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A Planning Study Of Off-Grid Based Rooftop Solar Power Generation System (PLTS) On Residential Houses Using PVSyst

Mazmur Irawan Ginting[1], Dino Erivianto[2], Erpandi Dalimunthe[3]
[1,2,3]Universitas Pembangunan Panca Budi, Medan, North Sumatera, Indonesia

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ABSTRACT
Solar energy is a renewable energy source that is abundant, environmentally friendly, and has great potential to be utilized, especially in tropical areas such as Indonesia. This research aims to design and analyze an off-grid rooftop solar power generation system (PLTS) for residential houses in Medan City using PVSyst software. The research location is at the coordinates of Latitude 3.5951°N and Longitude 98.6722°E, with the tilt angle of the solar panel adjusted at 30° (following the slope of the roof of the house) and the facing direction to the south with an azimuth angle of 180°. The PV modules used are monocrystalline silicon type (STP 250S-20/Wd+) with a total capacity of 3 kWp. The system is designed to meet a daily energy demand of 7.1 kWh/day and an annual demand of 2,598 kWh. The system configuration includes 12 PV modules, a battery with a capacity of 800 Ah (24 V), and an inverter to support standalone operation for 2.2 days without energy input from the solar panels. Simulation results show that the system generates an average energy of 9.1 kWh/day, with a Performance Ratio (PR) of 0.544 (54.4%). The main losses include losses in the PV Array (0.75 kWh/kWp/day), losses in the solar system (0.22 kWh/kWp/day), and unused energy of 1.01 kWh/kWp/day. Solar Fraction reached 99.7%, with Missing Energy of 6.972 kWh due to weather variations. This research shows that off-grid rooftop solar PV can be an effective solution to meet residential energy needs, reduce carbon emissions, and support the transition to a cleaner and more sustainable energy system.

Corresponding Author:
Mazmur Irawan Ginting
Universitas Pembangunan Panca Budi, Medan, North Sumatera, Indonesia
gura_itingx@yahoo.co.id

INTRODUCTION

Planning an off-grid rooftop solar power plant (PLTS) system for residential houses is a strategic step in utilizing abundant renewable energy sources, especially in tropical countries such as Indonesia. Solar power plants utilize sunlight radiation that is converted into electrical energy through solar panels, which are the main component in this system (Karsun et al., 2023). With the increasing demand for electrical energy and awareness of the importance of environmental sustainability, the application of off-grid solar power plants is becoming increasingly relevant, especially in areas that have not been reached by the PLN electricity grid (Ariyani et al., 2021).

Off-grid solar systems function autonomously, are not connected to the main power grid, and are usually equipped with batteries to store the generated energy. This allows users to still get electricity supply even in bad weather conditions or at night (Apriani et al., 2023). In a residential context, these systems can be designed to meet the daily energy needs of households, taking into account factors such as energy consumption, solar panel capacity, and required battery size (Tarigan, 2022).

The importance of careful planning in rooftop solar PV installations cannot be overlooked. The use of software such as PVSyst allows planners to perform in-depth simulations and analysis of the potential energy that can be generated, as well as the overall system efficiency (Dani & Erivianto, 2022; Sari & Murdianto, 2023). PVSyst also helps in determining the right components and predicting the performance of the system under various weather conditions, so that planning can be tailored to the specific needs of the user (Irfani et al., 2021).

In a study conducted by Mubarok et al., it was explained that climate change can affect the efficiency of energy production from solar power plants. Therefore, analyzing the impact of climate change is very important in planning solar power systems (Mubarok et al., 2022). In addition, choosing the right location for solar panel installation also has a significant effect on system performance. Research in various regions shows that the high intensity of solar radiation, such as in Indonesia, can be optimally utilized to produce electrical energy (Megawati et al., 2021).

