2022). The cooperation of a ground heat pump (power: 25 kW) and a PV system (power: 18 kW) was analysed for a single-family house with a usable area of 162.5 m^2 in Polish conditions. Additionally, the authors noted that the tested building has underfloor heating, which improves the quality of the pump's operation by being a heat receiver. Following the standard (PN–EN 12831), it was assumed that 213.46 kWh of heat was needed every month. According to the analysis, the highest energy production from the heat pump occurred in the period November–April, i.e. during the winter in Poland, while the opposite can be observed in the case of PV systems, where the production of energy for own needs adding to the surplus of energy, started in April and lasted until October. It should be added that from November to March, this production from solar energy was insufficient. Therefore, it comes to mind how much such hybrid systems can complement each other and provide heat and energy during the year when one device at a given time cannot provide the required amount of energy. The solution of the applied hybrid system of the PV system and the heat pump in the winter period was tested in Poland (Chwieduk & Chwieduk 2021), in Austria (Schreurs et al. 2021), the technical conditions of the best heat pump and the economics of these solutions were analysed. Similarly, in the case of work (Dermentzis et al. 2021), such solutions were studied in two multi-family buildings. However, regarding single-family houses (Patsch & Pilát 2018) tested the operation of a micro-cogeneration unit with high-temperature fuel cells. Due to variable energy consumption, the authors found it difficult to design such an installation correctly for a family house. The use of solar collectors for domestic hot water systems has been analysed (Dudkiewicz & Fidorów-Kaprawy 2020). The authors pointed out that solar collectors can cover a large share of the energy needs, even in Polish geographical locations. On the other hand, using biomass from sunflower husk pellets as a renewable energy source proved to be most favourable for a modernised office building in Ukraine (Deshko et al. 2023). Thermal modernisation of buildings can effectively increase the energy efficiency of buildings and, thus, reduce renewable and non-renewable energy consumption, as pointed out in (Orłowska 2023).

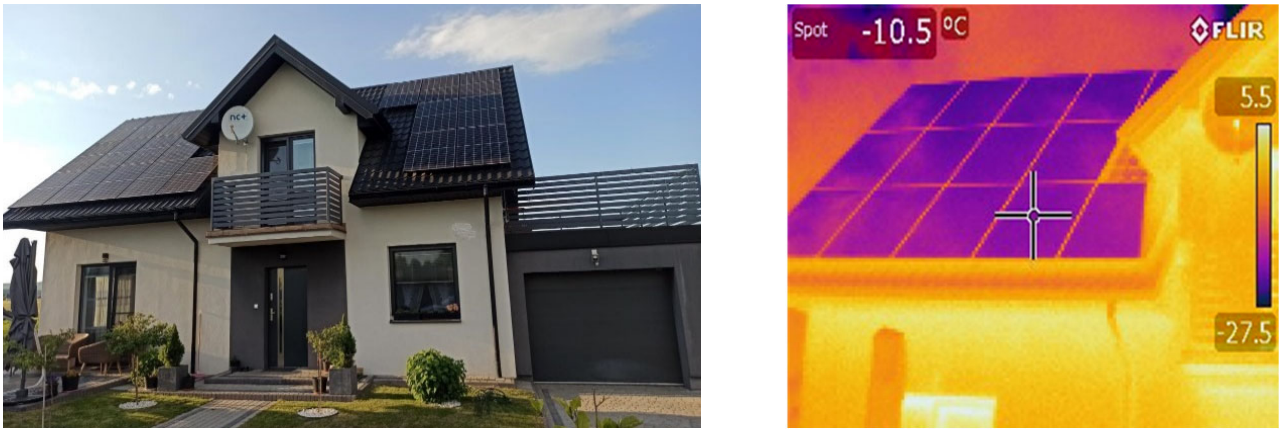
It needs to be noted that the efficient use of renewable energy sources in buildings requires proper heating design (Stokowiec et al. 2023) as well as domestic hot water (Amanowicz 2021) systems and installations. Renewable energy sources for heating buildings are considered to work very well with low-temperature systems, as indicated in (Amanowicz 2020), where the results of testing wall panels made with heat pipes were presented. It was concluded that water temperature had more influence on the thermal performance of the radiator than its mass flow rate. On the other hand, in (Kotrys-Działak & Stokowiec 2023), the comparison of two measuring methods of radiator temperature was presented. A correct design of all thermal energy sources in rooms is also important. Here, the requirement for maximal efficiency needs to be met with various design possibilities (Orman 2014, Orman & Chatys 2011, Pavlenko et al. 2014, Pavlenko & Szkarowski 2018).

Nowadays, much scientific effort is focused on the energy performance of buildings (Dudkiewicz & Szałański 2019, Ratajczak et al. 2023) and the problem of the sick building syndrome (Krawczyk et al. 2023). Using renewable energy sources in buildings can significantly help cover energy needs, which can also impact the air quality through proper ventilation. Heat accumulation can also be used (Nogaj et al. 2017, Radek et al. 2020, Turski & Jachura 2022) – possibly in combination with renewable energy sources – to enhance the energy performance potential further.

