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COMPARISON OF MEASURED AND CALCULATED ELECTRICAL ENERGY CAPTURED BY PHOTOVOLTAIC PANELS

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The main goal of the work was the measurement of photovoltaic panels on a family house in the village of Lucka in eastern Slovakia during 4 months. The panels were mounted on the south side of the building at a slope of 26 degrees. The measurement took place every day only during sunshine. Subsequently, the comparison of these actually measured values with the calculated values from the PVGIS software, which also serves to calculate photovoltaic panels. Photovoltaic panels were measured in the months of April, May, June, July in 2021. As was mentioned, the measurement took place only during sunshine, i.e. when the sun's rays hit the photovoltaic panels. From these measurement results, we will find out how much electricity we will actually produce in these months and how much the software will "produce" if we enter the same parameters for the location and type of photovoltaic panels as for a family house.

Keywords: photovoltaic panels, solar energy, electricity, family house, weather, outside temperature

Introduction

In recent years, solar energy represents one of the most important and promising renewable energy sources (Farh, 2018). Due to the rapid growth and expansion in business as well as the consistently increasing refinement of existing ways of living, the world supply energy is exposed to a huge strain. The PV system is affected because of the partial shading conditions (PSCs), which reduce the generated power (Sundararaj, 2020). Renewable energy sources not only decrease negative environmental impacts, but also reduce energy-import dependency. Consequently, different countries use various incentive systems to encourage the use of renewable energy sources for electricity. By 2050, the European Union (EU) aims to be climate-neutral, which consists of implementation of five dimensions, ranging from energy security and an integrated internal energy market to energy efficiency, climate action, and research and innovation (Grębosz-Krawczyk, 2021). Out of several available technologies, the silicon (Si)-based PV technology is the most commonly used, covering about 95 % of current PV usage (Grubišić Čabo, 2019). Over the last 5–7 years, there has been significant improvement in the material and energy utilization in the production of PV wafers, cells, and panels; therefore, updating the energy and environmental impacts of PV technologies is crucial in considering sustainable energy options and for assessing future scenarios with large penetration of PV into electric grids (Fthenakis, 2021). Photovoltaic (PV) has been widely investigated in solar cells as a sustainable energy source to replace fossil fuels (Zou, 2020). The panels can be connected in series and/or in parallel to form an array, arrays feed inverters, or inverter stages to form a PV plant. There are many ways to arrange and interconnect the panels (Orkisz, 2018). From the utility perspective, the PV system can be divided into two types, 1) stand-alone system and 2) grid feeding system (Panigrahi, 2020). Since the output voltage of a PV module is usually low (about 20–50 V), a front-end high step-up dc–dc converter is required to boost and regulate the PV voltage to the voltage level of the dc-bus (400 or 800 V) (Forouzesh, 2018). In a conventional PV system, usually, the dc-link voltage is controlled by the grid-tied inverter to a value higher than the peak voltage of the grid. Therefore, depending on the PV source and the inverter requirements, the PV voltage must be either elevated or reduced by the dc–dc converter (Zapata, 2018). Also, the rate and magnitude of PV degradation depend sensitively on cell technology and vary substantially across geographic locations (Sun, 2018). However, development of large utility-scale PV system installations is limited due to the cost and availability of land, decrease of efficiency at high operating PV cell temperature, and also potential environmental impact including biodiversity (Golroodbari, 2020). Photovoltaic (PV) solar energy generation capacity has been increasing significantly in the past decade. Its contribution to global electricity supply in 2018 was with 600 TWh almost 2.4 %, which is predicted to increase to 22 % in 2025, with potential up to 70 % (40,000 TWh) in 2050 (Golroodbari, 2020). Most of PV system revenue depends on its energy delivery, EPV. The useful energy generated by a PV system is a function of many parameters, such as: the nominal power of the PV system, the average global solar irradiance at the installation location, the PV array orientation, the environmental conditions (possible shadowing, temperature, soiling, snow, etc.) and the different system components efficiencies (i.e. PV array and inverter) (Ellabban, 2019). The PV generation costs can be calculated including the possible impacts of the new PV installations on the existing energy system and power plants (Veronese, 2021). The solar PV market continues to grow worldwide, with high variation across countries. At the end of 2015, China took a leading role in total solar power installed reaching 43.5 GW, equal to 19 % of the global world market share. Germany came in second place, with 40 GW of renewable energy connected to the grid, equal to 17.3 % of the global market share, followed by Japan with 34.3 GW, USA with 25.6 GW, and Italy with 18.6 GW. The UK had a total solar capacity of about 10 GW, France 6.5 GW, Spain 5.4 GW, Australia 5.1 GW, and India 5.1 GW (Refaat, 2017). There are a considerable number of configurations and approaches to solar-assisted heat pumps considering both solar thermal and PV technologies. It is easier to scale PV-powered heat pumps given that the systems can be installed and operated independently. It is also possible to install larger PV systems than the heating system requires, unlike solar thermal systems (Pearce, 2021). Research team (Ahmed, 2017) examined the effect of dust on hybrid photovoltaic and thermal (PV/T) systems under ambient conditions in Iraq, and the authors found that the major problem associated with solar batteries was the adverse effects of temperature and pollution on their efficiency. In the related experimental study, the authors studied the effect of dust on a PV/T collector. The results revealed that when dust was present on the outer surface of the collector, thermal efficiency decreased by 14 % (Acar, 2020). Efficiency is greatly influenced by moving clouds, dust, neighboring buildings, trees, and prevailing weather conditions. Due to these obstacles, the PV system delivers low power. The low performance of the PV system, when the irradiance falling on the PV array plane is not distributed uniformly, is called partial shading (PS) occurrence. (Motamarri, 2020). Improving the performance of the PV system by employing different techniques of cooling the panel surface was studied by several researchers (Tashtoush[1], 2019). Other works (Tashtoush[2], 2019) were focused on the improvement of the solar-driven air conditioning system.