Economic aspects are also an important consideration in planning solar power plants. Research by Hidayat (Hidayat et al., 2019)et al. shows that analysis of investment costs and cash flow during the investment period of PLTS is very important to ensure project feasibility . By considering initial costs, operational costs, and potential electricity cost savings, good planning can result in a favorable investment decision for homeowners (Hadianto et al., 2023).

Off-grid rooftop solar systems can also contribute to reducing carbon emissions and dependence on fossil energy sources (Ahmad Dani & Dino Erivianto, 2024). By utilizing renewable energy, homes can reduce their carbon footprint and contribute to global efforts to mitigate climate change (Tarigan, 2022). In addition, the use of solar power plants can provide energy security for households, especially in areas that experience frequent power outages (Firaldi et al., 2023).

In their implementation, off-grid solar systems are often equipped with additional components such as inverters and charge controllers to optimize the use of the generated energy (Tri Yoga et al., 2022). The use of new technologies, such as supercapacitors, is also being introduced to improve system efficiency and extend battery life (Taneza et al., 2024). Thus, careful planning and the use of appropriate technologies can improve the performance and reliability of rooftop solar systems

In the policy context, the Indonesian government has set a renewable energy mix target of 23% by 2025 in accordance with Presidential Regulation No. 22/2017. The implementation of rooftop solar PV, especially in off-grid systems, is expected to contribute significantly to achieving this target. Medan City, with its large energy potential, has the

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opportunity to become one of the pioneers in the implementation of solar energy at the household level (Dani & Erivianto, 2022).

This research aims to design an optimal off-grid rooftop solar PV system for residential houses by taking the coordinates of Medan City using PVSyst software. The results of this research are expected to contribute in encouraging the adoption of renewable energy at the local level, increasing household energy independence, and supporting the national energy transition towards a cleaner, sustainable, and environmentally friendly energy system.

METHODS

This research design adopts a quantitative approach using a simulation method to analyze an off-grid type of solar power generation (PLTS) system applied to residential houses. The purpose of this research is to design and optimize an off-grid PLTS system using PVSyst software. PVSyst is used to study, measure, and analyze data related to solar radiation and the potential for electrical energy generation from solar panels under Stand Alone/Off Grid PV System conditions. The software covers several systems, such as grid-connected systems, stand-alone systems, pumping systems, and direct current networks for public transportation (DC-grid).

PVsyst is software specifically designed for design and simulation. Its aim is to provide an easy-to-use method of developing solar energy related projects. PVsyst is equipped with a large database containing meteorological data from various locations around the world. In addition, the software also allows users to manually add measured data at locations not yet listed in the database. Solar PV system design can vary depending on the location, this is due to the different amount of solar radiation received at each place. The steps taken in this approach include:

1. Determine the research location point that will be used as solar radiation data collection.
2. Initial data collection includes household energy consumption data as input to design the solar PV system, local solar radiation data, temperature to simulate the potential energy production from solar panels.
3. Determining the tilt plane of the solar panel used by adjusting the installation angle according to the roof of the residence
4. The system design includes the selection of solar panel capacity, energy storage battery capacity, and inverter according to the household's energy needs.
5. Simulation Using PVSyst to analyze system performance under various conditions, such as variations in solar radiation, energy consumption patterns.

The location point of the solar radiation data collection carried out for this research is Medan City with North Latitude 3.5951 and 98.6722 East Longitude. With the sun path as shown in Figure 1.