The main aim of the work will be to analyse the production of electricity and heat using a heat pump and photovoltaic panels, as well as to present the economic costs of the system's interoperability for the climate conditions of Central Poland and weather patterns in the Swietokrzyskie Province. Such experimental reports containing real-life long-term data are very rare in the literature.

2. Object of the Investigation

The building under investigation is located in the Świętokrzyskie Province (Central Poland). It was built in 2018 and has a total floor area of 190 m^2. It is a single-family, single-story building without a basement, with a residential attic and a garage. The usable area of the residents is 118 m^2, and for the garage and boiler room, it is 28 m^2. The tested object was built in a rectangle with a gable roof with a slope 40°. The shape factor of the building is about 0.58 m^{-1}, while the area of the external walls is 217.5 m^2. The U-value ranges from ca. 0.1 W/(m^{2}K) for windows, through about 0.2 W/(m^{2}K) for the external walls as well as the floor and up to over 0.4 W/(m^{2}K) for the ceiling. The highest U-value for the internal wall is ca. 2.2 W/m^{2}K. Three adults occupy the building. It is equipped with natural ventilation. The n50 value of the building was not measured experimentally. Considering the present-day building condition and equipment with renewable energy sources, the EU, EK and EP values are currently estimated at the level of about 33.2 kWh/(m^{2}year), 14.6 kWh/(m^{2}year) and 38.3 kWh/(m^{2}year), respectively. The considered single-family building is presented in Figure 1a, while its infrared image is in Figure 1b, as presented by the co-author (Nowak 2024). Infrared images generated with a thermal camera with a resolution of 160x120 pixels and thermal sensitivity below 0.1 K (Flir Systems 2012) showed no thermal insulation defects in the building. Similarly, no defects in the photovoltaic modules were detected during the investigation.



a) b)

Fig. 1. The front facade of the single-family house: a) digital photo, b) infrared image

Two renewable energy systems have been installed in the house: photovoltaic panels on the rooftop and an air source heat pump. The building has 21 monocrystalline photovoltaic panels with a total power output of 7.88 kWp. The entire installation works with an inverter of a maximal power of 9.45 kW. The pump has a power of 7 kW and is a split system, i.e. one unit is located on the internal side and the other on the external side. It is the air-to-water heat pump, with the outside air being the lower heat source for the building. The heat pump provides heat to the central heating system consisting of traditional radiators and to the domestic hot water system via a storage tank of 250 dm^3.

The performance measurement of both systems took place between January 2021 and October 2023. The recorded parameters comprised monthly electricity production and measurements of electricity yields performed every 30 minutes from 5:00 a.m. to 7:30 p.m. around the 15th day of each month. In this period, the energy needed to operate the heat pump and the energy produced to heat the house and warm up domestic hot water was analysed. Additionally, the economic aspect of the operation of the renewable energy systems was considered by determining the simple payback time. Such studies – focused on the energy production and consumption in the Swiętokrzyskie region – are quite rare in literature. The present paper aims to provide valuable data on this issue.

3. Results and Discussion

3.1. Production of electricity from photovoltaic panels

Photovoltaic panels and other renewable energy sources have become increasingly common in Poland. The data collected by the co-author (Nowak 2024) and presented in Section 3 of this paper provides evidence supporting future even more widespread use of renewables in Poland.

Regarding photovoltaic systems, the most important issue from the practical point of view is the amount of energy these panels can generate. Data collected within three years enables us to conclude the potential of this system in the considered single-family house. The results for 2021, 2022 and 2023 are presented in Figure 2.

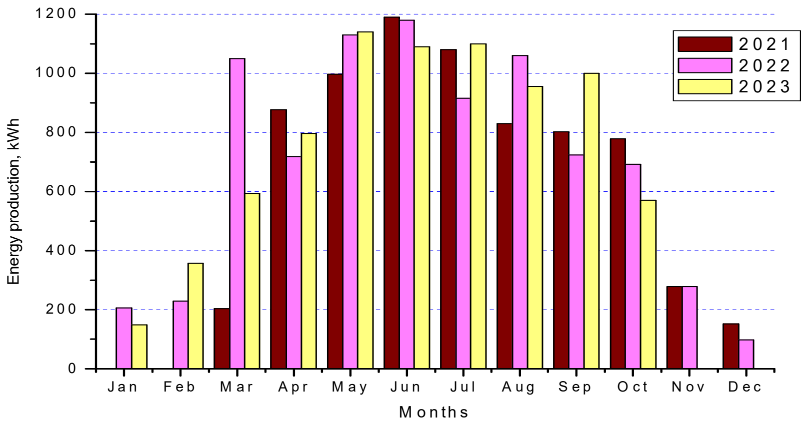


Fig. 2. Electricity production from the PV installation in 2021 (dark red), 2022 (pink), 2023 (yellow)

As already mentioned, the analysis period covered 3 years. In 2021 (starting from March), the amount of energy produced was 7186 kWh. In 2022, it was 8282.2 kWh; in 2023, this value was 7752 kWh (up to October). 2022 was the best year for producing energy from the sun – in March, the production amounted to 1050 kWh, as opposed to 2023, it was below 600 kWh. January and February of 2022, 2023, March but only for 2021, and November and December for 2021 and 2022 showed energy production below 400 kWh. In particular, this is positive information for future investors that the winter period may enable smaller or larger electricity production despite harsh climatic conditions. It may be one of the advantages of encouraging people to install PV installations.

