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PROFITABILITY ANALYSIS FOR INSTALLATIONS USING SOLAR ENERGY IN A SINGLE-FAMILY HOUSE

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Profitability analysis for installations using solar energy in a single-family house

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Abstract

In this study, the use of solar energy was analyzed, in conjunction with solar collectors and photovoltaics, for the preparation of domestic hot water in a single-family house. Both installations were considered for two countries, Poland and Finland. Irradiation, in both countries, was estimated by using the insolation calculator. Then flat plate and evacuated tube solar collectors were selected from two different companies. Next, their efficiencies, maximum heat outputs, SPBT (Simply Pay Back Time), and NPV (Net Present Value) were calculated. Eight different collectors were considered, and the most favorable option was selected from among them. In the next part of the thesis, the use of photovoltaics was analyzed. The power of installation and the number of panels were selected by the profitability calculator. The calculator presented three variants for which the power generated by photovoltaic panels was calculated. SPBT and NPV were also calculated. For the most favourable option, further analysis was carried out on the basis of external funding, for both countries. Additionally, a prosumer variant was analyzed for photovoltaics.

Keywords

energy, collector, flat plate collectors, evacuated tube collector, photovoltaic, domestic hot water, external financing, prosumer

CONTENTS

1 INTRODUCTION

Global demand for energy is increasing, while the resources of conventional and simultaneously non-renewable energy sources (fossil fuels) are running out. An alternative to them is renewable energy sources (RES), whose reserves are supplemented by natural ecosystem processes, making them inexhaustible [1]. Furthermore, EU directives impose actions on Member States that limit the reduction of pollution from conventional sources [2]. Countries must aim to increase the share of renewable energy sources in energy consumption. Figure 1 shows the worldwide energy consumption with divisions into sources in exajoules (1 exajoule = 10^{18} joules) with forecast.

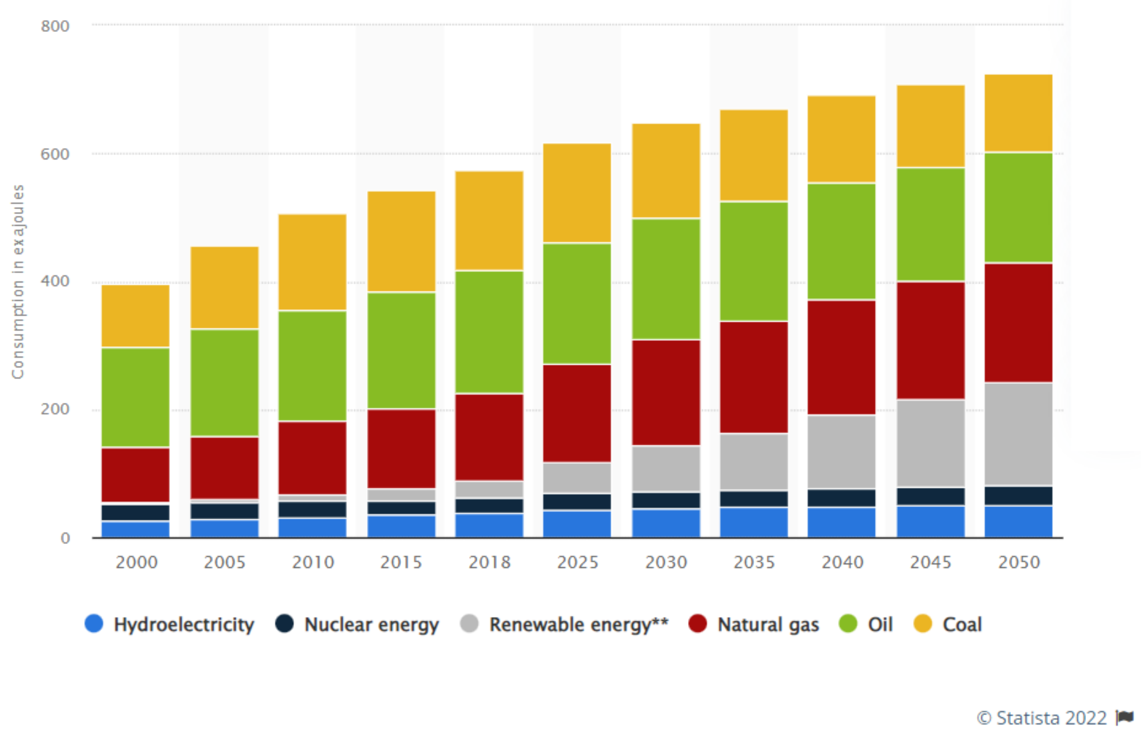


Figure 1 "Energy consumption worldwide from 2000 to 2018, with a forecast until 2050" from www.statista.com

In the present and future period, it is assumed to use solar energy for heating (especially domestic hot water using photovoltaic modules or solar collectors and electricity production using photovoltaic modules) [2].

The subject of the analysis is the use of solar energy to heat domestic hot water with the use of solar collectors and photovoltaic panels. The use of photovoltaics enables the production of electricity for the building's own needs, and the surplus of the produced energy may be sold to the external grid.

The determinants of solar energy radiation availability depend on:

- the use of solar energy is periodical, dependent on climate and weather, and uneven in space and time,
- the geographical position between north latitudes 49º and 55º there are favorable conditions for the exploitation of solar energy in the period from April to September,
- almost half of the reaching solar radiation is diffuse [3].

According to the above, the density of the solar radiation flux, depending on the time of day and year, has an influence on the share of solar energy in the total amount of energy consumed by installations for the preparation of hot water [4].

2 BACKGROUND

2.1 Importance of the location

Earth's north-south axis is tilted 23.5 degrees with respect to its elliptical orbit. From March to September, the northern hemisphere is more strongly oriented toward the sun, whereas from September to March, the southern hemisphere is more strongly oriented toward the sun. As can be seen in Figure 2. This results in different day lengths in summer and winter. The length of days also depends on latitude, that is, the further to the north, the longer (summer) or shorter (winter) the days. As Figure 3 shows.

In view of the above, the sun's rays fall at different angles depending on the geographical location [5].

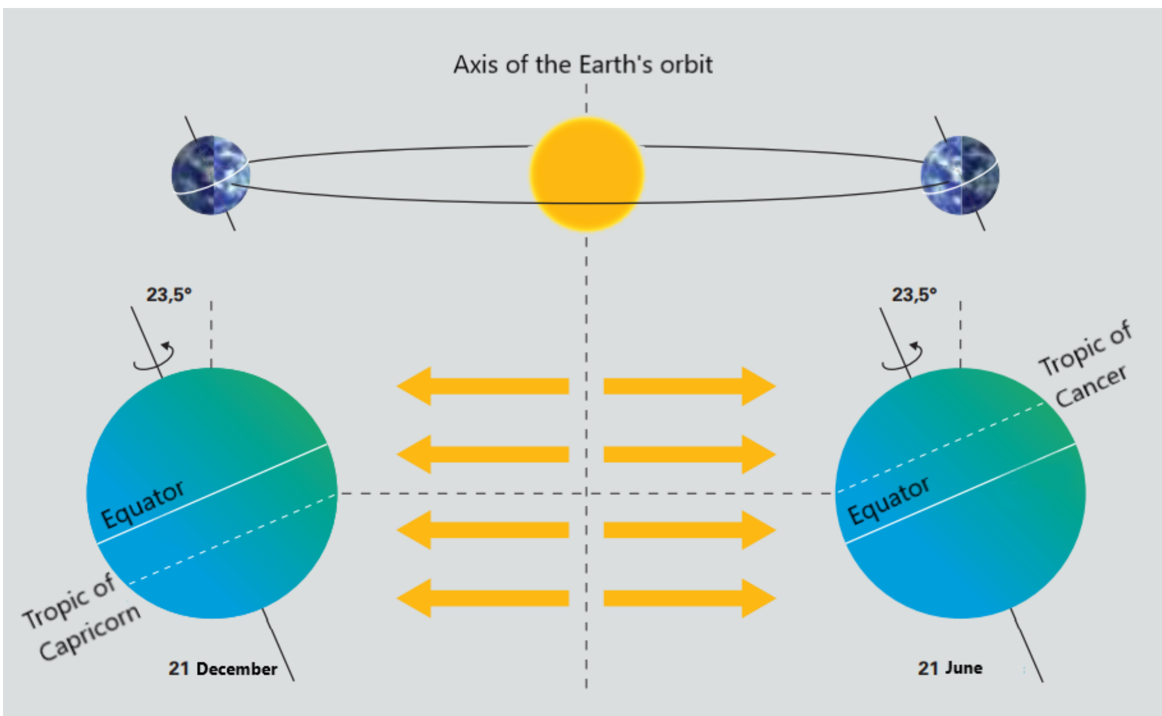


Figure 2 Earth's orbit around the Sun (Viessmann sp. z.o.o, 2018)

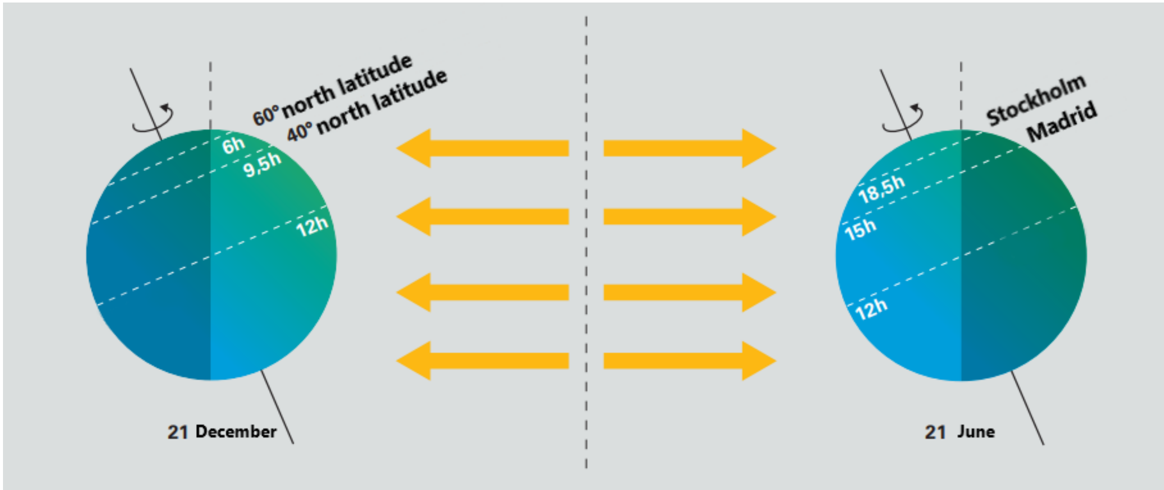


Figure 3 Day length depending on latitude and time of the year (Viessmann sp. z.o.o, 2018)

The atmosphere of the Earth partially reduces the power of the sun's rays. Some of the sun's rays are absorbed or reflected by it. Radiation that reaches the Earth's surface is direct radiation or diffused radiation after passing through a cloud cover [5]. For flat plate devices, the ability to convert solar energy into useful heat is determined by the total radiation, that is, direct, diffuse, and reflected radiation.

The power of radiation on a specified surface is called the irradiance. From a physical point of view, irradiance is the radiant power per surface and is defined in Watts per square meter (W/m^2). The power of solar irradiance is subject to a considerable change. In cloudy weather this power reaches 50 W/m^2, and in clear skies 1000 W/m^2 [5].

The irradiance against the horizontal surface decreases or increases depending on the inclination and orientation of the receiving surface.

The amount of energy is greatest when the sun's rays fall at right angles to the receiving surface. Because at our latitude the sun's rays never fall perpendicularly, it is necessary to set a specific surface of the plane to the horizontal at an optimal angle towards the south. The angle of inclination of the solar collector should vary from 27 ^{o} to 73 ^{o}. Either way, for the autumn-winter period, the angle of inclination should be higher (approx. 60 º) than in the spring-summer period (approx. 30 º), while the optimal angle during its year-round operation should be about 40 º [6].

In the northern hemisphere, the orientation in the southern direction is optimal. The deviation of the receiving surface from the south direction is defined as the azimuth. A surface facing perpendicularly south has an azimuth of 0 degrees.