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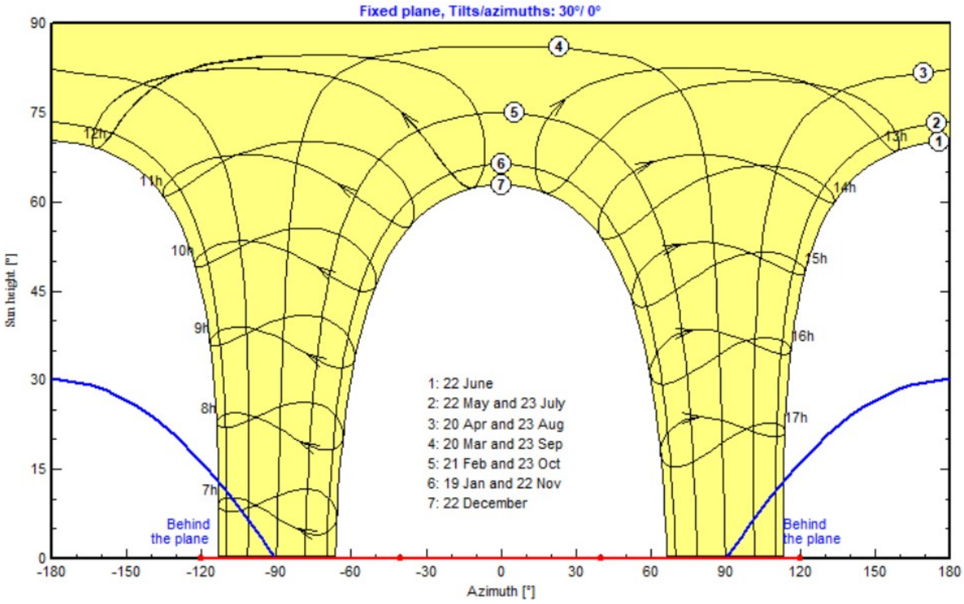

Figure 1. Sun Path at Medan City location

The tilt angle of a solar panel is defined as the angle at which the solar panel is installed to optimally face the sun. Since the position of the sun changes daily along with the rotation of the earth, it is necessary to adjust the installation angle of the solar panel. In general, the tilt angle of the solar panel is taken parallel to the latitude. The optimal value of this tilt angle is required to receive the maximum amount of solar radiation by the panels. Using PVSyst, it is found that the optimal tilt angle parallel to the latitude (Inclination/Tilt Angle), and the azimuth angle, which determines the direction of the sun.

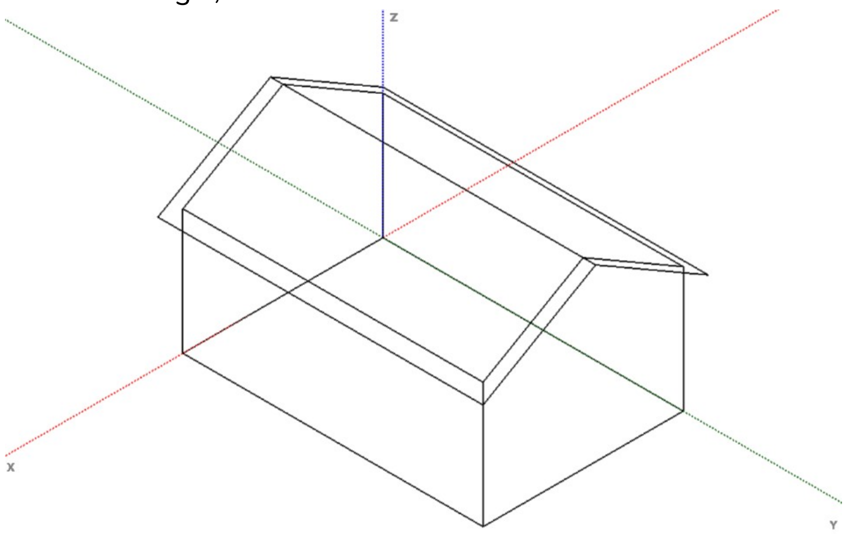

Figure 2.Model of a residential house with its roof slope shape

In the residential model used, the roof tilt angle is 30°. Therefore, it is necessary to adjust the tilt angle of the solar panel to the tilt angle of the roof of the house as shown in Figure 2. In this case, if the tilt angle of the roof is 30°, the solar panel will be installed with a