The highest electricity production occurs in the summer due to significant solar radiation. However, the question arises of how energy generation changes throughout the day. Figure 3 presents data on electricity production around the 15th day of each month (for a cloudless day) with a time step of 30 minutes.

Measurements of energy production from photovoltaic panels were performed from 5:00 a.m. to 7:30 p.m. According to the collected data, the start of production in January was 0.046 kWh at 8:00 a.m., and the end was at 4:00 p.m. with a value of 0.003 kWh. Compared to February, production started an hour earlier than in January, at 7:00 a.m. with an acquired value of 0.029 kWh, and ended half an hour later compared to January. Such changes can be noticed until May because from this month until July, energy production took place from 5:00 a.m. to 7:30 p.m. The highest energy yields occurred from 10 a.m. to 4:30 p.m. with values of 3.74 to 7.15 kWh, which is related to the intensity of solar radiation. From August, there were already noticeable changes related to the later start of operation of photovoltaic modules at 6:00 a.m. with the value of 0.133 kWh. Still, in August, it was also recorded at 1:00 p.m. – when the sun towered over the house with a production value of 5.71 kWh – compared with September only half an hour earlier, i.e. for 12:30 – the production value was 6.77 kWh. For the autumn and winter period, when the days are shorter and the nights are longer, in October, energy yields ranged from 3.87 to 5.78 kWh (from 11:00 a.m. to 3:30 p.m.), which is a very good result for such conditions. November also showed similar energy production, but this time, it was shortened from 11:30 to 13:30, and during this time, 3.69-5.26 kWh yields were obtained. Compared to other winter months, December was the worst, first of all, because the modules started operating at 9:00 a.m. and amounted to 0.064 kWh, and ended at 2:30 p.m. with a value of 0.399 kWh.

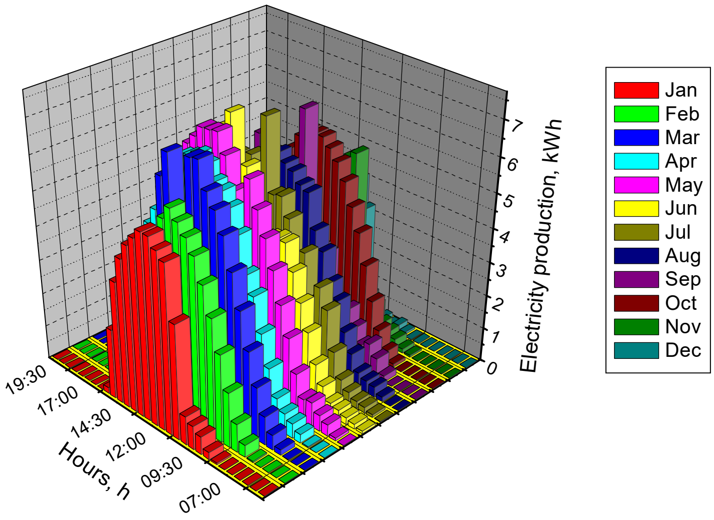


Fig. 3. Electricity yield around the 15th day of every month for the cloudless weather conditions

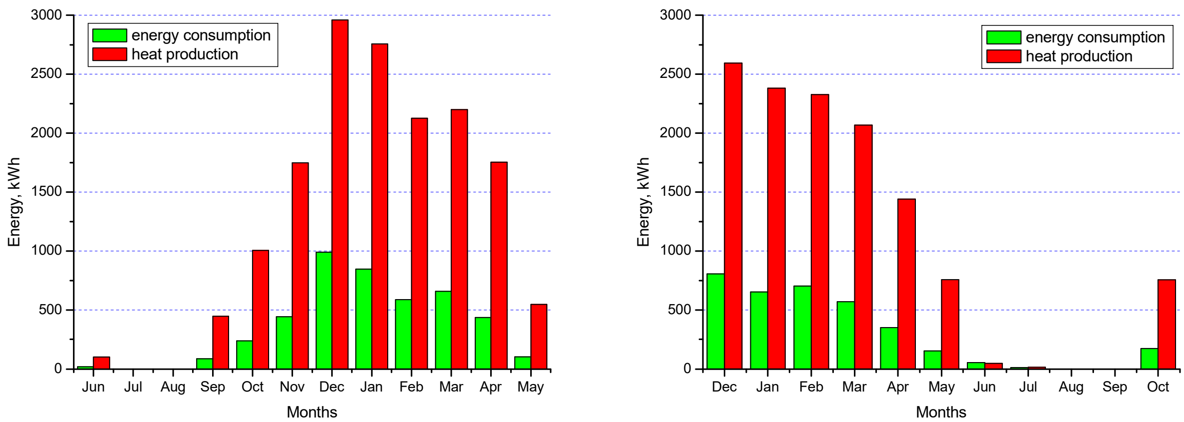
The main conclusion that comes to mind is that despite the winter period, the modules start working as soon as the sun appears in the sky. Still, it should be remembered that this period might also be characterised by possible intense cloud cover, and the energy gains may be smaller or larger, but they are still visible. It is quite a strong argument to invest in this type of energy production.