The aim of the article is to evaluate the measured gain of solar energy from photovoltaic panels and compare them with the calculated results from the design software.

Materials and Methods

The photovoltaic panels were installed on the family house on March 20, 2021. Captured solar energy will be used to heat water. During the assembly of photovoltaic panels, the following was used: 8 pcs photovoltaic panels, 1 pc solar inventer 3,000 W, 50 m cable 6 mm, 18 pcs of panel mounts, 8 pcs supporting aluminum structure, 10 pcs of support structure holders + seal, 1 pc fuse disconnector 32 A, 2 pcs MC4 connector, slats, cable protector, screws, nuts and other material.

Fig. 1. show us regulator for photovoltaic water heating which we used, detailed description can be found under this picture.

Regulator for photovoltaic water heating OPL 9AC 3 kW: OPL 9AC is a special regulator and DC/AC inverter for photovoltaic water heating with a power of 3kW with high efficiency (up to 99 %), which does not need an external power supply for its operation. The controller has a digital display of voltage, current and status LEDs that show controller states such as running, power, error and cooling. The regulator allows you to connect common heat appliances with a resistance coil to a photovoltaic power source with DC voltage. A big advantage is the low initial costs, which guarantee the highest return on investment of all current variants of photovoltaic systems.

The measurement of the panels was recorded from 1.4.2021–31.7.2021. The object on which the photovoltaic panels are mounted is a classic family house, consisting of two above-ground floors without a basement. The family house is located in Slovakia in the village of Lucka on plot 150/2. The house has a classic gable roof with a slope of 26 degrees. Photovoltaic panels are mounted on the south side of the building due to the most favorable solar radiation during the day. Fig. 2 shows us the orientation of the building, the slope of the roof and the type of panels that were installed on the building.

Fig. 1. Regulator for photovoltaic water heating OPL 9AC 3 kW

a *b* *c*

Fig. 2. Cardinal direction of family house (a), roof slope (b), photovoltaic panel (c)

Type of photovoltaic panels that were installed on the family house: model CS3K-300P-SF, maximum power 300 Wp, no-load voltage 39.3 V, maximum voltage 32.7 V, current 9 A, efficiency 18.1 %, size 1.675×992×35 mm, weight 18.5 kg, number of panels 8 pcs, installed power 2.4 kWp.

Results and discussion

As was mentioned, we measured over 4 months in April, May, June and July in 2021. Recorded values were measured in hours of sunlight, i.e. from sunrise to sunset. The results are processed graphically, where on the X-axis we have the day of the month measured, on the Y-axis on the left side we have how much electricity we measured, and on the right side, what was the average temperature on this day.