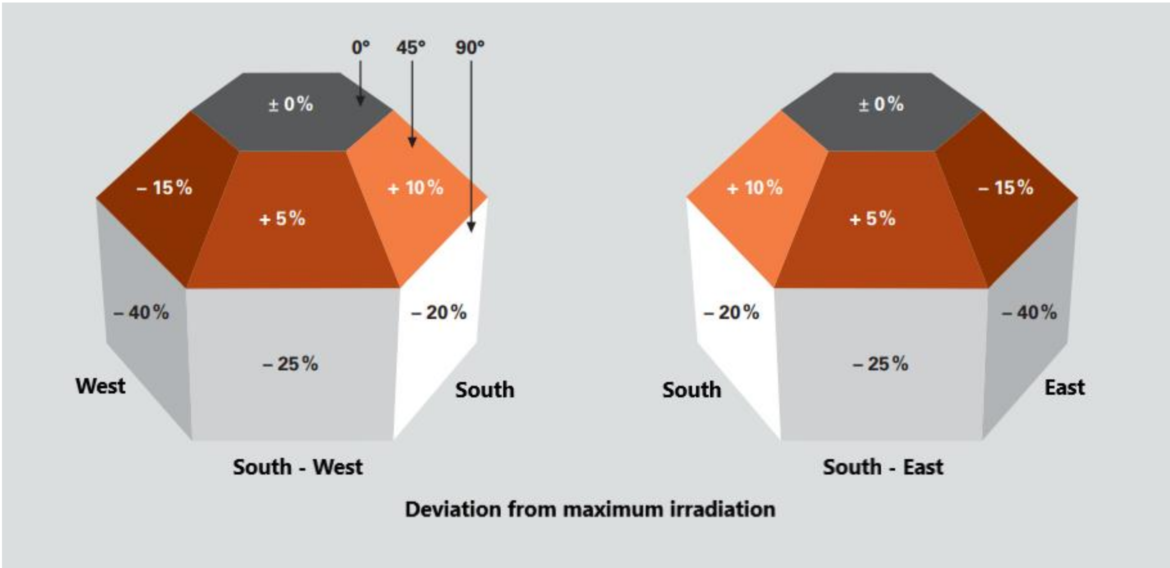


Figure 4 Radiation efficiency depending on the angle of incidence (Viessmann sp. z.o.o, 2018)

Figure 4 shows the dependence of the solar energy obtained on the location and inclination of the absorbing plane. Depending on horizontal positioning, there is a higher or lower efficiency of solar devices. The range in which the performance of a solar device is optimal can be defined between a south-easterly and a south-westerly angle between 25 º and 70 º [5]. As was mentioned before.

With the help of the "JRC Photovoltaic Geographical Information System" which is an insolation calculator, the irradiation was checked in Poland and Finland for the following locations (lat; lon) 52 º;19 º and 64 º;26 º. For both countries, this is their centre. For correct data, the installation information was filled in the same way as Figure 5 shows. The slope in Figure 5, that is, the fixed angle in the title of the graphs, is 30º because the calculator is supposed to show the overall irradiation potential considering the roof slope.

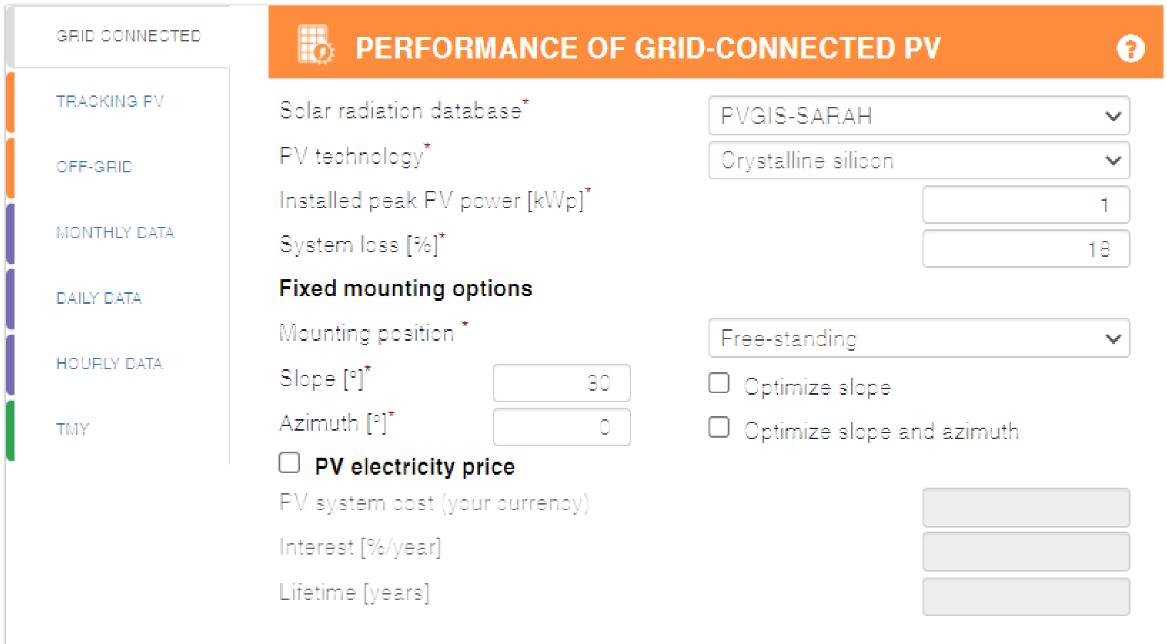


Figure 5 Data entered into JRC calculator

Two graphs were exported from the calculator and are shown below (Figure 6 and Figure 7). As can be seen, the irradiation is similar, whereas for Poland these values are higher. Also, the irradiation in Finland from November to January is negligible.

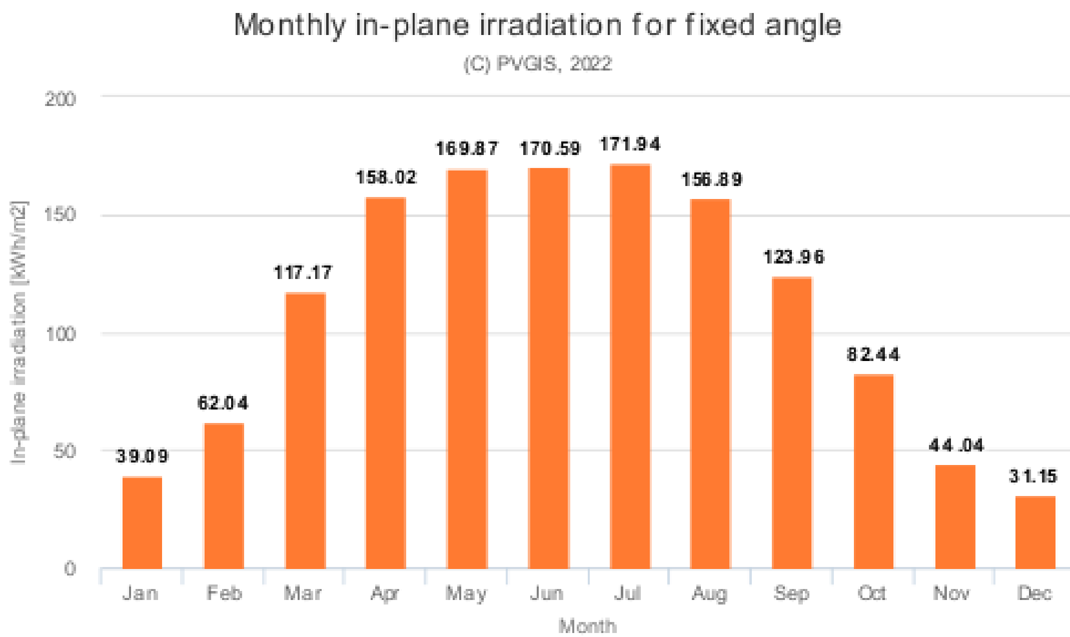


Figure 6 Monthly in-plane irradiation for fixed angle for Poland from JRC

The sum of all month in-plane irradiation in Poland is 1327.21 kWh/m^2.

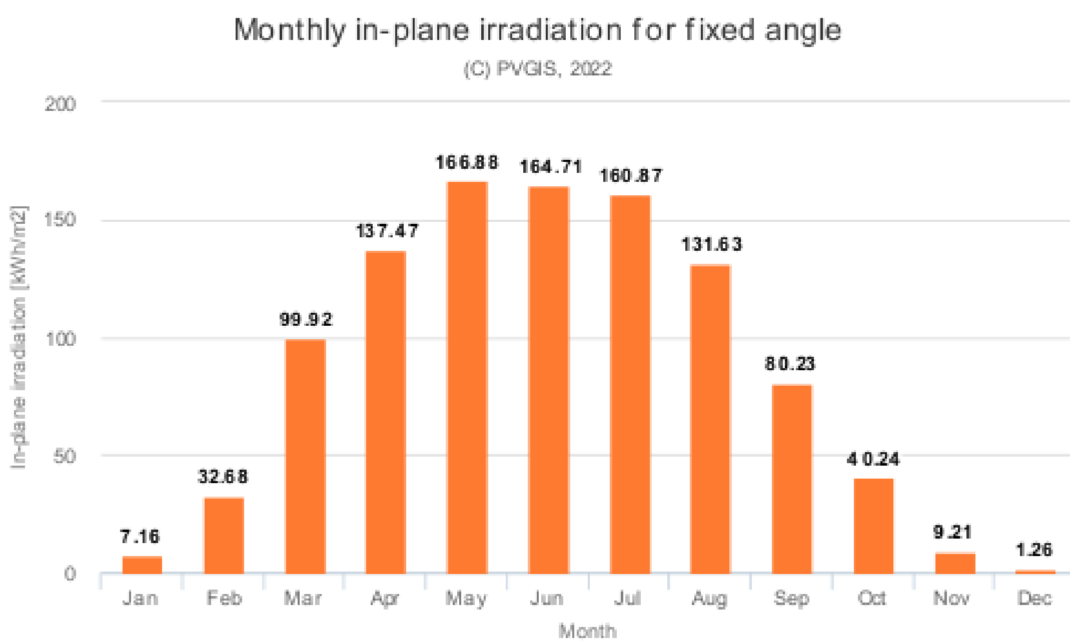


Figure 7 Monthly in-plane irradiation for fixed angle for Finland form JRC

The sum of all month in-plane irradiation in Finland is 1032.27 kWh/m^2.

The graphs show that the conditions for the use of solar energy are from March to September in Poland, whereas in Finland they are from March to August.

2.2 Solar collectors

The main function of a collector is to collect solar energy. The absorber, a copper or aluminum plate with a connected wiring system, usually of a meandering shape in which the working medium heated by the solar energy circulates, is directly responsible for generating energy. The heated working medium is directed to the water container by means of a circulation pump. As it flows through the coil in the tank, it heats the water contained in it [3].

There are two types of collectors, flat and evacuated tube collectors, which differ in their construction, type of heat transfer medium, and the temperature of the working medium [7].

2.2.1 Flat plate collectors

The flat collector consists of an insulated casing, an absorber, flow pipes, and a coating, which is usually a solar glass. The casings are most often made of aluminium welded components, duralumin sheets formed in an appropriate manner, or as extrusion or synthetic materials. They are characterized by corrosion resistance and mechanical strength. They can be painted in any colour. In turn, a layer of insulation is laid in the casing and then an absorber with good thermal conductivity. For the production of absorbers and their coatings, materials that are easily machined, low density, corrosion-resistant, and high temperatures are used, i.e. thin sheet metal, aluminium, steel, or copper strip, to which flow tubes are subsequently fitted in different configurations (series-parallel, series, serpentine, or parallel). To increase the absorption capacity of the absorbers, they are covered by selective coatings, i.e. black nickel, black chromium, black cobalt, black copper, black molybdenum, or titanium compounds. These coatings are called emissivity-low coatings due to the low thermal radiation emissivity from the surface of the heated absorber and the high absorption capacity. In the end, the manifold is covered by tempered glass with reduced iron content, bending strength, pressure, and abrasion caused by the weather conditions. In addition, the glass is covered on the inside with antireflective coatings, which reduce the reflection of solar radiation at the interface air glass [7]. Flat plate solar collectors can be easily and safely installed on the roof or on its slope. More and more often, collectors are installed on the facade or in the free standing position. Flat-plate collectors are cheaper than evacuated tube collectors and are used to heat domestic water, swimming pools, and to support space heating. Among flat plate collectors, the most popular are those with absorber areas of 2 – 2.5 m^2 [5].

2.2.2 Evacuated tube collectors

A technologically advanced solution is the use of evacuated tube collectors made of double-walled glass tubes whose ends are melted together to form a thermos bubble. These tubes are usually made of boron-silicon glass. The heat insulation function is a 10^{-6} bar vacuum in the space between the walls of the glass tube. On the outside surface of the inner surface of the glass tube, there is an absorbent layer - a thin formed sheet (copper or aluminium) conducting heat and adhering to the tube in such a way as to ensure thermal contact generally over the entire circuit. The heating of the fluid in pipes can be done in two ways: Either through a closed single pipe (so-called heat pipe) or through U-shaped flow channels with a heating factor [7]. The conversion of solar energy into heat in the absorber is identical in flat plate collectors as in evacuated tube collectors [5]. Evacuated tube collectors are better suited for applications at high temperatures. A flat plate collector is more sensitive to the difference between the temperature of the heat transfer medium in the collector and the ambient temperature. In addition, the optical efficiency of flat plate collectors decreases with increasing reflected radiation (higher heat losses), whereas in a vacuum collector the efficiency losses are lower due to their geometry, which means that a larger area of the absorber is exposed to solar radiation [7].

2.3 Photovoltaic panels

“Photovoltaics is a solar-power technology for generating electricity using semiconductor devices known as solar cells. A number of solar cells form a solar ‘module’ or ‘panel’, which can then be combined to form solar power systems, ranging from a few watts of electricity output to multi-megawatt power stations.” [8]

Photovoltaic is a zero emission system. This means that no harmful compounds and carbon dioxide or other greenhouse gases are emitted during energy production. Additionally, thanks to the use of semiconductor technology, the absence of moving parts, and the simplicity of the system, it becomes virtually maintenance-free. An additional advantage is the long component warranty periods, eg for photovoltaic panels up to 25 years [9].

“The basic elements of photovoltaic equipment are photovoltaic cells. The most popular are silicon cells. There are three types of silicon cells:

- monocrystalline,
- poly- or multicrystalline,
- amorphous.