3.2. Heat pump performance

The heat pump provides thermal energy to cover the heat losses of the building and warm domestic hot water up. It has proved to be the only heat source for the house (an auxiliary electric heater was never used in the considered period). The analyses were made separately for the central heating and domestic hot water systems.

Measurement results of electricity consumed by the heat pump and the production of thermal energy for the needs of the central heating system are presented in Figure 4 for two periods: from June 2021 to May 2022 and from December 2022 to October 2023.

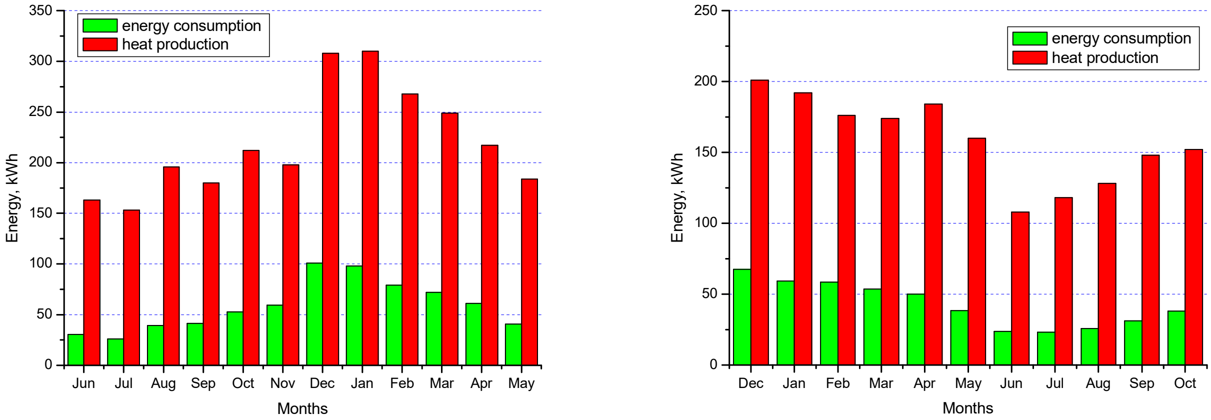
The same tendency of increased energy consumption and its production using a heat pump can be seen in both periods. For the winter period of 2021/2022, this production was above 3000 kWh per month in December and January. This is understandable because it is winter, and temperatures may be well below zero. Heat losses are significant, and the heat pump must recover more energy from the cold air to cover this need. The same is true for the 2022/2023 period. There is no heating needed in the summer, and energy production and consumption are equal to zero.



a) b)

Fig. 4. Consumption of electricity ("energy consumption") and production of heat for central heating ("heat production") in the period: a) June 2021-May 2022; b) December 2022-October 2023

Figure 5 presents the results of energy consumption by the heat pump in the form of electricity and the production of thermal energy to heat domestic hot water in the periods June 2021-May 2022 and December 2022-October 2023.



a) b)

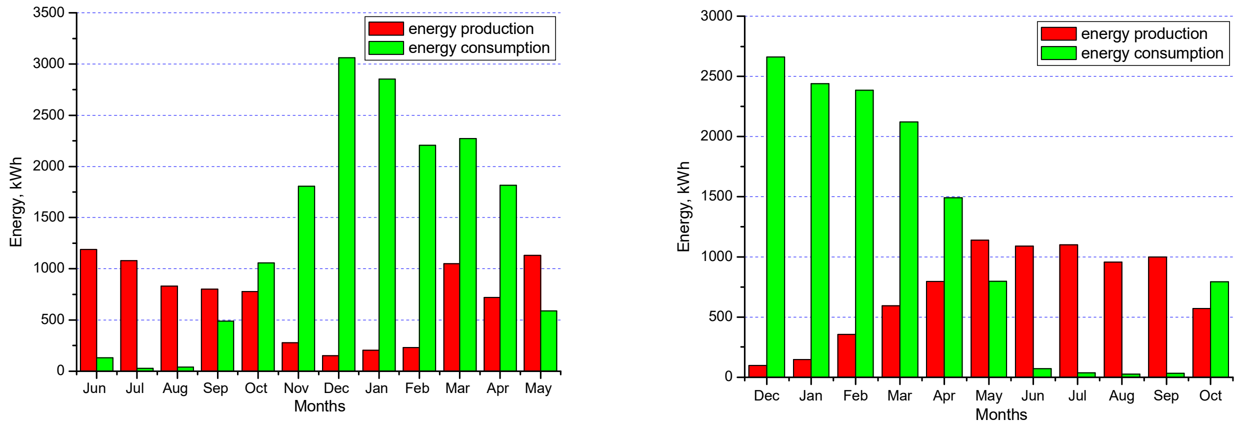
Fig. 5. Consumption of electricity ("energy consumption") and production of heat for domestic hot water system ("heat production") in the period: a) June 2021-May 2022; b) December 2022-October 2023