Fig. 3 show us the course of electricity production depending on the outside temperature in the month of April.

The yellow colour shows the temperature in °C on the given day, and the blue colour shows the produced electrical energy in kWh. From the graphs, it is possible to observe that the course of the produced electricity during the month depends significantly on to the average temperatures during the day in the measured months.

In the month of April 2021, we measured 179.6 kWh of electricity produced, which is an average of 6.0 kWh per day at an average outside temperature of 5.8 °C.

In the Fig. 4 we can see the course of electricity production depending on the outside temperature in the month of May.

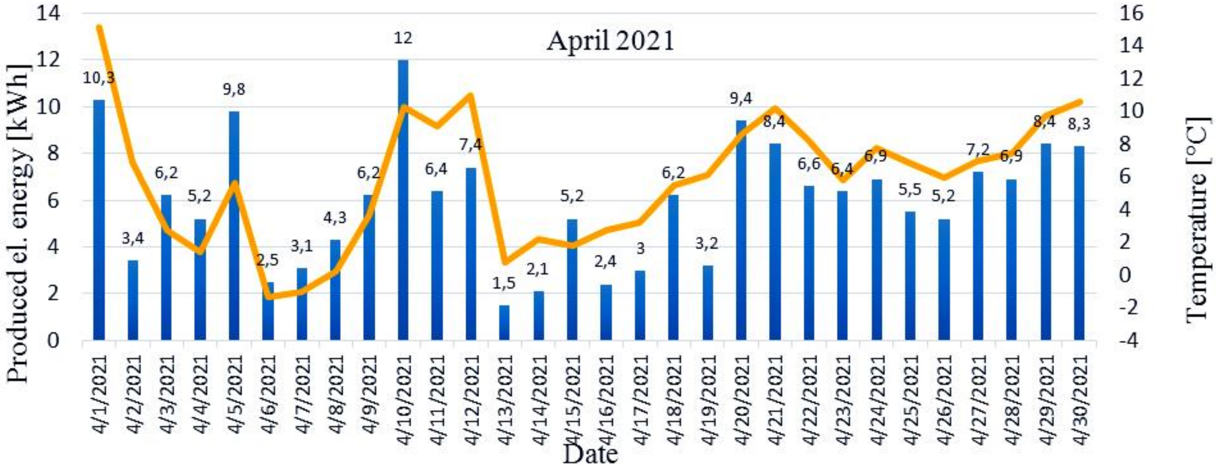

Fig. 3. Actual measured values for a family house for the month of April

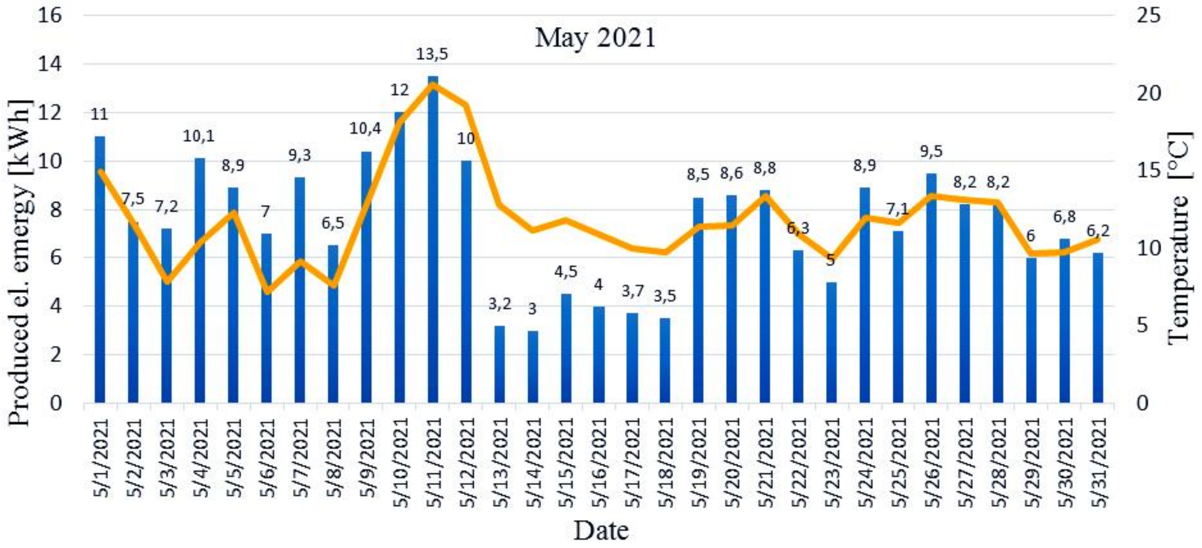

Fig. 4. Actual measured values for a family house for the month of May

In the month of May 2021, we measured 233.4 kWh of electricity produced, which is an average of 7.5 kWh per day at an average outside temperature of 11.9 °C.

In the Fig. 5 we can see the course of electricity production depending on the outside temperature in the month of June.

In the month of June 2021, we measured 305.4 kWh of electricity produced, which is an average of 10.2 kWh per day at an average outside temperature of 19.4 °C.

In the Fig. 6 we can see the course of electricity production depending on the outside temperature in the month of July.

In the month of July 2021, we measured 308.3 kWh of electricity produced, which is an average of 10.0 kWh per day at an average outside temperature of 20.7 °C.

We will compare the real measured values with the values from the PVGIS software. It is easy to use, where we search for the location of the object on which the PV panels will be mounted, then enter the type of panel, the installed power of the panels, the slope and the azimuth.