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tilt angle of 30°, following the slope of the roof. The optimal tilt angle may vary depending on the geographical location and local environmental conditions. Therefore, it is important to conduct a comprehensive analysis using software such as PVSyst to ensure that the selected tilt angle provides the best performance for the PV system. Even if the roof tilt angle is 30°, it may still be necessary to adjust the tilt angle of the solar panels to achieve maximum efficiency. However, in practice, solar panels are often installed following the slope of the roof for ease of installation and aesthetics. Therefore, in this study, the tilt angle of the solar panels is set according to the slope angle of the house roof, which is 30°, and the facing direction of solar panels is set to face south with an azimuth angle of 180°

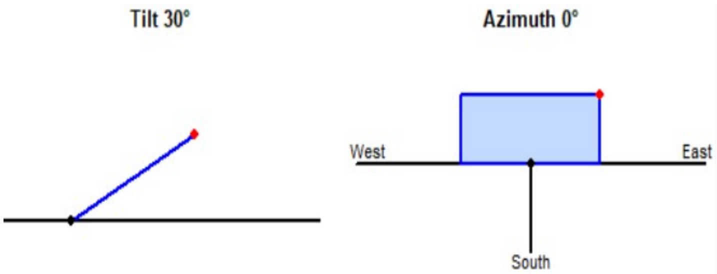

Figure 3. Solar panel tilt angle

In this study, the photovoltaic (PV) module used for simulation is a monocrystalline silicon-type solar cell module, specifically the STP 250S-20/Wd+ model, taken from the PVSyst database. The detailed specifications of this module are presented in Table 1.

Table 1. PV Module Specifications

PV module - STP 250S-20/Wd+	
Manufacturer	Suntech
Model	STP 250S-20/Wd+
Pnom STC power (manufacturer)	250Wp
Module size (W x L)	0.992 x 1.665m²
Number of cells	1 x 60
Specifications for the model	
Reference temperature (TRef)	25°C
Open circuit voltage (Voc)	37.4 V
Max. power point voltage (Vmpp)	30.7 V
=> maximum power (Pmpp)	250 W
Reference irradiance (GRef)	1000 W/m²
Short-circuit current (Isc)	8.63 A
Max. power point current (Impp)	8.15 A
Isc temperature coefficient (mulsc)	4.2 mA/°C
Model results for standard conditions	
Max. power point voltage (Vmpp)	30.7 V
Maximum power (Pmpp)	250Wp
Efficiency(/ Module area) (Eff_mod)	15.1 %

Efficiency(/Cells area) (Eff_cells)	16.6 %
Max. power point current (Impp)	8.17 A
Power temper. coefficient (muPmpp)	-0.45 %/°C
Fill factor (FF)	0.775

Solar radiation variability refers to fluctuations in the amount of solar energy received at a location over time. Factors that influence this variation include the Earth's tilt and orbit, seasonal changes, daily patterns, and geographical position. Data on solar radiation variation is useful for solar energy system optimization, monitoring solar energy production, and understanding the impact of solar radiation on the environment.