As you can see, from June to November 2022, the electricity needed for the pump to heat water increases from about 30 kWh (except for July, where this value is below 30 kWh). Thermal energy production from the pump ranges from approximately 150 kWh to 212 kWh in this period. From December to January, energy production and consumption remain steady and equal, ca. 300 kWh and 100 kWh, respectively. Then, a systematic decline is noticeable from February to May. The same is true for the period from December 2022 to October 2023. It can be seen that from December to May, the energy needed for the pump was ca. 40-70 kWh, while the generated heat was from 174 kWh to 201 kWh. In June, the minimum was observed. It might be quite surprising to see the energy demand at its lowest levels during the summer months. However, it can be explained by the fact that the time spent at home in the autumn and winter is longer than in the summer when holiday trips can happen. Moreover, heat losses occurring in the domestic hot water system might be larger due to lower temperatures within the house than in the summer months. Another possible explanation might be a subjective preference of the residents to wash their hands or bathe using water with higher temperatures during winter and lower temperatures during summer. Whatever the reason, this phenomenon was observed for two analysed years. However, the thermal energy generation for the hot water system operation differed for the same months of 2021-2023.

3.3. Economic analysis of the renewable energy systems

It would seem that investing in renewable energy sources would result in huge investment costs for the investor. However, analysing the actual costs incurred before and after installing renewable devices in the considered single-family houses in the Swietokrzyskie Province might provide additional support for this type of heat source and its more widespread use.

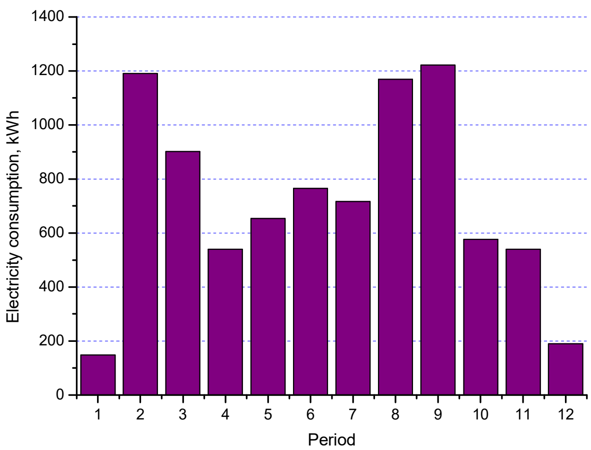
Figure 6 compares energy production by the photovoltaic system vs. energy consumption by the heat pump. As anticipated, the difference between these values is highest during winter, when photovoltaic panels cannot produce enough electricity to cover the energy needs of the building's central heating and domestic hot water systems. Thus, in winter, electricity needs to be provided mostly by the national grid (except in the spring months).



a) b)

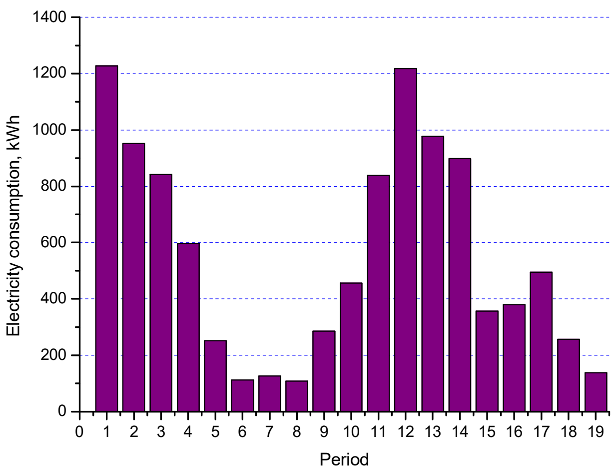
Fig. 6. Energy production in the PV system vs. energy consumption by the heat pump (for heating and domestic hot water preparation) in the period: a) June 2021-May 2022; b) December 2022-October 2023

Figure 7 shows electricity consumption from June 2019 to March 2021 – a period before the investment related to photovoltaic panels and the heat pump. On the other hand, Figure 8 presents energy consumption after installing RES devices in the form of photovoltaic panels and heat pump. Apart from them, the modernisation also covered other components such as radiators, but these changes are considered to have a marginal impact on energy consumption.



Legend	Period
1	Jun-Jul 2019
2	Jul-Sep 2019
3	Sep-Nov 2019
4	Nov-Jan 2019/2020
5	Jan-Mar 2020
6	Mar-May 2020
7	May-Jul 2020
8	Jul-Sep 2020
9	Sep-Nov 2020
10	Nov-Jan 2020/2021
11	Jan-Mar 2021
12	Mar-Mar 2021

Fig. 7. Electricity consumption in the period 06.2019 - 03.2021 before installing the hybrid system



Legend			
	Period		Period
1	31 Jan 2022	12	31 Dec 2022
2	28 Feb 2022	13	31 Jan 2023
3	31 Mar 2022	14	28 Feb 2023
4	30 Apr 2022	15	12 Mar 2023
5	31 May 2022	16	31 Mar 2023
6	30 Jun 2022	17	30 Apr 2023
7	31 Jul 2022	18	31 May 2023
8	31 Aug 2022	19	30 Jun 2023
9	30 Sep 2022		
10	31 Oct 2022		
11	30 Nov 2022		

Fig. 8. Electricity consumption in the period 01.2022-06.2023 after installing the hybrid system

In Figure 7, i.e. in the period before the installation of RES, apart from the months Jun-Jul 2019 and Mar-Mar 2021, where the total consumption was below 200 kWh, the periods from number 2 – Jul-Sep 2019 to number 11 – Jan-Mar 2021, the level total energy consumption was above 500 kWh. Moreover, they were high in summer periods. Comparing this to Figure 8, when the devices have been installed, in summer periods from number 5 to 9 (May-September), the total consumption was below 300 kWh and numbers 15-19 (March-June), when the consumption was below 500 kWh. Please note that the months from June to August 2022 and June 2023 have a total consumption below 200 kWh. A significant jump is visible in the winter period, such as items 1-4 (January-April) and 10-14 (October-February). Here, energy consumption is high due to the heat pump's operation and low solar radiation. Comparing energy consumption before and after installing renewable energy sources confirms the validity of investing in this type of energy solution because one can see the difference in the amount of energy consumed before and after the renewable energy sources.