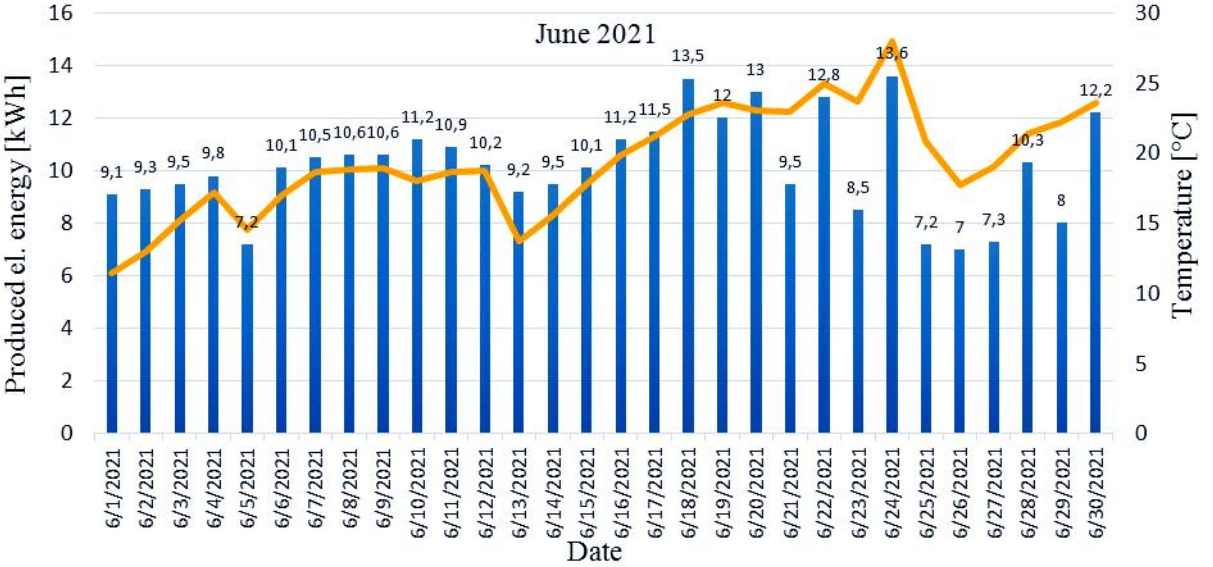

Fig. 5. Actual measured values for a family house for the month of June

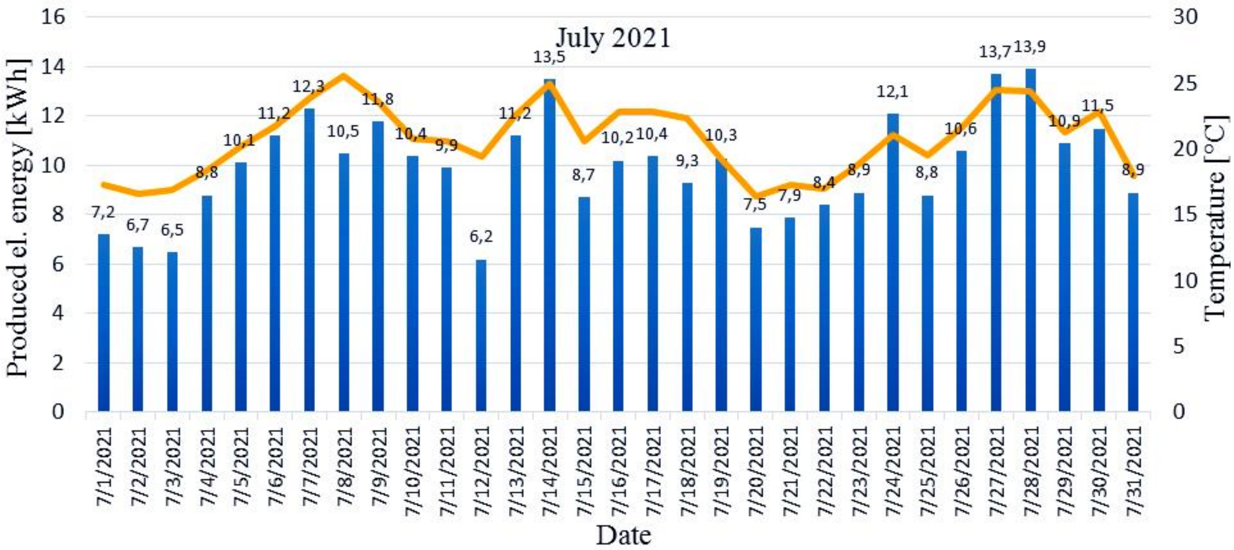

Fig. 6. Actual measured values for a family house for the month of July

In this software, we entered the same type of PV panels, number, installed power, slope and azimuth as on the measured family house in the village of Lucka.

Table 1 shows the calculated values from the PVIGS software. In the Table 1 we can see the average produced electrical energy depending on the outside air temperature in individual hours during the whole month.

The performance of photovoltaic panels was measured only during daylight hours, i.e. only during the time when sunlight can still fall on the surface of the panels (estimated time 6:00 a.m. – 7:00 p.m. for the month of April). From the measurement results, we can see that the photovoltaic panels (13 m²) produced an average of 6.0 kWh of electricity per day during the month of April 2021 at an average outdoor air temperature of 5.8 °C. In the month of April, they produced 179.6 kWh of electricity. Compared to the PVGIS software, which gives the results from 2019 for the given location, we can state that according to this software, the photovoltaic panels produced an average of 4.9 kWh of electricity per day with the same installed input, slope (26°) and azimuth (180°/ 0°) at an average outside air temperature of 10.6 °C.

According to the software, we estimate the total result of the produced electricity for the month of April 2019 at 148.0 kWh of electricity. From the results of real measurements and calculations thanks to the software, we can determine the coefficient of electrical energy in the ratio of the actual (measured) produced energy of the photovoltaic panels and the calculated (software) energy.

$$C = \frac{E_m}{E_c} . \tag{1}$$

Where: C – is coefficient of electrical energy, E_m is electrical energy [kWh] measured from the family house and E_c is electrical energy [kWh] calculated by PVGIS software.

In Table 2 we can see a comparison of the value of measured electrical energy and calculated electrical energy, where we see how much more electrical energy we would actually produce for a family home.