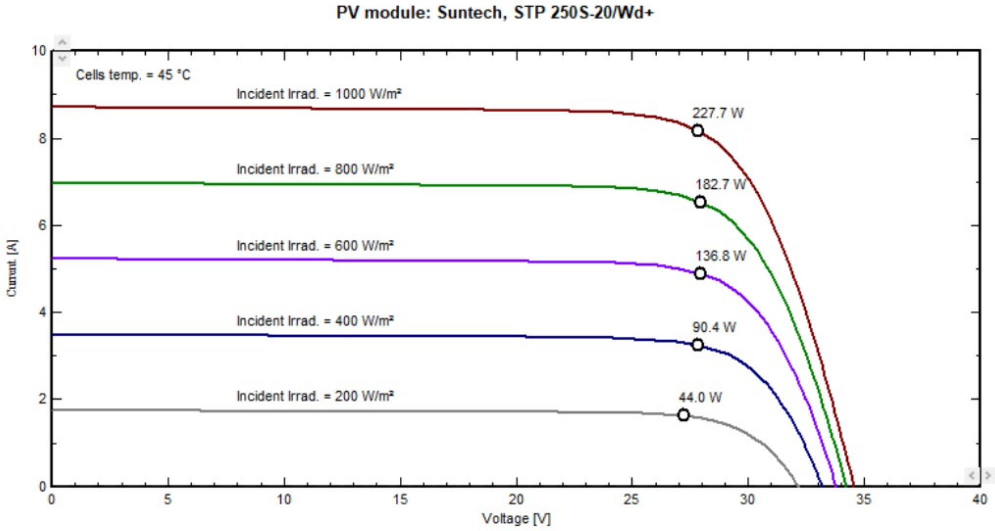

Figure 4. Characteristic Si-mono Effect of STP 250S-20/Wd+

RESULTS AND DISCUSSION

Household electricity load in daily life is used as usage data and can be calculated as load demand per day. The graph below shows the demand from the electricity load in each hour for one full day with a total demand of 7.1 kWh/day.

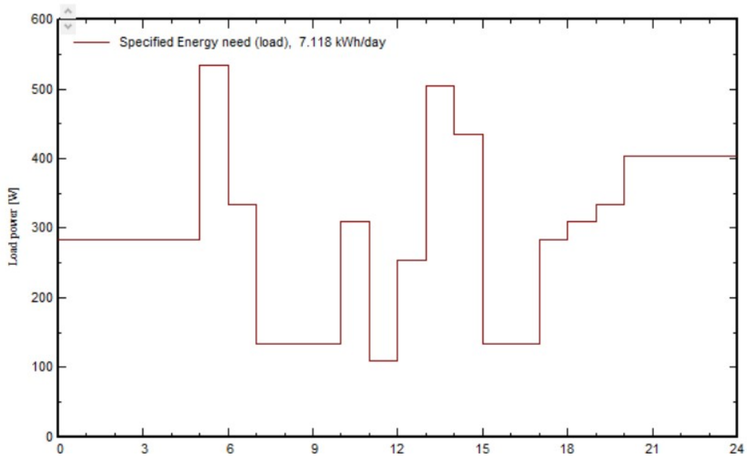

Figure 5. Daily load data graph

From Figure 6 of the monthly graph, it can be seen that the need for electrical energy supply to be sufficient in one year is 2598 kWh. This is the value of electrical energy that must be supplied using solar cells for one full year to meet the needs of the installed electrical load.

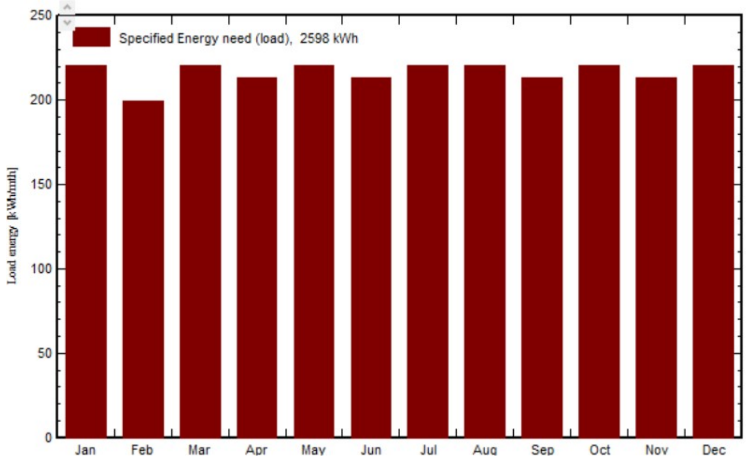

Figure 6. Monthly load data graph

Solar radiation and temperature data using the database from PVsyst Meteonorm 8.0 with locations taken in Medan City area (Latitude 3.5951°N, Longitude 98.6722°E). The results of solar radiation and temperature for one year with a change variation factor of 4.9% are shown in the table below

In the design of PLTS for use with the amount of energy of 7.1 kWh and 297 W of average power used in a day. The batteries used amounted to 8 batteries connected in parallel and 2 in series, with a total voltage of 24 V with a total capacity of 800 Ah. This battery capacity is able to support 2.2 days of time that the system can operate without energy input from solar panels. For the PV Array configuration using 6 strings, each consisting of 2 PV modules, with 3.00 kWp (kiloWatt peak) maximum power that can be generated under standard conditions. With this capacity, it is able to produce 9.1 kWh of energy on an average day.