For the studied single-family house, the annual electricity cost before installing renewable systems was ca. 3408 PLN for 2020, i.e. the monthly cost was 284 PLN. Assuming that the average Euro exchange rate for 2020 was 4.46 PLN per 1 Euro, the annual cost was approximately 764 EUR, and the monthly bill was approximately 64 EUR. After installing photovoltaic panels and an air heat pump, the energy cost dropped twice to ca. 1308 PLN per year and 109 PLN per month. For 2022, the average EURO exchange rate was 4.69 PLN per 1 euro and, translated into annual costs, the energy bill amounted to 279 EUR; for the monthly bill, it was 23.25 EUR. An annual saving of 2099 PLN (or 447.65 EUR) was calculated on this basis. In the entire analysis of the investment cost ratio, it should be added that before installing renewable systems, the investor bought eco-pea coal, which was used for the boiler before the heat pump appeared. The cost was 3000 PLN (approximately 640 EUR).

The total cost of installing photovoltaic panels and the heat pump, including assembly, was 66400 PLN (14561 EUR). However, in 2021, it was possible to partially finance such investment with the help of the "Clean Air" programme. As a result of this cost reduction, the total investment cost amounted to 46400 PLN (10175 EURO). The calculation of the simple payback time is presented in Figure 9.

From Figure 9, it can be seen that the investment will pay off 9 years after the installation is launched. This cost for the 9th year will be negative and amount to -504 PLN (110.53 EUR). However, in the 10th year, the household will be able to count on the cost of investment savings amounting to 4595 PLN (about 1008 EUR), while for the 15th year, it will amount to 30093 PLN (about 6599 EUR). The study (Rej-Witt & Dębska 2022) also analysed the cost of investment returns for a single-family house, but only for photovoltaic panels. This cost started to be recovered already in the 4th year, but this cost was still negative. However, for the 5th year, this cost amounted to 1266 PLN (approximately 280 EUR). As can be seen, there is a difference in years, but it should be added that in the current study, there is more than one such device and more panels in the house. Nevertheless, such an analysis should encourage many households to invest in hybrid systems first to become independent from energy supply companies and receive financial benefits through savings.

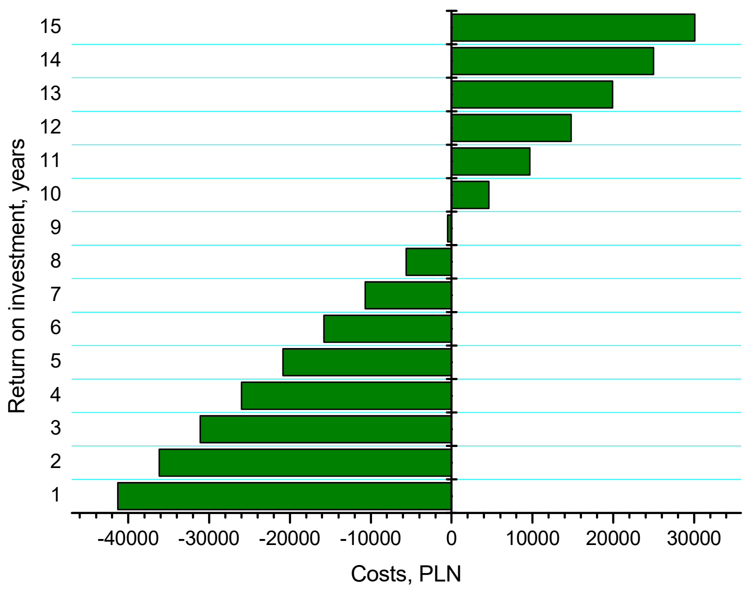


Fig. 9. Reimbursement of investment costs in the photovoltaic panels and heat pump

Additionally, the former heat source required maintenance to supply fuel and needed cleaning, etc., while the renewable energy sources installed in the house are much more user-friendly. They do not require frequent hand-made fuel supply and ash removal. Instead, they are almost maintenance-free, and their operation is automatically controlled. The user can only provide adequate parameter settings, which do not require much involvement from the house residents. Moreover, there is also an ecological aspect – the EP value is estimated to have been reduced by about 40% due to applying photovoltaic and heat pump systems.

4. Summary and Conclusions

Renewable energy sources, in this case, a photovoltaic system and a heat pump, have resulted in a significant decrease in energy consumption compared to the period before the installation of renewable energy sources. The simple payback period for such an investment was approximately 9 years, and the first financial benefits will be noticeable this year. Besides its economic and ecological advantages, the new system's operation is more favourable to the user than the traditional boiler that incinerates solid fuel.