Monocrystalline solar cells, also known as Czochralski or CZ-pulled cells (abbreviation: CZ-Si), are pulled, in a high temperature process, from a crystal (round) and cut into sheets approximately 0.3 mm thick. Pseudo-square wafers are created by sawing the round silicon sheets. [...] Monocrystalline silicon cells are the most expensive cells and reach the highest efficiency of about 20%. […] The voltage of individual solar cell ranges from 0.5 to 0.6 volt. Therefore, for the standard low voltage range of 6–24 volts, many cells are connected together in series. By doing this, one obtains a solar module or a solar panel that can consist of 12-42 solar cells. When building larger photovoltaic systems (PV systems), many solar modules are connected together in series and in parallel to make a solar generator.” [10] In the manufacturing process, the energy expended on poly- or multicrystalline silicon cells is lower than of monocrystalline cells as a result of which the price of poly- or multicrystalline silicon cells is also lower, but the efficiency of these cells is about 15%. Also, less energy is expanded in the process of manufacturing amorphous silicon cells, and the price of this kind of cell is the lowest, although the efficiency ranges from 5% to 10% [10].

The photovoltaic cells made of the modules consist of layers to which belong:

- positive electrode,
- p-type silicon semiconductor layers with a positive charge and n-type with a negative charge,
- antireflection coating,
- negative electrode.

The conversion of the energy of solar radiation into solar energy is possible through the use of semiconductors. Under the influence of incoming solar energy, at the border of p-type and n-type semiconductors, a p-n junction is formed. The energy reaching the junction generates electron-hole pairs in it. Because of the p-n junction, it is possible to diffuse positive charges from the area of p to n and negative electrons from the area of n to p. Due to the potential difference created after the electrical circuit closure, current flows [11].

2.4 House design

An existing building is considered in the analysis. The building was constructed in 2018. For analysis purposes, the building is being considered in both Poland and Finland. The location of the building is not determined to any locality, as the analysis concerns the overall use of solar energy in the country.

Figure 8 House design from www.archeton.pl

Figure 8 shows the building accepted for analysis. The project is taken from the website www.archeton.pl, and the project number is E-1393.

Basic Data on the building:

- single-family house
- detached house
- one storey building
- usable floor area 96.0 m^2
- net area 100.6 m^2
- roof slope 30^o
- roof area 184.7 m^2
- ridge roof
- for 4 people
- hot water consumption 50 litres per day per person

The front of the house faces north so that the installation on the roof on the other side faces south. There are no roof windows because the attic is not a usable part of the house. The house is also heated by a condensing boiler.

2.5 Annual energy demand for domestic hot water

The calculation assumes methodology according to [12].

Based on domestic hot water consumption of 50 l per person which gives 200 l per day (assuming 4 people), the energy demand for heating water Q_{cwu} can be determined:

$$Q_{cwu} = V \cdot c_p \cdot (T_{cw} - T_{zw}), kWh/d$$

Guidelines:

V – daily hot water consumption, $V = 200\, l/d \approx 200 kg/d$

c_p – specific heat capacity of water, ($c_p = 1.16\, Wh/kg \cdot K$)

T_{cw} – the design hot water temperature at the tap, ($T_{cw} = 55^o C$)

T_{zw} – calculation water temperature before heating, ($T_{zw} = 10^o C$)

$$Q_{cwu} = 200\, kg/d \cdot 1.163\, Wh/kg\, K \cdot (55 - 10) = 10467\, Wh/d = 10.467\, kWh/d$$

Annual energy demand of DHW:

$$10.467\, kWh/d \cdot 365 = 3820.46\, kWh/a$$

3 METHODS

The purpose of the analysis was to show a favourable variant for heating water in a single-family building. This study compared the devices with respect to the amount of energy produced by the device and the economic aspects. At the beginning of the work, the water demand in the considered single-family house was calculated. The irradiation falling on the roof at an angle of 30 degrees was estimated for both countries using the JRC irradiation calculator. The first analyzed cases were solar collectors. Flat plate and evacuated tube solar collectors from two companies, Viessmann and Immergas, were used for the analysis. Next, by calculating their efficiency in July, comparing the technical parameters and profitability of all collectors, the particular collector was selected. Then, an analysis of the use of photovoltaics was carried out. Three ready-made sets were chosen using the photovoltaic profitability calculator. After which their technical parameters, the amount of energy produced, and profitability were compared. The solar collectors and photovoltaics were then compared and, using the NPV indicator, the device that would work best in the single-family building in question was selected. The selected variant was analyzed in terms of external financing and the prosumer variant in both countries. In the consumer variant, the benefits that will be obtained from running photovoltaics were calculated in the case of using energy for the current purposes of the building, heating of domestic hot water, and sale and purchase of energy.

4 LITERATURE ANALYSIS OF THE POSSIBILITY OF USING SOLAR COLLECTORS IN A SINGLE-FAMILY HOUSE

The article [13] presents the results of the studies carried out to gain knowledge of the use of alternative energy sources, such as solar collectors, to produce domestic hot water compared to conventional sources. The research was based on the need to use alternative energy sources as one of the determinants of sustainable development. The highest annual financial savings can be achieved in the case of a hybrid system with electricity followed by fuel oil. Whereas the lowest in gas and coal-fired installations.

Solar installations in a typical single-family house, used to heat domestic hot water from April to September, can cover more than 94% of the demand. And more than 72% of the heat demand for domestic water heating throughout the year. From May to August, there is a significant surplus of heat that the solar collectors could capture and heat more water (an average of 1.5 m^3 more each month) [14].

The energy that can be obtained from solar collectors depends on the amount of solar radiation, which, after passing through the atmosphere of the Earth, reaches its surface. It should be noted that this energy is less in value than the energy that enters the orbit. This decrease, known as radiation attenuation, is the result of reflection, absorption, and scattering processes that occur in the atmosphere. The decrease in the intensity of the radiation depends on the way it is taken in the atmosphere. The effect of radiation is further reduced by the effects of cloud cover and precipitation. In addition, the amount of radiation at the Earth's surface due to the position of the sun relative to the horizon and weather conditions depends significantly on the season [15]. Recalling the conclusions from [15] it can be said that as the air temperature increases, the amount of heat absorbed by the manifolds increases. The efficiency of solar collectors depends on a large number of parameters. In the work, only the influence of two parameters – air temperature and length of day – was investigated. In each case, the effect is the same. The trend in the characteristics of the collector power as a function of the average air temperature and the length of the day shows an increasing linear relationship.

The article [16] shows that the efficiency of the collector is the ratio of the energy received by the working medium to the amount of solar energy entering the collector. The efficiency of the collector decreases as the temperature difference between the working medium and the environment increases.

It should be noted that as the temperature difference ΔT decreases or increases, the heat efficiency of the collectors changes. With this, the flat collector compared to the evacuated tube collector has a higher thermal efficiency with low temperature differences of up to approximately 25 K. As this difference increases, the efficiency of this collector decreases, and the thermal efficiency of the evacuated tube collector remains high. Therefore, in terms of energy, flat collectors are more efficient during summer periods (spring, summer) and evacuated tube collectors during transition periods (autumn, winter) [6].

4.1 Selection of solar collectors for the considered single-family house

4.1.1 Efficiency of collectors

$$\eta = \eta_0 - \frac{k_1 \cdot \Delta T}{E_g} - \frac{k_2 \cdot \Delta T^2}{E_g}$$

η_0 – optical efficiency [%]

k_1 and k_2 – heat loss coefficient [$W/(m^2 \cdot K)$] and $W/(m^2 \cdot K^2)$

ΔT – the temperature difference between the absorber and the environment [K]

E_g – irradiation [W/m^2]

All the necessary data for the equation are given below for each type of collector. ΔT is 40K, because this assumption was in the Viessmann datasheet. Also, the E_g is assumed 800 W/m^2 to compare the efficiencies of individual collectors. 800 W/m^2 is an average solar energy which falls on a surface during the summer months.

4.1.2 Collectors from the Viessmann company

Using the demo version of the ESOP 4.0 R4 simulation software, simulations were performed for flat plate collectors. The program belongs to the Viessmann company, therefore, the simulation is carried out only with collectors of this company. Additionally, in this version of the software, the simulation location is Würzburg in Germany, where yearly in-plane irradiation is 1091.31 kWh/m^2. Therefore, its value is close to Poland.

When the assumed water consumption 50 litres per person and the rest of the data which is 4 inhabitants, the design hot water temperature 55^{o}C at the tap, roof slope 30^o to south direction has been entered into the ESOP program, the simulation shows that:

The maximum energy gain of a solar installation is approximately 3.5 kWh/(m^{2}d). All collectors are combined with the Vitocell 100-B bivalent heater (300 liters) and the Vitodens 200-W condensing boiler (8.8-35kW). In all cases, the rated power of the condensing boiler is 11 kW. All of those devices have been selected by program.

In addition, below (Figure 9) is shown the system of installation on which the simulation was carried out.

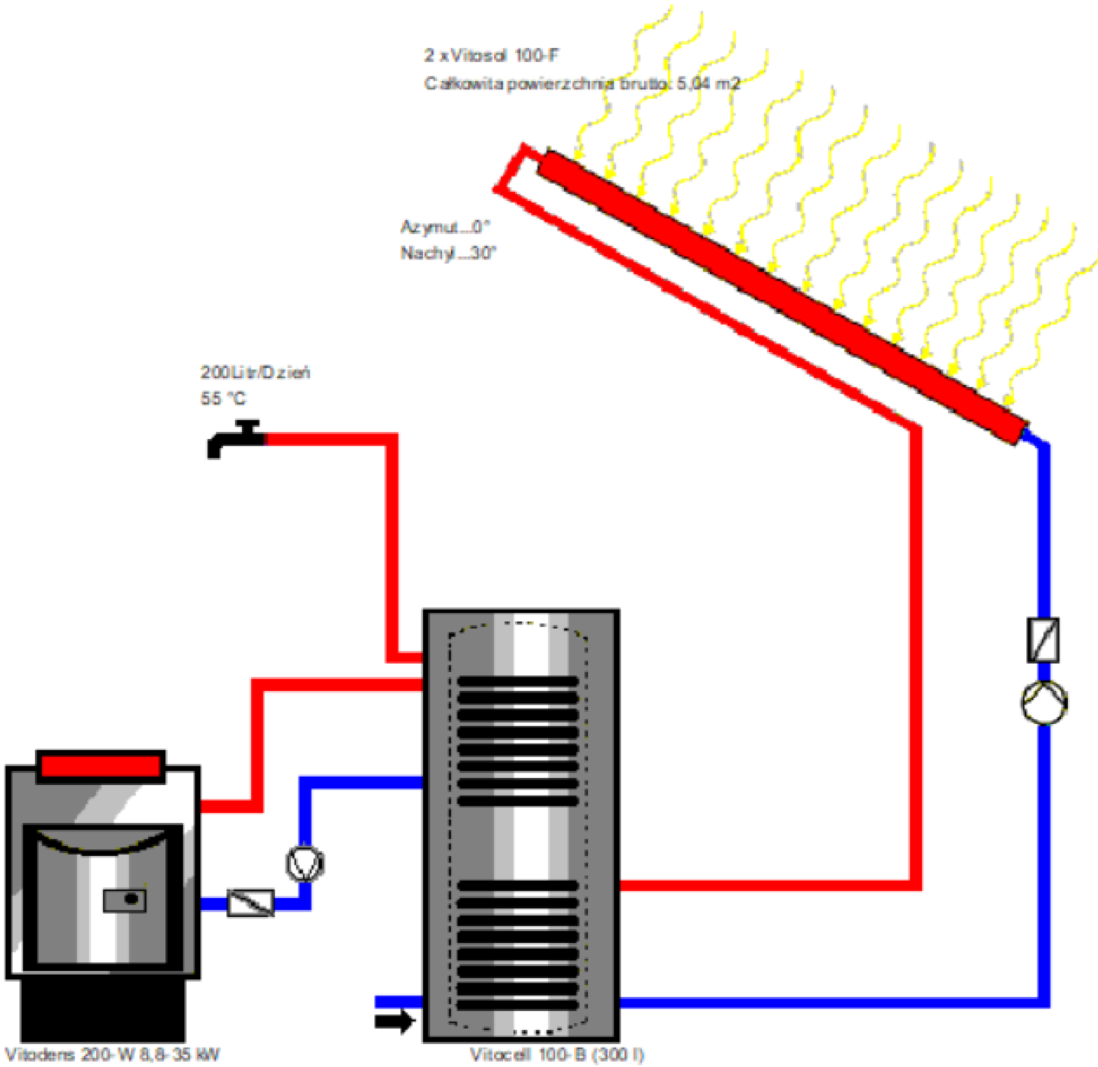


Figure 9 Installation with Vitosol 100-F

The same system is considered for Vitosol 200-F.