Table 2. Radiation and temperature data

MONTHS	Irradian (Kwh/m^2/mth)	Temperature (°C)
January	149.0	26.8
Februar	147.7	27.2
March	160.0	27.7
April	157.0	27.5
May	145.5	27.9
June	145.0	27.6
July	154.7	27.6
August	148.9	27.4
September	144.1	26.6

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MONTHS	Irradian (Kwh/m^2/mth)	Temperature (^0C)
October	127.0	26.8
November	129.0	26.5
December	117.5	26.7
Annual	1725.6	27.2

PV Array Characteristics

PV module

Manufacturer	Suntech
Model	STP 250S-20/Wd+
(Original PVsyst database)	
Unit Nom. Power	250 Wp
Number of PV modules	12 units
Nominal (STC)	3000 Wp
Modules	6 string x 2 In series
At operating cond. (50°C)	
Pmpp	2663 Wp
U mpp	54 V
I mpp	49 A

Controller

Universal controller	
Technology	MPPT converter
Temp coeff.	-5.0 mV/°C/Elem.
Converter	
Maxi and EURO efficiencies	97.0 / 95.0 %

Total PV power

Nominal (STC)	3.00 kWp
Total	12 modules
Module area	19.8 m²
Cell area	17.1 m²

Battery

Manufacturer	Generic
Model	Open 12V / 100 Ah
Technology	Lead-acid, vented, plates
Nb. of units	8 in parallel x 2 in series
Discharging min. SOC	20.0 %
Stored energy	15.4 kWh
Battery Pack Characteristics	
Voltage	24 V
Nominal Capacity	800 Ah (C10)
Temperature	Fixed 20 °C

Battery Management control

Threshold commands as	SOC calculation
Charging	SOC = 0.92 / 0.75
approx.	27.1 / 24.8 V
Discharging	SOC = 0.20 / 0.45
approx.	23.3 / 24.1 V

Figure 7. PV Array Characteristics

In this section, the simulation results of the Solar Panel System are analyzed by exploring various key parameters such as system output power, system losses, and performance ratio (PR). The simulation was conducted using PVsyst software to design a Rooftop Solar Panel System. The system includes 12 solar panels with a capacity of 250 Wp each, a total area of 19.8 m², as well as 800 Ah capacity batteries connected in series and parallel. Figure 7 illustrates the simulation parameters and overall characteristics of all system components used.