Table 1

Calculation results from PVGIS software.
(P.E.E.: Produced electric energy [kWh]; Temp.: Outdoor air temperature [°C])

Month	April 2021		May 2021		June 2021		July 2021	
Time [h]	P.E.E. [kWh]	Temp. [°C]	P.E.E. [kWh]	Temp. [°C]	P.E.E. [kWh]	Temp. [°C]	P.E.E. [kWh]	Temp. [°C]
6:00	2.8	4.8	4.9	7.2	5.8	13.6	5.9	15.0
7:00	4.7	5.9	7.6	9.1	7.9	15.1	8.2	16.7
8:00	6.6	7.0	10.0	12.1	10.2	16.2	10.3	17.9
9:00	7.8	8.6	11.6	13.2	11.8	17.1	11.9	18.9
10:00	7.9	10.1	12.6	14.1	12.9	18.0	13.2	20.0
11:00	7.9	11.6	12.7	14.7	13.3	18.6	13.5	20.4
12:00	8.0	12.3	12.9	15.2	13.9	19.1	14.2	20.9
13:00	7.4	12.9	10.5	15.6	11.5	19.3	12.5	21.2
14:00	6.1	13.6	8.2	15.6	10.0	19.4	11.5	21.3
15:00	4.8	13.4	5.5	15.5	7.3	19.3	8.7	21.2
16:00	3.2	13.2	3.3	15.1	5.4	18.9	7.2	20.9
17:00	1.5	13.0	1.8	14.6	4.2	18.5	5.1	20.4
18:00	0.3	11.5	1.0	13.8	2.2	17.8	3.1	19.6
19:00	0.1	10.1	0.5	11.3	1.3	16.9	1.5	18.6
20:00	–	–	0.1	9.9	1.0	15.8	0.6	17.6
21:00	–	–	–	–	0.0	14.8	0.0	16.7
∑ Per month	148.0		213.2		222.5		246.8	
Average per day	4.9	10.6	6.9	13.1	7.4	17.4	8.0	19.2

Table 2

Measured and calculated data

Month	El. energy measured from the family house [kWh]	El. energy calculated by PVGIS software [kWh]	Coefficient of electrical energy [-]
April	179.6	148.0	1.2
May	233.4	213.1	1.1
June	305.4	222.5	1.37
July	308.3	246.8	1.25

From the data, we found that we actually produced 20 % more energy than the PVGIS software indicates, but we have to take into account the difference in average outdoor temperatures per month in different years and the possibility of clouds that shade energy sources.

From the measurement results in May 2021, we produced an average of 7.5 kWh of electricity per day at an average outdoor air temperature of 11.9 °C. In the month of May, they produced 233.4 kWh of electricity. According to the PVGIS software, PV panels would produce an average of 6.9 kWh of electricity per day at an average outside air temperature of 13.1°C. According to the software, we estimate the total result of the produced electricity for the month of May 2019 at 213.1 kWh of electricity.

The results in June 2021 showed the production of electricity of energy per day, 10.2 kWh of electricity at an average outdoor air temperature of 19.4°C. In the month of June, they produced 305.4 kWh of electricity. The results of the PVGIS software showed that on average we produce 7.4kWh of electricity per day at an average outside air temperature of 17.4°C. According to the software, we estimate the total result of the produced electricity for the month of June 2019 at 222.5 kWh of electricity.

The last measurement in the month of July 2021 showed the production of el. energy per day 10 kWh of electricity at an average outside air temperature of 20.7 °C. In the month of July, they produced 308.3 kWh of electricity. The PVGIS software showed that on average we produce 8.0 kWh of electricity per day at an average outside air temperature of 19.2 °C. The total result of the produced electricity for the month of July 2019 according to the software is 246.5 kWh of electricity.