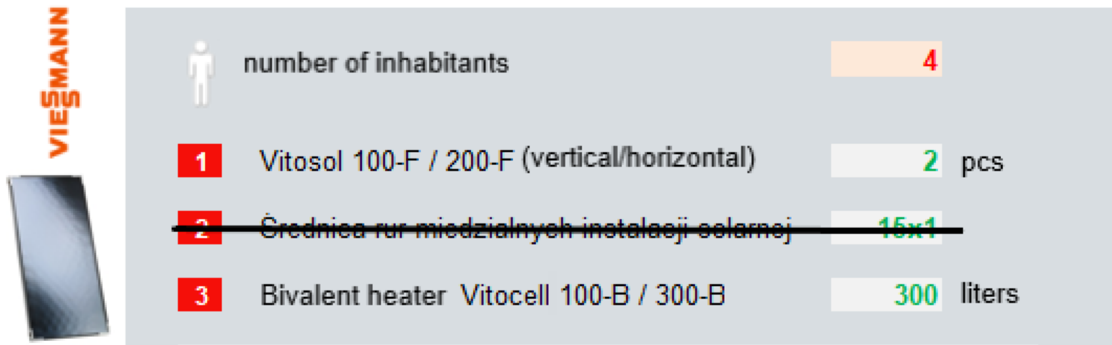


Figure 11 Selection of Vitosol 100-F / 200-F installation using the Viessmann Excel file

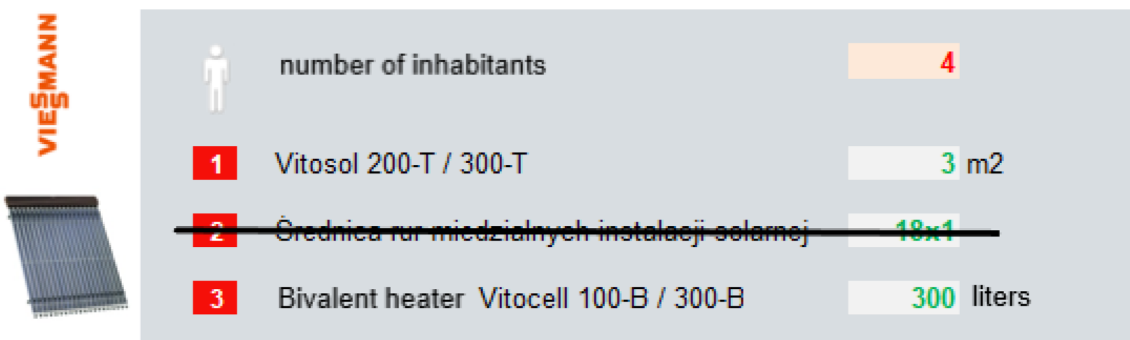


Figure 10 Selection of the Vitosol 200-T / 300-T installation using the Viessmann Excel file

Figures 10 and 11 show the results from an Excel file from the Viessmann company, which calculate how many pieces or square meters (depending on the type of collector) given the number of inhabitants needed to meet their needs. The simulator and the excel calculator show that 2 flat plate collectors Vitosol 100F as well as Vitosol 200F are needed. The Excel file (Figure 10) shows that 3m2 is required for evacuated tube solar collectors, which is equivalent to the surface of one evacuated tube collector.

- Solar collectors from the Viessmann company
    - 2 flat plate solar collectors (Vitosol 100-F / 200-F)
    - 1 evacuated tube solar collectors (Vitosol 200-T / 300-T)

The calculations for the collectors and their data from the datasheets are below.

4.1.2.1 Flat plate solar collectors calculations

In both cases of flat plate solar collectors from Viessmann company, the simulation showed that the thermal power of the installed collectors is 3.53 kW, the annual irradiation of the surface of the installed collectors 5.71 MWh, and the total annual heat for domestic hot water heating 3.4 MWh. For the 50^{o}C DHW temperature that the program assumes.

Vitosol 100-F

Table 1 shows the results of the simulation and Figure 12 shows the percentage coverage of domestic hot water demand by the collectors Vitosol 100-F in every month. The results allow to visualize the real results which can be obtained in this case for Poland, because the irradiation in the set location of the demo program is similar to that of Poland.

Table 1 Results of the annual simulation for Vitosol 100-F

Heat from the collector system transferred to the domestic hot water system	1831.97 kWh
Degree of coverage for domestic hot water heating	49.7%
Efficiency of the system	32.1%
Total gross area	5.02 m^2
Total active area	4.66 m^2

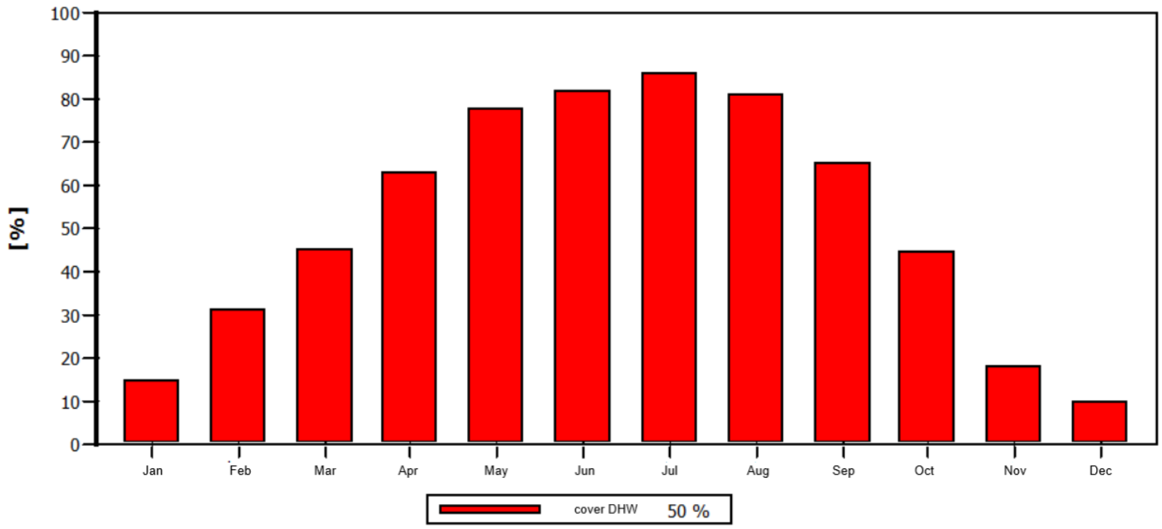


Figure 12 Cover DHW Vitosol 100-F

Based on Figure 12 and Table 1, using the percentage DHW cover in July (86%) and the annual heat from the collector system transferred to the DHW system (1831.97 kWh) from simulation, the heat output was estimated in this month. As a result, the heat output in July for Vitosol 100-F is 54.8 kWh/m^2.

Efficiency

$\eta_0 = 81\%$

$k_1 = 4.81\ W/(m^2 \cdot K)$

$k_2 = 0.022\ W/(m^2 \cdot K^2)$

$\Delta T = 40K$

$E_g = 800\ W/m^2$

$$\eta = \eta_0 - \frac{k_1 \cdot \Delta T}{E_g} - \frac{k_2 \cdot \Delta T^2}{E_g}$$

$$\eta = 0.81 - \frac{4.81 \cdot 40}{800} - \frac{0.022 \cdot 40^2}{800} = 0.526 = 52.6\%$$

Table 2 shows the maximum heat output for July taking into account the calculated efficiency (which is as close to the efficiency in summer months) and Figure 13 shows data from the datasheet for the Vitosol 100-F collectors.

The irradiation in July in Poland is 171.94 kWh/m^2 and 160.87 kWh/m^2 in Finland as Figure 6 and Figure 7 show (these data was used to calculate the heat output in July of each collector).

Table 2 Maximum heat output Vitosol 100-F

Maximum heat output in July	Poland	90.4 kWh/m^2
	Finland	84.6 kWh/m^2

There are variations in the results from the simulation (54.8 kWh/m^2) and the calculations (in Poland 90.4 kWh/m^2 and 84.6 kWh/m^2 in Finland). This is because the simulation program has different monthly irradiation and assumes how much heat from the collectors will be transferred to the DHW system, taking into account differences in collector efficiencies. Additionally, it considers losses in system operation. Whereas calculations take into consideration the monthly irradiation and calculated efficiency.

Vitosol 100-FM

Type		Vitosol 100-FM Typ SV1F
Gross area	m^2	2,51
Absorber area	m^2	2,32
Apparatus area	m^2	2,33
Dimensions		
Width	mm	1056
Height	mm	2380
Depth	mm	72
Weight	kg	42

Figure 13 Technical specifications for Vitosol 100-FM

Vitosol 200-F

Table 3 shows the results of the simulation and Figure 4 shows the percentage coverage of domestic hot water demand by Vitosol 200-F collectors per month.

Table 3 Results of the annual simulation for Vitosol 200-F

Heat from the collector system transferred to the domestic hot water system	1932.9 kWh
Degree of coverage for domestic hot water heating	52.1 %
Efficiency of the system	33.9 %
Total gross area	5.02 m^2
Total active area	4.654 m^2

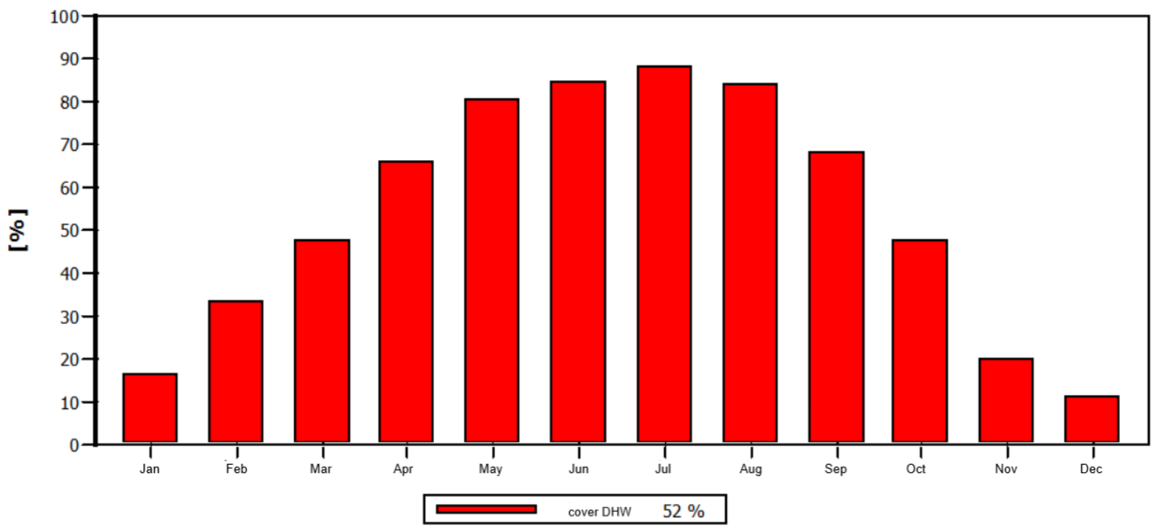


Figure 14 Cover DHW Vitosol 200-F

Based on Figure 14 and Table 3, using the percentage DHW cover in July (88%) and the annual heat from the collector system transferred to the DHW system (1932.9 kWh) from simulation, the heat output was estimated in this month. As a result, the heat output in July for Vitosol 200-F is 56.4 kWh/m^2.

Efficiency

$\eta_0 = 82\%$

$k_1 = 4.75\ W/(m^2 \cdot K)$

$k_2 = 0.024\ W/(m^2 \cdot K^2)$

$\Delta T = 40K$

$E_g = 800\ W/m^2$

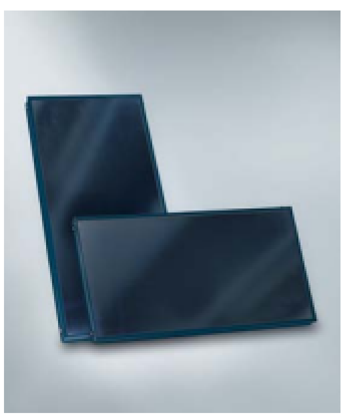
$$\eta = \eta_0 - \frac{k_1 \cdot \Delta T}{E_g} - \frac{k_2 \cdot \Delta T^2}{E_g}$$

$$\eta = 0.82 - \frac{4.75 \cdot 40}{800} - \frac{0.024 \cdot 40^2}{800} = 0.535 = 53.5\%$$

Table 4 shows the maximum heat output in July taking into account the calculated efficiency, and Figure 15 shows data from the datasheet for the collectors Vitosol 200-F. Again, there is a variation in the results, the reason for which is the same as in the case of Vitosol 100-F collectors.

Table 4 Maximum heat output Vitosol 200-F

Maximum heat output in July	Poland	92.0 kWh/m^2
	Finland	86.1 kWh/m^2



Vitosol 200-FM

Type		Vitosol 200-FM Typ SV2F
Gross area	m^2	2,51
Absorber area	m^2	2,32
Apparatus area	m^2	2,33
Dimensions		
Width	mm	1056
Height	mm	2380
Depth	mm	90
Weight	kg	41

Figure 15 Technical specifications for Vitosol 200-FM

The simulation has shown that the results were better for Vitosol 200-F despite very close parameters. The surfaces of both collectors are the same, but the efficiencies are different. For example, the efficiency for Vitosol 100-F is 52.6%, compared to the efficiency for Vitosol 200-F it is 53.5%. But this is an insignificant difference.

4.1.2.2 Calculations of evacuated tube solar collectors

Simulation for evacuated tube solar collectors is not possible because the program does not have actual data for tube collectors.