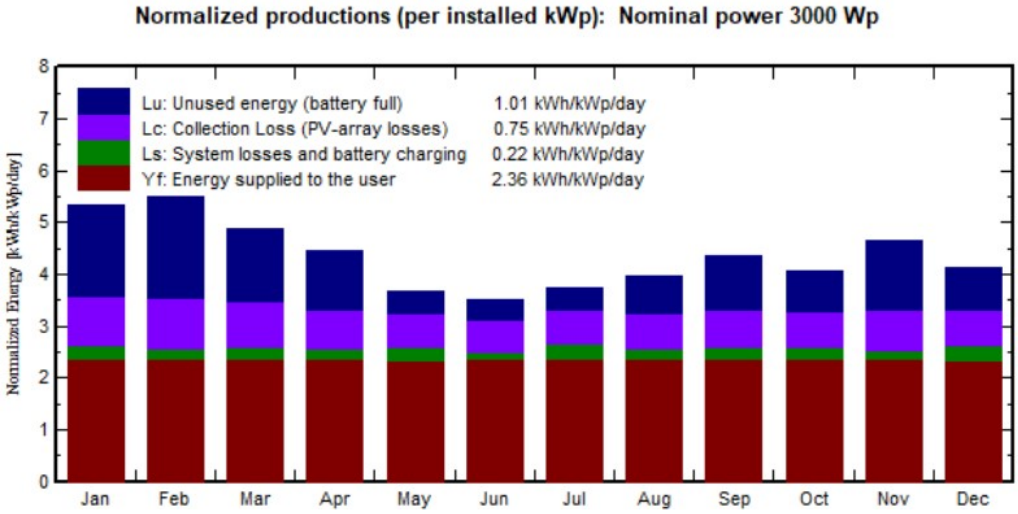

Figure 8. Energy Yield of the Solar Panel System

The performance of the Rooftop Solar Panel System is presented in Figures 8, 9, and 10. Figure 8 shows the parameters that illustrate the performance results of the Solar Panel System, so it can be seen that:

a. Lu: Unused energy of 1.01 kWh/kWp/day
b. Lc: Loss on PV Array of 0.75 kWh/kWp/day
c. Ls: Loss in the solar system of 0.22 kWh/kWp/day
d. Yf: Energy supplied to users at 2.36 kWh/kWp/day

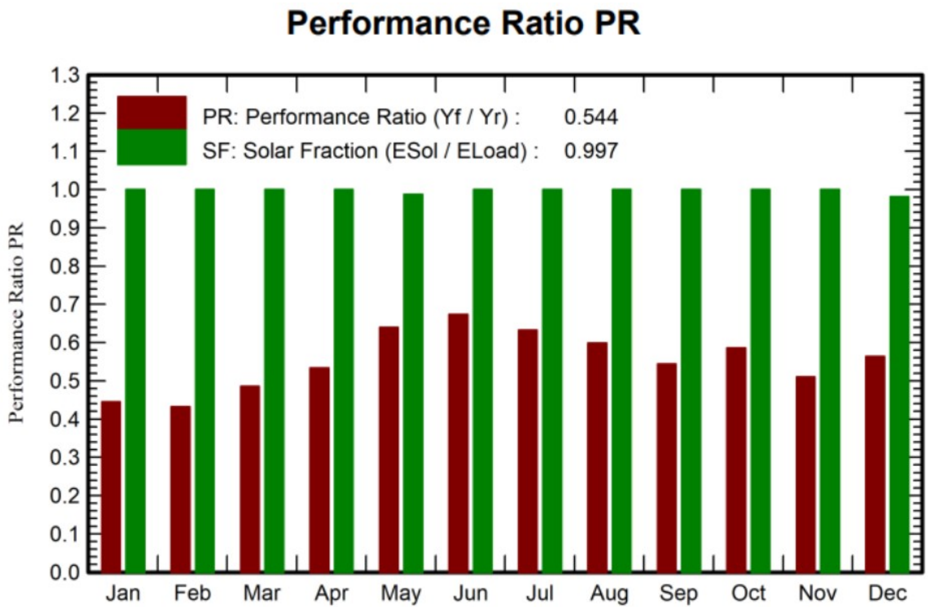

Figure 9. Performance Ratio and Solar Fraction

Performance Ratio (PR) is a way to measure how efficiently a solar power plant works. This PR is calculated by comparing the electrical energy actually generated by the system with the maximum energy that could have been generated if the solar panels worked ideally, that is, when all the sunlight received is fully converted into electrical energy according to the system capacity. From the simulation results, Figure 9 shows that the PR value for this solar power plant is 0.544. This means that the system is able to work around 54.4% of its maximum potential. This value gives an idea of how well the system performs under real conditions, including the influence of factors such as weather, temperature, and other technical losses.