The analysis of electricity generation from the photovoltaic panels revealed that they can provide yields of over 800 kWh from April till September, with the peak in June (reaching 1200 kWh). The time of day plays a significant role in electricity generation, especially during the winter when the days are short. The greatest demand for heating domestic water occurred in the winter period, as in the case of the heating needs – thermal energy production by the heat pump was highest in December and January.

Undoubtedly, investing in renewable energy sources leads to financial benefits that will help improve household budgets and become less dependent on energy suppliers. It might be anticipated that in the future, with more efficient technologies and cheaper production techniques, such systems will be even more common in Poland and abroad.

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References

Al-Qudah, Hamzah, E., Fadlallah, Sulaiman, O. (2021). *Techno-economic analysis of PV-based power systems for Cape York, Australia*. The University of Auckland. Conference contribution. https://doi.org/10.17608/k6.auckland.13578182.v2

Amanowicz, Ł. (2020). Controlling the thermal power of a wall heating panel with heat pipes by changing the mass flowrate and temperature of supplying water—experimental investigations. *Energies*, *13*, 6547. https://doi.org/10.3390/en13246547

Amanowicz, Ł. (2021). Peak power of heat source for domestic hot water preparation (DHW) for residential estate in Poland as a representative case study for the climate of Central Europe. *Energies*, *14*, 8047. https://doi.org/10.3390/en14238047

Berardi, U., Jones, S. (2022). The efficiency and GHG emissions of air source heat pumps under future climate scenarios across Canada. *Energy and Buildings*, *262*, 112000. https://doi.org/10.1016/j.enbuild.2022.112000

Chwieduk, B., Chwieduk, D. (2021). Analysis of operation and energy performance of a heat pump driven by a PV system for space heating of a single family house in polish conditions. *Renewable Energy*, *165*, 117-126. https://doi.org/10.1016/j.renene.2020.11.026

Deshko, V., Bilous, I., Buyak, N., Naumchuk, O. (2023). Prospects for the Use of Renewable Energy Sources while Increasing the Energy Efficiency Level of Office Buildings to the Level of nZEB. *Rocznik Ochrona Środowiska*, *25*, 148-158. https://doi.org/10.54740/ros.2023.015

Dermentzis, G., Ochs, F., Franzoi, N. (2021). Four years monitoring of heat pump, solar thermal and PV system in two net-zero energy multi-family buildings. *Journal of Building Engineering*, *43*, 103199. https://doi.org/10.1016/j.jobe.2021.103199

Dudkiewicz, E., Fidorów-Kaprawy, N. (2020). Hybrid domestic hot water system performance in industrial hall. *Resources*, *9*, 65. https://doi.org/10.3390/resources9060065

Dudkiewicz, E., Szałański, P. (2019). A review of heat recovery possibility in flue gases discharge system of gas radiant heaters. *Proc. of Int. Conf. on Advances in Energy Systems and Environmental Engineering (ASEE19). E3S Web of Conferences*, 116, 00017. https://doi.org/10.1051/e3sconf/201911600017

Emanuel, M., Akinyele, D., Rayudu, R. (2017). Techno-economic analysis of a 10 kWp utility interactive photovoltaic system at Maungaraki school, Wellington, New Zealand. *Energy*, *120*, 573-583. https://doi.org/10.1016/j.energy.2016.11.107

Flir Systems (2012), Technical Data Flir E30bx

Kotrys-Działak, D., Stokowiec, K. (2023). Temperature Distribution Analysis on the Surface of the Radiator: Infrared Camera and Thermocouples Results Comparison. *Rocznik Ochrona Środowiska*, *25*, 37-44. https://doi.org/10.54740/ros.2023.005

Krawczyk, N., Dębska, L., Piotrowski, J. Zb., Honus, S., Majewski, G. (2023). Validation of the Fanger Model and Assessment of SBS Symptoms in the Lecture Room. *Rocznik Ochrona Środowiska*, *25*, 68-76. https://doi.org/10.54740/ros.2023.008

Lu, Z., Ziviani, D. (2022). Operating cost comparison of state-of-the-art heat pumps in residential buildings across the United States. *Energy and Buildings*, *277*, 112553. https://doi.org/10.1016/j.enbuild.2022.112553

Marijanovic, Z., Theile, P., Czock, BH. (2022). Value of short-term heating system flexibility – A case study for residential heat pumps on the German intraday market. *Energy*, *249*, 123664. https://doi.org/10.1016/j.energy.2022.123664

Miravet-Sanchez, BL., Garcia-Rivero, AE., Yuli-Posadas, RA., Inostroza-Ruiz, LA., Fernandez-Guzman, V., Chavez-Juanito, YA., Rutti-Marin, JM., Apesteguia-Infantes, JA. (2022). Solar photovoltaic technology in isolated rural communities in Latin America and the Caribbean. *Energy Reports*, *8*, 1238-1248. https://doi.org/10.1016/j.egyr.2021.12.052