Vitosol 200-T

Efficiency

$\eta_0 = 71\%$

$k_1 = 1.2\, W/(m^2 \cdot K)$

$k_2 = 0.006\, W/(m^2 \cdot K^2)$

$\Delta T = 40K$

$E_g = 800\, W/m^2$

$$\eta = \eta_0 - \frac{k_1 \cdot \Delta T}{E_g} - \frac{k_2 \cdot \Delta T^2}{E_g}$$

$$\eta = 0.71 - \frac{1.2 \cdot 40}{800} - \frac{0.006 \cdot 40^2}{800} = 0.638 = 63.8\%$$

Table 5 shows the maximum heat output in July taking into account the calculated efficiency, and Figure 16 shows data from the datasheet for the collectors Vitosol 200-T.

Table 5 Maximum heat output Vitosol 200-T

Maximum heat output in July	Poland	109.7 kWh/m^2
	Finland	102.6 kWh/m^2

Type			Vitosol 200-TM typ SPEA
Absorber area		m^2	3,26
Gross area		m^2	5,25
Apparatus area		m^2	3,46
Dimensions	Width	mm	2364
	Height	mm	2244
	Depth	mm	174
Weight		kg	113

Figure 16 Technical specifications for Vitosol 200-TM

Vitosol 300-T

Efficiency

$\eta_0 = 76\%$

$k_1 = 1.3\ W/(m^2 \cdot K)$

$k_2 = 0.007\ W/(m^2 \cdot K^2)$

$\Delta T = 40K$

$E_g = 800\ W/m^2$

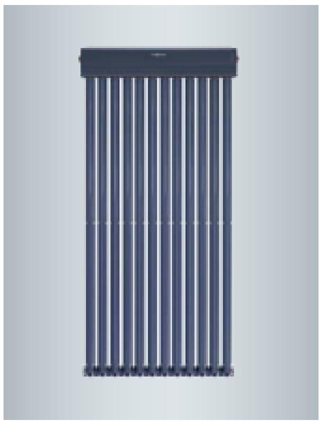
$$\eta = \eta_0 - \frac{k_1 \cdot \Delta T}{E_g} - \frac{k_2 \cdot \Delta T^2}{E_g}$$

$$\eta = 0.76 - \frac{1.3 \cdot 40}{800} - \frac{0.007 \cdot 40^2}{800} = 0.681 = 68.1\%$$

Table 6 shows the maximum heat output in July taking into account the calculated efficiency and Figure 17 shows data from the datasheet for the collectors Vitosol 300-T.

Table 6 Maximum heat output Vitosol 300-T

Maximum heat output in July	Poland	117.1 kWh/m^2
	Finland	109.6 kWh/m^2



Type			Vitosol 300-TM typ SP3C
Absorber area		m^2	3,03
Gross area		m^2	4,62
Apparatus area		m^2	3,19
Dimensions	Width	mm	2061
	Height	mm	2241
	Depth	mm	150
Weight		kg	79

Figure 17 Technical specifications for Vitosol 300-TM

Calculations have shown that a Vitosol 300-F collector can obtain maximum heat output which is even 22.8% more energy than the rest of the results for Viessmann collectors.

4.1.3 Collectors from the Immegas company

The Immergas company does not have a calculator that can select the needed pieces or square meters of solar collectors or bivalent heaters. Therefore, the calculations for the bivalent heater and the selection of solar collectors have been done according to the instructions of the Immergas company.

4.1.3.1 Flat plate solar collectors calculations

For the building, we take the following input data:

- singe-family house with a normal water consumption profile
- the roof slope is 30 degrees
- roof facing south

- hot water consumption per person of 50 liters per day
- the building height is 6 m

V_d - domestic hot water consumption

$$V_d = 4 \cdot 50l = 200l$$

V_{zas} – tank volume

$$V_{zas} = m \cdot V_d = (1.5 \cdot 200) = 300\ liters$$

A tank with a volume of 300l was selected, this is the UBS 300 SOL tank. For the tank volume defined in this way, the required surface area of the collectors was determined from the table.

DHW tank volume [l]	Optimal active area of collectors [m2]	Maximum active area of collectors [m2]
200	3	6
300	5	10
400	7	13
500	8	16
750	12	25
1000	16	33

Figure 18 Table for pre-selection of flat collector surfaces for 70% solar coverage

As Figure 18 shows for a tank with a volume of 300l, the active area of the collectors is between 5 ÷ 10 m^2:

- 3 flat collectors EP 2.0 with a total active area of 5.58 m^2
- 2 flat collectors EP 2.6 with a total active area of 4.92 m^2

The calculations for the collectors and their data from the datasheets are below.

EP 2.0

Efficiency

$\eta_0 = 76.1\%$

$k_1 = 4.034\ W/(m^2 \cdot K)$

$k_2 = 0.01\ W/(m^2 \cdot K^2)$

$\Delta T = 40K$

$E_g = 800\ W/m^2$

$$\eta = \eta_0 - \frac{k_1 \cdot \Delta T}{E_g} - \frac{k_2 \cdot \Delta T^2}{E_g}$$

$$\eta = 0.761 - \frac{4.034 \cdot 40}{800} - \frac{0.01 \cdot 40^2}{800} = 0.539 = 53.9\%$$

Table 7 shows the maximum heat output in July taking into account the calculated efficiency and

Table 8 shows data from the datasheet for the EP 2.0 collectors. Again, the data form Figure 6 and Figure 7 was used, specifically the irradiation in July in Poland is 171.94 kWh/m^2 and 160.87 kWh/m^2 in Finland.

Table 7 Maximum heat output EP 2.0

Maximum heat output in July	Poland	92.7 kWh/m^2
	Finland	86.7 kWh/m^2

Table 8 Technical specifications for EP 2.0

	Type			**EP 2.0**
	Absorber area		m^2	1.97
	Gross area		m^2	2.02
	Apparatus area		m^2	1.86
	Dimensions	Width	mm	1006
		Height	mm	2007
		Depth	mm	85
	Weight		kg	40

EP 2.6

Efficiency

$\eta_0 = 79.8\%$

$k_1 = 3.688\ W/(m^2 \cdot K)$

$k_2 = 0.019\ W/(m^2 \cdot K^2)$

$\Delta T = 40K$

$E_g = 800\ W/m^2$

$$\eta = \eta_0 - \frac{k_1 \cdot \Delta T}{E_g} - \frac{k_2 \cdot \Delta T^2}{E_g}$$

$$\eta = 0.798 - \frac{3.688 \cdot 40}{800} - \frac{0.019 \cdot 40^2}{800} = 0.576 = 57.6\%$$

Table 9 shows the maximum heat output in July taking into account the calculated efficiency, and Table 10 shows data from the datasheet for collectors EP 2.6.

Table 9 Maximum heat output EP 2.6

<table>
<tr><td rowspan="2">Maximum heat output in July</td><td>Poland</td><td>99.0 kWh/m²</td></tr>
<tr><td>Finland</td><td>92.7 kWh/m²</td></tr>
</table>

Table 10 Technical specifications for EP 2.6

<table>
<tr><td rowspan="8"></td><td colspan="3">Type</td><td>EP 2.6</td></tr>
<tr><td colspan="2">Absorber area</td><td>m²</td><td>2.57</td></tr>
<tr><td colspan="2">Gross area</td><td>m²</td><td>2.65</td></tr>
<tr><td colspan="2">Apparatus area</td><td>m²</td><td>2.46</td></tr>
<tr><td rowspan="3">Dimensions</td><td>Width</td><td>mm</td><td>1120</td></tr>
<tr><td>Height</td><td>mm</td><td>2356</td></tr>
<tr><td>Depth</td><td>mm</td><td>85</td></tr>
<tr><td colspan="2">Weight</td><td>kg</td><td>48</td></tr>
</table>

Calculations have shown that from EP 2.6 collector a higher heat output can be obtained and achieve higher efficiency even 3.7% more than with EP 2.0 collector. Additionally, in the case of EP 2.6 collector, one piece fewer is needed.

4.1.3.2 Evacuated tube solar collectors calculation

The input data and the DHW tank are the same as in the case with flat collectors.

DHW tank volume [l]	Optimal active area of collectors [m2]	Maximum active area of collectors [m2]
200	3	4
300	4	6
400	6	8
500	7	9
750	10	15
1000	14	20

Figure 19 Table for pre-selection of tube collector surfaces for 70% solar coverage

As Figure 19 shows for a tank with a volume of 300l, the active area of the collectors is between 4 ÷ 6 m^2:

- 3 tube collectors EV 3.0 with a total active area of 5.01 m^2
- 2 tube collectors EV 3.6 with a total active area of 4.1 m^2

The calculations for the collectors and their data from the datasheets are below.

EV 3.0 and EV 3.6

Efficiency

Both collectors have the same data from the datasheet, and only the dimensions are different.

$\eta_0 = 69.1\%$

$k_1 = 2.6245\ W/(m^2 \cdot K)$

$k_2 = 0.0271\ W/(m^2 \cdot K^2)$

$\Delta T = 40K$

$E_g = 800\ W/m^2$

$$\eta = \eta_0 - \frac{k_1 \cdot \Delta T}{E_g} - \frac{k_2 \cdot \Delta T^2}{E_g}$$

$$\eta = 0.691 - \frac{2.6245 \cdot 40}{800} - \frac{0.0271 \cdot 40^2}{800} = 0.506 = 50.6\%$$

Table 11 shows the maximum heat output in July taking into account the calculated efficiency of both collectors, and Table 12 and Table 13 show data from the datasheet for the collectors EV 3.0 and EV 3.6.

Table 11 Maximum heat output EV 3.0 and 3.6

Maximum heat output in July	Poland	87.0 kWh/m^2
	Finland	81.4 kWh/m^2

Table 12 Technical specifications for EV 3.0

	**Type**			**EV 3.0**
	Number of vacuum tubes		pcs	18
	Absorber area		m^2	1.46
	Gross area		m^2	3.03
	Apparatus area		m^2	1.67
	Dimensions	Width	mm	1529
		Height	mm	1980
		Depth	mm	155
	Weight		kg	63

Table 13 Technical specifications for EV 3.6

	Type			EV 3.6
	Number of vacuum tubes		pcs	22
	Absorber area		m^2	1.79
	Gross area		m^2	3.66
	Apparatus area		m^2	2.05
	Dimensions	Width	mm	1849
		Height	mm	1980
		Depth	mm	155
	Weight		kg	82

The efficiencies achieved by evacuated tube collectors EV 3.0 and EV 3.6 are lower than flat plate collectors EP 2.0 and EP 2.6.

4.2 Comparison of the results for solar collectors

Table 14 Comparison between the collectors analyzed for Poland

Name	Apparatus area of one collector [m^2]	Area including the number of collectors [m^2]	Efficiency calculated [%]	Obtained energy in July for Poland [kWh/ m^2]	Obtained energy per necessary area in July	Profit in July (energy price 0,20pln / kWh) [pln]	Net cost of a collector [pln]	Net cost of the whole set [pln]
Vitosol 100-F	2.33	4.66	52.6	90.4	421.3	84.3	3006	8045
Vitosol 200-F	2.33	4.66	53.5	92.0	428.7	85.7	4181	10395
Vitosol 200-T	3.46	3.46	63.8	109.7	379.6	75.9	11298	12319
Vitosol 300-T	3.19	3.19	68.1	117.1	373.5	74.7	12915	13959
EP 2.0	1.86	5.58	53.9	92.7	517.3	103.5	1818	7383
EP 2.6	2.46	4.92	57.6	99.0	487.1	97.4	2450	6955
EV 3.0	1.67	5.01	50.6	87.0	435.9	87.2	3153	11153
EV3.6	2.05	4.1	50.6	87.0	356.7	71.3	3830	9306

Table 15 Comparison between the analyzed collectors for Finland

Name	Apparatus area of one collector [m^2]	Total area [m^2]	Efficiency calculated [%]	Obtained energy in July for Finland [kWh/ m^2]	Obtained energy per necessary area in July	Profit in July (energy price 0,06 € (0,28 pln)/ kWh) [pln]	Net cost of a collector [pln]	Net cost of the whole set [pln]
Vitosol 100-F	2.33	4.66	52.6	84.6	394.2	110.4	3006	8045
Vitosol 200-F	2.33	4.66	53.5	86.1	401.2	112.3	4181	10395
Vitosol 200-T	3.46	3.46	63.8	102.6	355.0	99.4	11298	12319
Vitosol 300-T	3.19	3.19	68.1	109.6	349.6	97.9	12915	13959
EP 2.0	1.86	5.58	53.9	86.7	483.8	135.5	1818	7383
EP 2.6	2.46	4.92	57.6	92.7	456.1	127.7	2450	6955
EV 3.0	1.67	5.01	50.6	81.4	407.8	114.2	3153	11153
EV3.6	2.05	4.1	50.6	81.4	333.7	93.4	3830	9306

Table 14 and Table 15 show the comparison of all data. The meanings of the column are described below:

- the apparatus area of one collector (from tables with “Technical specifications”);
- total area - area including a number of collectors (apparatus area multiplied by a number of collectors);
- the results of calculated efficiencies of each collector;

- obtained energy in July, in Poland and in Finland (from tables with "Maximum heat output", calculated for all collectors;
- obtained energy per necessary area in July (obtained energy in July multiplied by total area of collectors);
- the profit taking into account the price for kWh of energy from gas (obtained energy per necessary area multiplied by the price of kWh in the country);
- the net costs for one collector and costs for the whole set (which has been taken from the price list of Viessmann and Immergas companies).