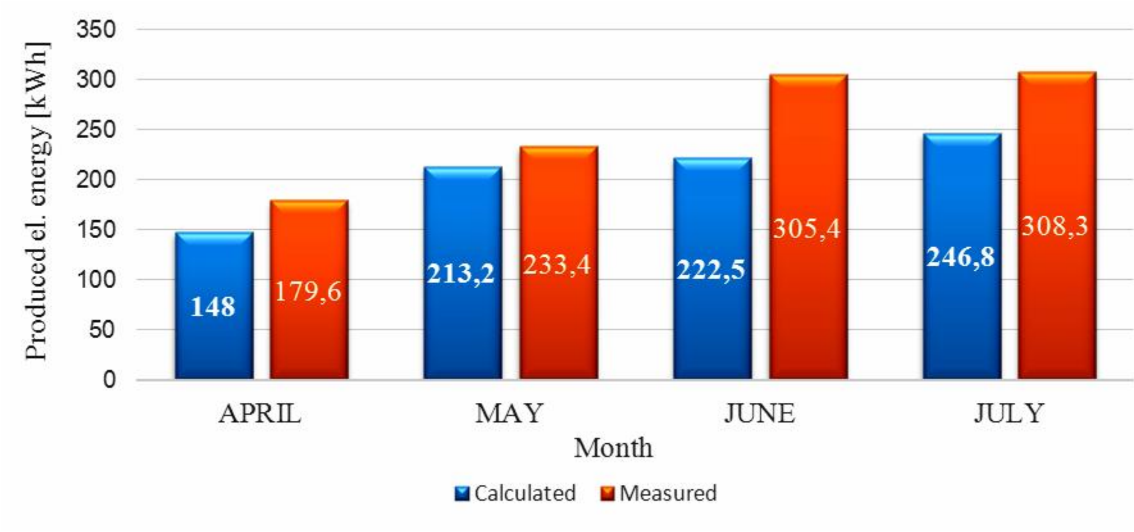

Fig. 7. Comparison of measured and calculated electrical energy

From the graph (Fig.7), we can see how much electricity we actually produced and how much the software calculated for us. We can see that in April we produced 20 % more electricity than the software showed us. In May it is 10 %, in June we produced up to 37 % more and in July 25 %.

Conclusions

From the measurement results, we can see how much electricity the photovoltaic panels on the family house actually produced for us compared to the PVGIS software. The difference between the measured and calculated value of electric energy produced with the help of photovoltaics can be caused by the deviation of the measurement time, i.e. year 2021 and from records indicating software from 2019. When designing PV systems, it is therefore necessary to take into account a possible deviation of approx. 10–40 %.

Prospects for further research

The measurement will continue the photovoltaic panels for several years for the most detailed comparison of the results of the produced electricity with the PVGIS software. In the future, these results could make it easier for us to choose a specific type of panels, and at the same time, we would be able to more accurately determine the amount of electricity produced.

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ПОРІВНЯННЯ ВИМІРЯНОЇ ТА РОЗРАХУНКОВОЇ ЕЛЕКТРИЧНОЇ ЕНЕРГІЇ, ВИРОБЛЕНОЇ ФОТОГРАФІЧНИМИ ПАНЕЛЯМИ

Основною метою цієї статті є опис досліджень роботи фотоелектричних панелей протягом 4 місяців, що були встановлені у сімейному будинку в селі Лучка в східній Словаччині. Панелі було змонтовано з південного боку будівлі під ухилом 26 градусів. Згодом було здійснено порівняння цих фактично виміряних значень з обчисленими значеннями за допомогою програмного забезпечення PVGIS, яке також використовується для розрахунку фотоелектричних панелей. Оскільки це програмне забезпечення працює з даними з 2019 року, цим ми можемо пояснити відхилення даних попередніх років. Вимірювання фотоелектричних панелей проводилось у квітні, травні, червні та липні 2021 року. Вимірювання відбувалося лише під час активності сонячного проміння, тобто коли сонячні промені падали на фотоелектричні панелі, тому з цих результатів вимірювань можна дізнатися, скільки електроенергії можна фактично виробити за ці місяці та скільки «виробить» програмне забезпечення, якщо ми введемо ті самі параметри для розташування та тип фотоелектричних панелей, що й для сімейного будинку. У майбутньому планується продовжувати вимірювати кількість виробленої електроенергії за допомогою цих фотоелектричних панелей для подальших досліджень. Ці вимірювання можуть бути дуже корисними, оскільки завдяки цим результатам ми зможемо точніше визначити, скільки електроенергії вироблятимуть для нас фотоелектричні панелі, або допомогти у виборі правильних фотоелектричних панелей. Вимірювання заплановано на 2022, 2023, 2024, 2025 роки. Буде порівняно кінцеві результати з програмним забезпеченням PVGIS і буде вказано на відхилення виміряних і розрахункових значень від отриманих даних. У 2024 році на цьому сімейному будинку планується збільшити кількість фотоелектричних панелей до 16 штук. У зв'язку зі збільшенням кількості фотоелектричних панелей різні значення порівнюватимуться з програмним забезпеченням PVGIS, але за тією самою процедурою.

Ключові слова: фотоелектричні панелі, сонячна енергія, електроенергія, сімейний будинок, погода, зовнішня температура.