Niekurzak, M., Lewicki, W., Drożdż, W., Miązek, P. (2022). Measures for Assessing the Effectiveness of Investments for Electricity and Heat Generation from the Hybrid Cooperation of a Photovoltaic Installation with a Heat Pump on the Example of a Household. *Energies*, *15*(16), 6089. https://doi.org/10.3390/en15166089

Nogaj, K., Turski, M., Sekret, R. (2017). The influence of using heat storage with PCM on inlet and outlet temperatures in substation in DHS. *Proc of Int. Conf. on Advances in Energy Systems and Environmental Engineering* (ASEE17), Wrocław, Poland, July 2-5, 2017, *E3S Web of Conferences*, *22*, 00124. https://doi.org/10.1051/e3sconf/20172200124

Nowak, A. (2024). Analiza zastosowania systemów OZE w budynku mieszkalnym jednorodzinnym (diploma dissertation). Kielce University of Technology. (in Polish)

Orłowska, M. (2023). Thermomodernization – Rescue for the Building. *Rocznik Ochrona Środowiska*, *25*, 208-214. https://doi.org/10.54740/ros.2023.020

Orman, Ł.J. (2014). Boiling heat transfer on single phosphor bronze and copper mesh microstructures. *Proc of Int. Conf. "EFM13 – Experimental Fluid Mechanics 2013" (Czech Republic), EPJ Web of Conferences*, *67,* 02087. https://doi.org/10.1051/epjconf/20146702087

Orman, Ł.J., Chatys, R. (2011). *Heat transfer augmentation possibility for vehicle heat exchangers*. Proc. of 15th Int. Conf. "TRANSPORT MEANS" (Kaunas, Lithuania). 9-12.

Patsch, M., Pilát, P. (2018). Simulation of Combustion Air Flow in the Gasification Biomass Boiler. *Proc of XXI. Int. Conf. "The Application of Experimental and Numerical Methods in Fluid Mechanics and Energy 2018", MATEC Web of Conferences,* 168, 02015, https://doi.org/10.1051/matecconf/201816802015

Pavlenko, A., Szkarowski, A. (2018). Thermal insulation materials with high-porous structure based on the soluble glass and technogenic mineral fillers. *Rocznik Ochrona Środowiska*, *20*, 725-740.

Pavlenko, A., Szkarowski, A., Janta-Lipińska, S. (2014). Research on Burning of Water Black Oil Emulsions. *Rocznik Ochrona Środowiska*, *16*(1), 376-385.

Radek, N., Pietraszek, J., Gądek-Moszczak, A., Orman, Ł.J., Szczotok, A. (2020). The Morphology and Mechanical Properties of ESD Coatings before and after Laser Beam Machining. *Materials*, *13*, 2331. https://doi.org/10.3390/ma13102331

Ramirez-Sagner, G., Mata-Torres, C., Pino, A., Escobar, RA. (2017). Economic feasibility of residential and commercial PV technology: The Chilean case. *Renewable Energy*, *111*, 332-343. https://doi.org/10.1016/j.renene.2017.04.011

Ratajczak, K., Amanowicz, Ł., Pałaszyńska, K., Pawlak, F., Sinacka, J. (2023). Recent Achievements in Research on Thermal Comfort and Ventilation in the Aspect of Providing People with Appropriate Conditions in Different Types of Buildings—Semi-Systematic Review. *Energies*, 16, 6254. https://doi.org/10.3390/en16176254

Rej-Witt, M., Dębska, L. (2022). The use of a photovoltaic system in a single family house in Poland – case study. *E3S Web of Conference*, 336, 00010. https://doi.org/10.1051/e3sconf/202233600010

Schreurs, T., Madani, H., Zottl, A., Sommerfeldt, N., Zucker, G. (2021). Techno-economic analysis of combined heat pump and solar PV system for multi-family houses: An Austrian case study. *Energy Strategy Reviews*, *36*, 100666. https://doi.org/10.1016/j.esr.2021.100666

Shah, A., Krarti, M., Huang, J. (2022). Energy Performance Evaluation of Shallow Ground Source Heat Pumps for Residential Buildings. *Energies*, *15*(3), 1025. https://doi.org/10.3390/en15031025

Stokowiec, K., Wciślik, S., Kotrys-Działak, D. (2023). Innovative modernisation of building heating systems: the economy and ecology of a hybrid district-heating substation. *Inventions*, *8*, 43. https://doi.org/10.3390/inventions8010043

Turski, M., Jachura, A. (2022). Life cycle assessment of dispersed phase change material heat accumulators for cooperation with buildings in the district heating system. *Energies*, *15*(16), 5771. https://doi.org/10.3390/en15165771

Vering, C., Maier, L., Breuer, K., Krutzfeldt, H., Streblow, R., Muller, D. (2022). Evaluating heat pump system design methods towards a sustainable heat supply in residential buildings. *Applied Energy*, *308*, 118204. https://doi.org/10.1016/j.apenergy.2021.118204

Yang, LW., Hua, N., Pu, JH, Xia, Y., Zhou, WB, Xu, RJ, Yang, T., Belyayev, Y., Wang, HS. (2022). Analysis of operation performance of three indirect expansion solar assisted air source heat pumps for domestic heating. *Energy Conversation and Management*, *252*, 115061. https://doi.org/10.1016/j.enconman.2021.115061