According to Danielewicz, where the operating efficiency range for the installations by the f-chart method was analyzed and it was set at the level of 0.25-0.30 (0.30 is assumed). The irradiance for Poland and Finland is respectively 1327.21 kWh/(m^2a) and 1032.27 kWh/(m^2a). By multiplying those data, the annual obtained energy, that would be used to heat the hot water was estimated [2]. The results of these estimations are shown in Table 16.

Table 16 Annual obtained energy in kWh/a

Name	**V 100F**	**V 200F**	**V 200T**	**V 300T**	**EP 2.0**	**EP 2.6**	**EV 3.0**	**EV 3.6**
Poland	1855.4	1855.4	1377.6	1270.1	2221.7	1959.0	1994.8	1632.5
Finland	1443.1	1443.1	1071.5	987.9	1728.0	1523.6	1551.5	1269.7

Example of SPBT for EP 2.0:

Annual profit in Poland considering the price for kWh of energy from gas:

$$2221.7\, kWh/a \cdot 0.2\, pln/kWh = 444.3\, pln/a$$

Annual profit in Finland considering the price for kWh of energy from gas:

$$1728.0\, kWh/a \cdot 0.28\, pln/kWh = 483.8\, pln/a$$

SPBT in Poland:

$$\frac{8045\ pln}{444.3\ pln/a} = 16.6\ years$$

SPBT in Finland:

$$\frac{8045\ pln}{483.8\ pln/a} = 15.3\ years$$

Table 17 Determination of the estimated payback period SPBT

Name	V 100F	V 200F	V 200T	V 300T	EP 2.0	EP 2.6	EV 3.0	EV 3.6
SPBT, Poland	21.7	28.0	44.7	55.0	16.6	17.8	28.0	28.5
SPBT, Finland	19.9	25.7	41.1	50.5	15.3	16.3	25.7	26.2

Table 17 shows SPBT (Simply Pay Back Time) capital expenditure. As can be seen, the quickest return of investment is with EP 2.0 and EP 2.6 collectors from Immergas company. Based on the data in Table 14 and Table 15, three particular collectors that are highly efficient can be selected. One of them is from the Viessmann company, this is the evacuated tube collector Vitosol 300-T, but it is a very expensive option. Another two collectors are from the Immergas company, and both are flat plate collectors. Collector EP 2.0 has a relatively low efficiency compared to EP 2.6, but the obtained energy is the highest, bacause of the total area. Therefore through analysis, the EP 2.0 Immergas collector is the most favourable option. These collectors achieve the highest results and have the biggest total area, the fourth highest efficiency, the second lowest price, and the SPBT is the shortest return period.

To evaluate the profitability of using solar collectors NPV (Net Present Value) was calculated. Table 18 and Table 19 show the results of this calculation during a 20-years period, for installations with selected Immergas EP 2.0 collectors. Cash flow which means the annual profit calculated above, is PLN 444,3 in Poland and PLN 483,8 in Finland. The estimated cost of the selected collectors set is PLN 7383 . The discount rate (i) was 3%.

Table 18 NPV determination for installations with selected Immergas EP 2.0 collectors for Poland

Year (t)	Cash flow	Discount rate 1/(1+i)^t	Discounted Cash Flow
0	-7383	1	-7383
1	444.3	0.9709	431
2	444.3	0.9426	419
3	444.3	0.9151	407
4	444.3	0.8885	395
5	444.3	0.8626	383
6	444.3	0.8375	372
7	444.3	0.8131	361
8	444.3	0.7894	351
9	444.3	0.7664	341
10	444.3	0.7441	331
11	444.3	0.7224	321
12	444.3	0.7014	312
13	444.3	0.6810	303
14	444.3	0.6611	294
15	444.3	0.6419	285
16	444.3	0.6232	277
17	444.3	0.6050	269
18	444.3	0.5874	261
19	444.3	0.5703	253
20	444.3	0.5537	246
		NPV=	-773 pln

Table 19 NPV determination for installations with selected Immergas EP 2.0 collectors for Finland

Year (t)	Cash flow	Discount rate 1/(1+i)^t	Discounted Cash Flow
0	-7383	1	-7383
1	483.8	0.9709	470
2	483.8	0.9426	456
3	483.8	0.9151	443
4	483.8	0.8885	430
5	483.8	0.8626	417
6	483.8	0.8375	405
7	483.8	0.8131	393
8	483.8	0.7894	382
9	483.8	0.7664	371
10	483.8	0.7441	360
11	483.8	0.7224	350
12	483.8	0.7014	339
13	483.8	0.6810	329
14	483.8	0.6611	320
15	483.8	0.6419	311
16	483.8	0.6232	301
17	483.8	0.6050	293
18	483.8	0.5874	284
19	483.8	0.5703	276
20	483.8	0.5537	268
		NPV=	-185 pln

The analysis does not take into account the increase in prices of energy carriers (for the calculations PLN 0,20 per kWh of energy from gas was used). But in [2] analysis of the sensitivity of the discounted energy cost to the changes in the parameters was made from which results that the annual energy cost is most sensitive to changes in the cost of fuel and electricity, then to changes in the discount rate and finally to changes in capital expenditures. Table 18 and Table 19 show that the NPV (Net Present Value) parameter reached a negative value, which proves the unprofitability of such a solution from the perspective of economic efficiency.

5 LITERATURE ANALYSIS OF THE POSSIBILITY OF USING PHOTOVOLTAIC PANELS IN SINGLE-FAMILY HOUSES

The energy efficiency of a photovoltaic system depends on many factors. One of the most important is the amount of solar radiation falling on the surface of the modules, which in turn depends on local weather conditions. Determining the solar energy potential is crucial for predicting the energy yield of a solar installation. The geographical location of the installation (longitude and latitude), along with the individual characteristics of the system, such as the azimuth orientation or the angle of inclination of the modules, determine the energy yield and the performance of the system. The most favorable is to position the modules at an angle of 35 ^{o} to the horizontal (at our latitude) and face to the south (azimuth 0 ^{o}) [1]. The following conclusion was presented in the summary of the analysis carried out in the article for single-family house [1]. The amount of electricity produced is closely related to the position of the PV modules in relation to azimuth. This is a determining factor in the efficiency of the solar system, regardless of the technology of the photovoltaic cells that build it.

During the summer, solar exposure conditions allow for higher temperature rises and minimize the need to use grid energy to heat water. In this situation, the power of photovoltaic modules could reduce annual water heating costs in the range of 300-500 PLN per year. During the summer, surplus energy could also be used to power other electrical appliances in the apartment or sold to the electric grid [17].

The foundation of an efficiently operating photovoltaic installation is to design it on the basis of a reliable determination of the energy demand of the household throughout the year [18].

The disadvantage is that the conversion of solar energy into electricity is quite low. Although laboratory cells are produced with efficiency above 40%, only 17-20% of sunlight is processed by those available on the market. Another problem is the high cost of panel production. Prices per 1 Wp of solar cells are still high, and consequently, electricity production by this method is still not competitive [19]. The price ranges from 1.8 to 5 PLN/Wp.

Referring further to [19] and [20], in silicon cells there is also the following relationship: the higher the temperature, the lower the efficiency of light conversion to electricity. This phenomenon makes the use of solar panels very difficult. When solar light falls on the surface of the battery, only a portion of the sunlight (of adequate energy) is converted into electrical current, and the other photons increase the internal energy of the cell (heating) and, therefore, a decrease in efficiency. Photovoltaic cells achieve the highest efficiency at temperatures below 25^{o}C. The temperature increase above this value causes a decrease in the conversion efficiency to an extent addicted to the type of used material. Excessive heating of PV cells installed on the roofs of buildings causes a decline in the efficiency of the panels at a level of up to 0.5% / 1^{o}C.

5.1 Analysis of a sample installation for the considered single-family building

Analysis was carried out for a single-family building with an electrical connection, therefore an on-grid system (connected to the external grid) was used to ensure greater energy independence. The electrical energy generated by the sun's radiation on the surface of the photovoltaic module would be handled directly to the inverter, where direct current is converted to alternating current. Energy is first used for the present needs of electrical appliances, while excess energy is returned to the power grid. To simplify the analysis, it was assumed that the electricity produced would be recalculated according to the electricity prices paid in the current state by the users [2].

The positioning of the photovoltaic panels was assumed to be the same as that of the solar collectors, which means that the angle of the roof in the south orientation is 30 degrees.

The Table 20 shows the data from Section 2.1.

Table 20 Monthly irradiation for Poland and Finland

Month	kWh/m^2 per month in Poland	kWh/m^2 per month in Finland
January	39.09	7.16
February	62.04	32.68
March	117.17	99.92
April	158.02	137.47
May	169.87	166.88
June	170.59	164.71
July	171.94	160.87
August	156.89	131.63
September	123.96	80.23
October	82.44	40.24
November	44.04	9.21
December	31.15	1.26
Total	1327.21	1032.27

5.2 Photovoltaic panels data

Using the profitability calculator available on the fotowoltaikaonline.pl website, the analysis was carried out. The building data and location were entered into the calculator such as roof slope from range 25-35 degrees; inclined south direction; no shading; location as it was for JRC calculator. Additionally, the calculator required the bill amount for electricity (200 PLN was assumed with this the calculator estimated the energy demand). Based on these data, the calculator itself selected three sets and divided them into different categories. The first variant is with budget components, and therefore the lowest price. The second variant has components that match quality with price. The last one is with the best components available on the market.

1. Kensol KS330MBF-60 (330W)
2. SOLARWATT Eco 120M Style (360W)
3. LG NEON R LG365Q1C-V5 (365W)

The parameters of the PV modules from the data sheets are shown in Table 21.

Table 21 Parameters of selected modules

Module parameter	**1**	**2**	**3**
Peak power [Wp]	330	360	365
Dimensions [mm]	1665x1002x35	1755x1038x40	1700x1016x40
Weight [kg]	18.6	21	17.5
Number of cells per module	60	120	60
Material	Monocrystal	Monocrystal	Monocrystal
Dimensions of the cell [mm]	158.75x158.75	166x83	162x162
Selected	14 pcs	13 pcs	13 pcs
Area [m^2]	23.36	24.34	22.45
Module efficiency [%]	19.8	19.9	21.1

Figure 20 below shows the results of the fotowoltaikaonline.pl analysis. The data presented there mainly show the installation costs.

PV panels: kensol	PV panels: SOLARWATT	PV panels: LG
Inwerter: DELTA	Inwerter: SMA	Inwerter: solaredge
Details of a sample cost estimate	**Details of a sample cost estimate**	**Details of a sample cost estimate**
Power 4,6 kWp	Power 4,7 kWp	Power 4,7 kWp
PV panels Type of PV panels Monokrystalic 14 x Kensol KS330MBF 6024 zł Product guarantee 15 years Guarantee on yield 80.2% after 25 years Estimated yield in 25 years 102 mWh Area of installation 23.36 m^2 Weight of installation 280 kg	PV panels Type of PV panels Monokrystalic 13 x SOLARWATT Eco 120M Style 8555 zł Product guarantee 15 years Guarantee on yield 81% after 25 years Estimated yield in 25 years 104 mWh Area of installation 24.34 m^2 Weight of installation 260 kg	PV panels Type of PV panels Monokrystalic 13 x LG NeON®2 365 W 15 991 zł Product guarantee 25 years Guarantee on yield 88.4% after 25 years Estimated yield in 25 years 110 mWh Area of installation 22.45 m^2 Weight of installation 241 kg
Inwerter Delta H5A Flex (5 KW) 3604 zł	Inwerter SMA Sunny Boy 4.0-1AV-40 (4.5 KW) 4589 zł	Inwerter SolarEdge SE5K (5 KW) 5386 zł Power Optimizers: 3047 zł
Other material cables, frames 2990 zł	Other material cables, frames 2873 zł	Other material cables, frames 2873 zł
Executive work Labour 5250 zł	Executive work Labour 4875 zł	Executive work Labour 4875 zł
Total 3,75 zł/Wp 17 869 zł	Total 4,69 zł/Wp 20 892 zł	Total 7,03 zł/Wp 32 172 zł
Savings	**Savings**	**Savings**
Old power bill 2400 zł	Old power bill 2400 zł	Old power bill 2400 zł
New power bill 217 zł	New power bill 217 zł	New power bill 217 zł
Savings yearly 2183 zł	Savings yearly 2183 zł	Savings yearly 2183 zł
Result	**Result**	**Result**
Refund period 17 869 zł / 2183 zł 7.6 years	Refund period 20 892 zł / 2183 zł 8.9 years	Refund period 32 172 zł / 2183 zł 13.6 years
Savings For a total of 25 years 38 026 zł	Savings For a total of 25 years 35 227 zł	Savings For a total of 25 years 24 783 zł

Figure 20 Summary of the results of the analysis

As can be seen, the quickest return period of investment is with the first set, because it is 7.6 years in comparison to the third set where it is 13.6 years (Figure 20), the return period of the investment is twice as long. However, as regards the efficiencies, the third set has the highest efficiency. The difference between these efficiencies is 1.2 %. Compared with the second set with the third one, the powers obtained from the operation of the PV are very close. According to this and the installation costs, the most favourable set is the second one with SOLARWATT PV panels, where the return period of the investment is 8.9 years and the annual power is comparable to the third set (according to calculator calculations). Also, their power of 4.7 kWp is the same.