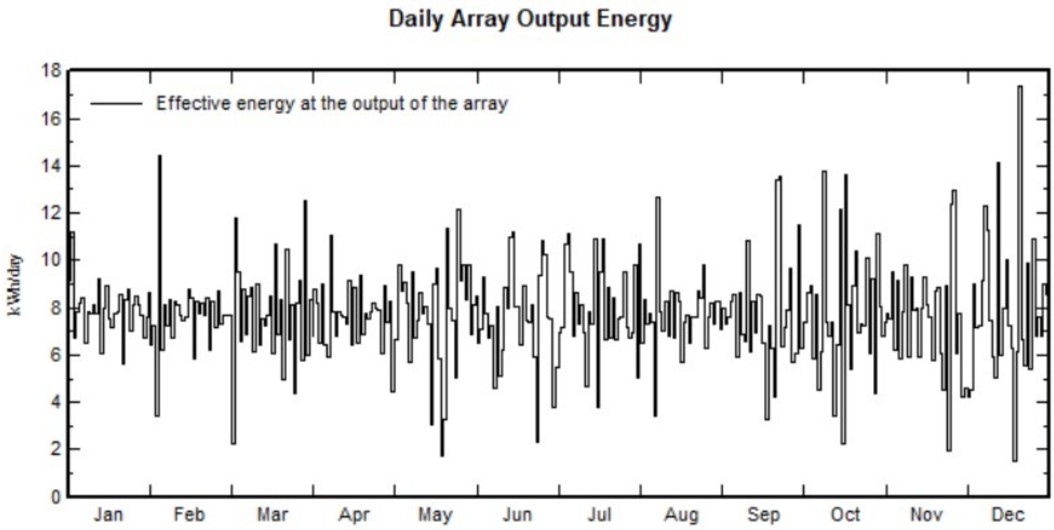

Figure 10. Daily Energy Output of Solar Panels

Figure 10 presents the daily output of energy generated by the Solar Panels. The graph illustrates the fluctuations in energy generated due to changes in weather conditions that occur throughout the month, affecting the kWh/day value generated by the Solar Panels.

Table 3. Solar Panel Power Output Results for Each Month for One Year

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail kWh	EUnused kWh	E_Miss kWh	E_User kWh	E_Load kWh	SolFrac ratio
January	149.0	161.8	398.7	162.9	0.000	220.7	220.7	1.000
February	147.7	149.9	371.0	163.8	0.000	199.3	199.3	1.000
March	160.0	147.1	361.7	133.8	0.000	220.7	220.7	1.000
April	157.0	128.4	320.9	100.6	0.000	213.5	213.5	1.000
May	145.5	108.1	269.3	40.6	2.825	217.8	220.7	0.987
June	145.0	100.0	250.3	36.2	0.000	213.5	213.5	1.000
July	154.7	110.4	276.9	41.7	0.000	220.7	220.7	1.000
August	148.9	117.8	295.7	68.2	0.000	220.7	220.7	1.000
September	144.1	126.4	314.7	93.3	0.000	213.5	213.5	1.000
October	127.0	122.1	301.2	72.4	0.000	220.7	220.7	1.000
November	129.0	136.0	336.4	120.5	0.000	213.5	213.5	1.000
December	117.5	125.0	308.6	76.8	4.147	216.5	220.7	0.981
Year	1725.6	1533.0	3805.3	110.0	6.972	2591.2	2591.2	0.997

CONCLUSIONS

This research shows that off-grid rooftop solar PV can be an effective alternative to meet household energy needs in Medan City. The use of Pvsyst Software makes it possible to design the system and predict the electrical energy generated by the Solar Panel System. With careful planning and optimization of components, this system can provide energy independence, reduce carbon emissions, and support the transition to a cleaner and more sustainable energy system. The amount of electrical energy generated from the Solar Panel System is able to meet the needs of the electricity load for a year. So that the source of electrical energy is enough to use the Solar Panel System alone without having to supply electricity from PLN.

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