5.3 Electricity generated from photovoltaic modules per annum

To determine the power obtained from the operation of the PV installation during the year, the following formula was used from the source [2]:

$$E = \frac{E_{sun} \cdot W_k \cdot n \cdot P_1 \cdot E_{ta}}{N_{stc}}, kWh/a$$

E_{sun} – irradiation, power of solar radiation per unit area of the pv module, kWh/m^2

W_k – correction factor

n – numer of modules

P_1 – power of the module, kW

E_{ta} – efficiency ratio - coefficient taking into account the level of losses of the pv installation (after module exit), value assumed as in the source [2], 82%

N_{stc} – intensity of STC irradiation, at which PV module tests are performed, 1 kWh/m^2

The correction factor in this calculation is not taken into consideration because the irradiation from the JRC calculator is calculated with a 30^o slope. This W_k shoud be considered only with the irradiation on horizontal plane.

Table 22 shows the results of power obtained from the operation of the PV for both countries for three sets. The assumptions in the source [2] are very similar to those in this work, and therefore the results in Table 22 are also similar.

Table 22 Power obtained from the operation of the PV

Irradiation		**1**	**2**	**3**
kWh/(m^{2}a)		kWh/a	kWh/a	kWh/a
Poland	1327.21	5028	5093	5164
Finland	1032.27	3911	3961	4016

Economic profitability was analyzed for the second set.

- Sales (export) price in Poland 0.25 PLN/kWh and in Finland 0.043 €/kWh or 0.20 PLN/kWh.
- Purchase (import) price in Poland 0.62 PLN/kWh and in Finland 0.138 €/kWh or 0.64 PLN/kWh.

For the analysis, it was assumed that the considered single-family house consumes 4000 kWh/a of electricity. For the profitability analysis and SPBT calculation for the selected set, it was assumed that in the case of Poland, where the produced PV energy (Table 22) is higher than the demand, the excess energy will be sold to the grid and 4000 kWh/a of this energy will be consumed, whereas in the case of Finland, the energy produced by PV (Table 22) is less than the demand and therefore purchase from the grid is necessary.

Poland

Excess energy sold to the grid:

$$5093\ kWh/a - 4000\ kWh/a = 1093\ kWh/a$$

$$1093\ kWh/a \cdot 0.25\ pln/kWh = 273.3\ pln/a$$

Consumed energy from PV (counting the profit if this energy would be imported from the grid):

$$4000\ kWh/a \cdot 0.62\ pln/kWh = 2480\ pln/a$$

$$SPBT_{Poland} = \frac{20892\ pln}{2480\ pln/a + 273.3\ pln/a} = \frac{20892\ pln}{2753.3\ pln/a} = 7.6\ years$$

Finland

Energy purchased from the grid:

$$4000\ kWh/a - 3961\ kWh/a = 39\ kWh/a$$

$$39\ kWh/a \cdot 0.64\ pln/kWh = 25\ pln/a$$

Consumed energy from PV (counting the profit if this energy would be imported from the grid):

$$3961\ kWh/a \cdot 0.64\ pln/kWh = 2535\ pln/a$$

$$SPBT_{Finland} = \frac{20892\ pln}{2535\ pln/a + 25\ pln/a} = \frac{20892\ pln}{2560\ pln/a} = 8.2\ years$$

To determine the NPV for Poland, the amount of the grant and tax relief of PLN 8552 was deducted from the total costs of the chosen photovoltaic set, which amounts to PLN 20892. The final cost is PLN 12340. The grant analysis is shown in section 5. According to this paragraph, the external financing of the investment in Finland is not possible. The analysis was carried out in accordance with the above calculations. Cash flow in Poland is PLN 2753.3 and in Finland it is PLN 2560.

The discount rate (i) was 3%. The analysis does not take into account the increase in energy prices.

Table 23 NPV determination for installations with selected PV panels for Poland

Year (t)	Cash flow	Discount rate 1/(1+i)^t	Discounted Cash Flow
0	-12340	1	-12340
1	2753.3	0.9709	2673
2	2753.3	0.9426	2595
3	2753.3	0.9151	2520
4	2753.3	0.8885	2446
5	2753.3	0.8626	2375
6	2753.3	0.8375	2306
7	2753.3	0.8131	2239
8	2753.3	0.7894	2173
9	2753.3	0.7664	2110
10	2753.3	0.7441	2049
11	2753.3	0.7224	1989
12	2753.3	0.7014	1931
13	2753.3	0.6810	1875
14	2753.3	0.6611	1820
15	2753.3	0.6419	1767
16	2753.3	0.6232	1716
17	2753.3	0.6050	1666
18	2753.3	0.5874	1617
19	2753.3	0.5703	1570
20	2753.3	0.5537	1524
		NPV=	28622 pln

Table 24 NPV determination for installations with selected PV panels for Finland

Year (t)	**Cash flow**	**Discount rate 1/(1+i)^t**	**Discounted Cash Flow**
0	-20892	1	-20892
1	2560	0.9709	2485
2	2560	0.9426	2413
3	2560	0.9151	2343
4	2560	0.8885	2275
5	2560	0.8626	2208
6	2560	0.8375	2144
7	2560	0.8131	2082
8	2560	0.7894	2021
9	2560	0.7664	1962
10	2560	0.7441	1905
11	2560	0.7224	1849
12	2560	0.7014	1796
13	2560	0.6810	1743
14	2560	0.6611	1692
15	2560	0.6419	1643
16	2560	0.6232	1595
17	2560	0.6050	1549
18	2560	0.5874	1504
19	2560	0.5703	1460
20	2560	0.5537	1417
		NPV=	17194 pln

Table 23 and Table 24 show that the positive NPV value proves that photovoltaic installations should be considered economically profitable.

6 PROFITABILITY ANALYSIS OF THE SELECTED SOLUTIONS TAKING INTO ACCOUNT THE POSSIBILITIES OF EXTERNAL FINANCING OF THE INVESTMENT

The analysis shows that the use of photovoltaic cells was economically sound. Therefore, the use of photovoltaics will be considered in further analysis.

In Poland there are three programs by which the external financing of the photovoltaic investment is possible. The first two can be combined together, but the third one is closed at the moment (the next edition of this program is provided). The third one was not considered for this analysis. Below are short descriptions of the programs based on which the considered building the reference was made.

The first program is "Czyste powietrze" that is clean air. The purpose of the program is to improve air quality and reduce greenhouse gas emissions through the replacement of heat sources and improving the energy efficiency of single family houses. The program consists of two parts, divided into a few options. The grant may amount to up to PLN 30 000 for the basic level of funding (first part) and PLN 37 000 for the higher level of funding (second part). Types of supported projects mainly include the dismantling of inefficient solid fuel heat sources and the purchase and installation of a new one. In those kinds of project additionally the following can be made:

- dismantling and purchase and installation of a new central heating or hot water system (including solar collectors),
- purchase and installation of a photovoltaic microinstallation.

The next type of supported project does not include the replacement of a solid fuel heat source with a new heat source. In this kind of project, the above activities cannot be carried out. However, it concerns mechanical ventilation with heat recovery and insulation. Information on the program has been obtained from www.czystepowietrze.gov.pl.

The second program is ”Ulga termomodernizacyjna” that is thermo-modernization relief. A deduction for taxpayers who own and co-own single-family homes. The relief can be combined, for example, with a grant from the "Clean Air" program. The tax relief consists in deducting from the tax base (income - in the case of a lump-sum tax) the expenses incurred for the execution of a thermomodernization project in a single-family house if the modernization works are completed within 3 years of the end of the tax year in which the first expenditure was incurred. The amount of the deduction may not exceed PLN 53 000 for all thermomodernization projects implemented and the amount of the tax refief depends on the tax rate paid by the owner, which is 17% or 32% depending on the income. Information on the program has been obtained from www.czystepowietrze.gov.pl.

The last one is the ”Mój Prad” program that is my current, but the recruitment is already closed.

In Finland, "The Ministry of Finland does not grant energy subsidies for energy conservation investments in residential buildings. [...] Energy Efficiency Agreement is for industries and municipalities. [...] The aim of these agreements is to improve the efficient use of energy within the industry, the energy sector, service sector, property and building sector, municipalities, and oil-heated real estate. [...] The Government grants energy subsidies to support the implementation of new energy-efficient technology and, case-dependently, the conventional energy efficiency investments and energy audits of the participant companies and municipalities." [21]

In view of the above, a further analysis is considered only for Poland. The grant calculator from the website www.czystepowietrze.gov.pl was used to calculate the grant amount. To calculate the amount of the subsidy, the conversion of the old heat source (coal boiler) to a new heat source, such as a condensing boiler, was adopted. Part of this project also includes a microphotovoltaic installation. A higher level of funding was assumed. This means that the average monthly income per household member does not exceed PLN 1564 in holding.

A second set was selected, the cost of which is PLN 20 892.

As a result, the possible grant from the program "Czyste powietrze" is PLN 14 000 (heat source replacement is included). However, the maximum amount of the grant for photovoltaics is PLN 5000.

With the assumed average monthly income mentioned above, the tax rate is 17%. The result is that the possible tax relief from the program ”Ulga termomodernizacyjna” is PLN 3 552.

In summary, the installation cost with regard to the grant and tax relief is

$$20892pln - (5000pln + 3552pln) = 12340pln$$

The saved amount is 58.8% of the total cost of installation.

7 COMPARISON OF PROFITABILITY OF PHOTOVOLTAIC INVESTMENT USING ELECTRICITY TO HEAT THE HOT WATER WITH THE PROSUMER VARIANT

Prosumer of renewable energy – the final customer generating electricity exclusively from renewable energy sources for his own needs in a microinstallation.

Prosumer settlement system applicable until 31 March 2022:

The prosumer benefits from the discount system 1:0.7 / 1:0.8 (settlement of accounts for the amount of energy produced); does not bear the costs of the variable distribution fee; uses the settlement of accounts system for 15 years; may account for surplus of energy for 12 months; may voluntarily decide to transfer to the net-billing system. The prosumer settlement of accounts system with the use of the discount mechanism is based on a noncash settlement of the surplus of electricity produced in the PV microinstallation and injected into the power grid and the energy consumed by the prosumer. The settlement of accounts of energy depends on the capacity of the installation and takes place in a proportion (1:0.8 in the case of prosumer microinstallation not exceeding 10 kWp, 1:0.7 in the case of prosumer microinstallation exceeding 10 kWp).

Prosumer settlement system applicable from 1 April 2022:

The prosumer will be the settlement of accounts in the net-billing system (valuable settlement for excess energy); bears the costs of the variable distribution fee; uses the settlement of net-billing system for 15 years; may account for the surplus of energy for 12 months; released from the obligation to discharge income tax PIT and VAT. The prosumer settlement of accounts system with the use of the net-billing is based on that a prosumer, who is an active market participant, will aim to feed electricity to the grid when the prices are high and to take electricity from the grid when the prices are low. [22]

In Finland there is a net-billing system by which the prosumer must enter into an agreement with the local electricity distributor. The distributor is responsible for the operation and maintenance of the distribution network in its area of operation. Distributors are regulated local monopolies, and consumers cannot switch distribution service providers. The contract with the electric company also includes purchasing additional energy and selling excess energy as needed. Most often, the price for importing electricity is significantly higher than for exporting, which adds interest in increasing energy self-consumption. Absolute self-consumption is defined as the amount of electric energy generated on site that can be directly used by the prosumer. Price for excess electricity sold is 0.043 €/kWh or 0.20 PLN/kWh. However, when electricity is purchased from the grid, taxes and distribution fees are charged, and in addition possible sales margins are charged, making the sales price significantly lower than the purchase price. Price for electricity purchased is 0.138 €/kWh or 0.64 PLN/kWh [21, 23]. Price for electricity purchased is similar to price for electricity in households without PV installation.

Referring to the current system in the case of Poland, the settlement will be analyzed with the discount system. When the prosumer takes energy from the grid, he loses at least 20% of the energy previously put into the grid under the discount balancing. In case of Finland, the cost of energy will be calculated with respect to the difference between energy taken from the grid and current consumption.

The current consumption of electricity generated by PV in a single-family house statistically reaches only 10-20%. The real discount factor (in case of Poland), taking into account the self-consumption of electricity of 20% is 84 %. The average annual electricity consumption for a 100 m^2 building for a four-person family was assumed to be 4 000 kWh/a (for both countries) based on the [24].

Energy prices were assumed as in Section 4. ”Sales (export) price in Poland 0.25 PLN/kWh and in Finland 0.043 €/kWh or 0.20 PLN/kWh. Purchase (import) price in Poland 0.62 PLN/kWh and in Finland 0.138 €/kWh or 0.64 PLN/kWh.”

Table 25 and Table 26 show the energy consumption per month for both countries. The meanings of the column are described below (calculations are shown for July in Poland):

- Irradiation per month from Table 20.
- Percentage of irradiation per month from the total irradiation.

$$\frac{171.94\ kWh/m^2}{1327.21\ kWh/m^2} = 0.1285 = 12.85\%$$

- Energy from PV from Table 22 (for chosen set of PV) including calculated percent.

$$5093\ kWh/a\ \cdot 0.1285 = 659.54\ kWh/month$$

- Energy per day in every month (depending on the number of days in a month).

$$\frac{659.54\ kWh/month}{31} = 21.82\ kWh/day$$

- Energy for DHW (daily energy demand was calculated from annual energy demand for domestic hot water [3820.45 kWh/a]).

$$\frac{3820.45\ kWh/a}{365} = 10.5\ kWh/day$$

On this basis, the months in which the photovoltaic will cover the demand for DHW (energy per day is higher than daily energy demand) are marked in blue. Then it was calculated, how much energy is needed taking into account the number of days in these months:

$$10.5\ kWh/day \cdot 31 = 325.5\ kWh/month$$

- Remainder of the energy (energy from PV per month minus energy for DHW).

$$659.54\ kWh/month - 325.5\ kWh/month = 334.04\ kWh/month$$

- The current consumption of remainder or unused energy amounts to 20% as was mentioned above. In the case of the month when the energy is used for DHW, the current consumption of electricity generated from PV is calculated from the remainder of energy. But in the case of a month when the energy is not used for DHW, the current consumption of electricity generated from PV is calculated from energy from PV per month.

$$334.04\ kWh/month \cdot 0.2 = 66.81\ kWh/month$$

- Energy sent to the grid. In the case of the month when the energy is used for DHW, the energy sent to the grid is calculated from the remainder of energy. But in the case of a month when the energy is not used for DHW, the energy sent to the grid is calculated from energy from PV per month.

$$334.04\ kWh/month - 66.81\ kWh/month = 267.23\ kWh/month$$

Table 25 Energy consumption calculations for Poland

Month	Irradiation per month	% of irradiation per month from the total 1327.21 kWh/a)	Energy from PV (5093 kWh/a) including calculated percent	Energy per day in every month	Energy for DHW	Remainder of the energy	The current consumption of remainder energy or unused	Energy send to the grid
Jan	39.09	2.95	150.24	4.85	-	-	30.05	120.19
Feb	62.04	4.67	237.84	8.20	-	-	47.57	190.27
Mar	117.17	8.83	449.71	14.51	325.5	124.21	24.84	99.37
Apr	158.02	11.91	606.58	20.22	315	291.58	58.32	233.26
May	169.87	12.8	651.90	21.03	325.5	326.40	65.28	261.12
Jun	170.59	12.85	654.45	21.82	315	339.45	67.89	271.56
Jul	171.94	12.95	659.54	21.28	325.5	334.04	66.81	267.23
Aug	156.89	11.82	601.99	19.42	325.5	276.49	55.3	221.19
Sep	123.96	9.34	475.69	15.86	315	160.69	32.14	128.55
Oct	82.44	6.21	316.28	10.20	-	-	63.26	253.02
Nov	44.04	3.32	169.09	5.64	-	-	33.82	135.27
Dec	31.15	2.35	119.69	3.86	-	-	23.94	95.75
Sum	**1327.21**	**100**	**5093**	**-**	**2247**	**1852.87**	**569.22**	**2276.78**

Table 26 Energy consumption calculations for Finland

Month	Irradiation per month	% of irradiation per month from the total 11110(1032,27kWh/a)	Energy from PV (3961 kWh/a) including calculated percent	Energy per day in every month	Energy for DHW	Remainder of the energy	The current consumption of remainder energy or unused	Energy send to the grid
Jan	7.16	0.69	27.33	0.88	-	-	5.47	21.86
Feb	32.68	3.17	125.56	4.33	-	-	25.11	100.45
Mar	99.92	9.68	383.42	12.37	325.5	57.92	11.58	46.34
Apr	137.47	13.32	527.61	17.59	315	212.61	42.52	170.09
May	166.88	16.17	640.49	20.66	325.5	314.99	63	251.99
Jun	164.71	15.96	632.18	21.07	315	317.18	63.44	253.74
Jul	160.87	15.58	617.12	19.91	325.5	291.62	58.32	233.30
Aug	131.63	12.75	505.03	16.29	325.5	179.53	35.91	143.62
Sep	80.23	7.77	307.77	10.26	-	-	61.55	246.22
Oct	40.24	3.9	154.48	4.98	-	-	30.9	123.58
Nov	9.21	0.89	35.25	1.18	-	-	7.05	28.2
Dec	1.26	0.12	4.75	0.15	-	-	0.95	3.8
Sum	**1032.27**	**100**	**3961.00**	**-**	**1932**	**1373.85**	**405.80**	**1623.19**

Table 27 shows the results of the tables above compared to Poland and Finland.

Table 27 Comparison of results from Tables 25 and 26

		Poland	Finland
Power from PV panels from Table 22 [kWh/a]		5093	3961
Annual final energy demand for the domestic hot water preparation system [kWh/a]		3820.45	
Current energy consumption [kWh/a]	(with energy use for DHW)	569.2	405.8
Energy for DHW [kWh/a]		2247	1932
Sum current energy consumption and energy for DHW [kWh/a]		2816.22	2337.80
Energy sent to the grid [kWh/a]		2276.78	1623.19
Energy taken from the grid [kWh/a]		1183.78	1662.20
Current consumption [kWh/a]	(without energy use for DHW)	1018.6	792.2
Energy sent to the grid [kWh/a]		4074.4	3168.8
Energy taken from the grid [kWh/a]		2981.4	3207.8

- Energy taken from the grid (with energy use for DHW):

Poland: $4000\ kWh/a - 2816.22\ kWh/a = 1183.78\ kWh/a$

Finland: $4000\ kWh/a - 2337.80\ kWh/a = 1662.2\ kWh/a$

- Current consumption (without energy use for DHW) is calculated below taking into account 20% of current energy consumption of electicity generated from PV:

Poland: $5093\ kWh/a \cdot 0.2 = 1018.6\ kWh/a$

Finland: $3961\ kWh/a \cdot 0.2 = 792.2\ kWh/a$

- Energy sent to the grid (without energy use for DHW):

Poland: $5093\ kWh/a - 1018.6\ kWh/a = 4074.4\ kWh/a$

Finland: $3961\ kWh/a - 792.2\ kWh/a = 3168.8\ kWh/a$

- Energy taken from the grid (without energy use for DHW):

Poland: $4000\ kWh/a - 1018.6\ kWh/a = 2981.4\ kWh/a$

Finland: $4000\ kWh/a - 792.2\ kWh/a = 3207.8\ kWh/a$

Example (with energy use for DHW):

Discount system in Polnad:

$$\text{for 1 kWh sent to the grid 0.8 kWh can be taken}$$

$$\text{for 2276.78 kWh sent to the grid 1821.42 kWh can be taken}$$

$$1183.78\ \text{kWh} - 1821.41\ \text{kWh} = -637.63\ \text{kWh}$$

Energy which can be taken from the grid having regard to discount system in Poland is bigger than energy taken from the grid, what means that in that case the surplus can be sold to the grid.

$$0.62\ \text{pln} \cdot 637.63\ \text{kWh} = 395.33\ \text{pln}$$

For Finland were calculated the cost of sent energy to the grid and the cost of energy taken from the grid:

$$1623.19\ \text{kWh} \cdot 0.2\ \text{pln/kWh} = 324.64\ \text{pln}$$

$$1662.20\ \text{kWh} \cdot 0.64\ \text{pln/kWh} = 1063.8\ \text{pln}$$

$$1063.8\ \text{pln} - 324.64\ \text{pln} = 739.16\ \text{pln}$$

As can be seen, in Poland due to discout system in this considered case, there are no costs for purchasing energy, because there is a surplus of energy that the prosumer earns on. In Finland due to net billing the annual bill for electricity using photovoltaic amounts to PLN 739.16 in Finland.

Example (without energy use for DHW):

Discount system in Poland:

$$\text{for 1 kWh sent to the grid 0.8 kWh can be taken}$$

$$\text{for 4074.4 kWh sent to the grid 3259.52 kWh can be taken}$$

$$2981.4\ \text{kWh} - 3259.52\ \text{kWh} = -278.12\ \text{kWh}$$

Energy which can be taken from the grid having regard to discount system in Poland is bigger than energy taken from the grid, what means that in that case the surplus can be sold to the grid.

$$0.62\ \text{pln} \cdot 278.12\ \text{kWh} = 172.43\ \text{pln}$$

For Finland were calculated the cost of sent energy to the grid and the cost of energy taken from the grid:

$$3168.8\ kWh \cdot 0.2\ pln/kWh = 633.76\ pln$$

$$3207.8\ kWh \cdot 0.64\ pln/kWh = 2052.99\ pln$$

$$2052.99\ pln - 633.76\ pln = 1419.23\ pln$$

Due to the net billing system in Finland the prices of difference is PLN 1419.23 in favor of the distributor. Because this is the price which has to be paid for energy.

Example (without PV):

Annual final energy demand for the domestic hot water preparation system is 3820.45 kWh/a. Without photovoltaic the cost of use that amount of energy will be:

Poland: $3820.45\ kWh/a \cdot 0.62\ pln/kWh = 2368.68\ pln/a$

Finland: $3820.45\ kWh/a \cdot 0.64\ pln/kWh = 2445.09\ pln/a$

As can be seen, in the case of Poland there is an excess of energy. So the prosumer earns on PV energy. Higher profit is with the use of the generated electricity to heat DHW. The profit with the use of the DHW heating system is PLN 395.33, but without using this system the profit is PLN 172.43. In Finland, the annual bill for electricity using photovoltaic amounts to PLN 739.16 with the use of DHW heating system, but without this, the bill amounts to PLN 1419.23. This proves that the use of generated energy from the PV panels for heating DHW has a positive effect on the final results. In comparison to the cost of energy without photovoltaic a big difference can be seen. In Poland, the annual bill for electricity is PLN 2368.68 and in Finland, it is PLN 2445.09. In the considered case for Poland, there is no bill for electricity because of excess energy, but the profit is $2368.68\ pln + 395.33\ pln = 2764.01\ pln$. In Finland profit of using PV panels is $2445.09\ pln - 739.16\ pln = 1705.93\ pln$.

8 CONCLUSIONS

The analysis was carried out for backyard installations using the most common solar energy technology solutions, namely installation with solar collectors and photovoltaic panels.

Through the analysis of solar collectors, where four solar collectors from the Viessmann company, and four solar collectors from the Immergas company were examined, the flat plate solar collector EP 2.0 from the Immergas company was chosen. This collector achieves the highest results of obtained energy in both countries its efficiency in July is 53.9 %, SPBT in comparison to the rest is the shortest, and it is 16.6 years in Poland and 15.3 years in Finland. However, the NPV parameter reached a negative value, which shows unprofitability from the perspective of economic efficiency.

Through the analysis of photovoltaic, the set with SOLARWATT PV panels were chosen, where the investment return period SPBT is 7.6 years in Poland and 8.2 years in Finland. This is due to the fact that in Poland there is the possibility of external financing with which 58.8% is saved of the total cost of installation. Additionally, the chosen set achieves higher results in Poland than in Finland because the irradiation in Poland is greater. The NPV parameter reached a positive value, so these installations should be considered economically profitable for both countries. Photovoltaics have proven to be more profitable than solar collectors in heating domestic hot water. The determining factor is a relatively short SPBT and a positive NPV value for the calculations of PV panels.

According to the analysis about the prosumer variant, where cost of using generated electricity from PV panels were calculated, the profit in Poland is PLN 395.33, because of excess of energy. In comparison with the annual bill of electricity without PV panels, that profit is PLN 2764.01. In Finland, where there is no discount system as in Poland, the profit of using PV panels is PLN 1705.93 in comparison with the annual bill of electricity without photovoltaic. This is an additional asset of photovoltaic. Thanks to this, the annual costs of energy are lower as regards annual costs without a photovoltaic system.

In Poland, there is a discount system but from 1 April 2022, the settlement of accounts system will be by the net-billing system. Thereby, it will be better to use as much of the generated energy as possible to avoid losing on selling energy to the grid due to market prices, because the selling price is lower than the buying price of power from the grid.

9 DISCUSSION

This study shows that photovoltaics is a more favorable variant for the considered single-family house. Additionally, in Poland, there is a possibility of external financing and a prosumer option in both countries. In Poland, the prosumer variant offers greater benefits due to its geographical location.

Possible limitations or disadvantages related to photovoltaics are the cost of purchasing the set, installation of the set in the wrong place, and weather conditions.

For solar collectors that were rejected as a result of the comparison, the calculated solar collector efficiencies are only theoretical, since the accurate data for the installation can be read from the measurements of the installation. Equally, the powers achieved by collectors and photovoltaics are also theoretical values. The radiation estimate from the JRC calculator may also cause errors in the results.

The results achieved, however, are close to the actual parameters that devices such as solar collectors or photovoltaic panels can achieve. Additionally, the costs and simple payback period also show the real payback time of your investment.

To avoid errors, the location of photovoltaic panels on the roof of the building must be carefully analyzed so that they achieve the highest possible efficiency. The installation of the system should be carried out by qualified specialists to prevent assembly errors or leaks. With respect to the costs of the photovoltaic set, cost reduction is possible in the case of external financing. There is also a possibility that over time there will be a breakthrough in the technology of producing photovoltaic panels, which would increase their efficiency, and it is possible that over time the price of photovoltaic panels will decrease.

The results presented in the paper clearly show that photovoltaics, despite the high investment costs, is still profitable. And the presented results are much similar to the real ones. It is an installation that allows the owner to significantly reduce the energy bills and reduce the negative impact on the environment.

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