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Solar Photovoltaics Efficiencies on Net Zero Energy House at Greater Jakarta

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Abstract—**The previous few decades have seen increasing aggravation of the contemporary environmental problem, climate change. Climate change caused by the accumulated emission of fossil fuels that we call greenhouse gases into the atmosphere has caused an increasing significance on the earth's temperature, which will cause natural disasters and environmental damage. Net zero energy buildings, primarily net zero energy houses, are very effective at reducing the consequences of climate change because of their notable reductions in energy consumption and reliance on renewable energy sources. Nonetheless, Indonesia still needs to adopt net-zero energy homes. Research on the most efficient solar PV installation methods for achieving net zero energy homes in Indonesia, particularly Jakarta, still needs to be initiated. This research aims to find the optimal tilt angle and orientation of solar photovoltaic (PV) energy production on house roofs to achieve the goal of a net-zero energy house. Experiments on solar PV installations were conducted in Jakarta residential areas to analyze and find the ideal tilt angle and orientation of solar PV panels for the Jakarta Area. A finding of effective solar PV installation and how it applies to net zero energy targets is also a novelty of this research. This study's contribution and impact on architects in designing a net zero energy house will relate to the area and form of the house roof. Furthermore, it hopes to have implications for future research on other building typologies and alternatives to renewable energy.**

Keywords— **Homes; house; net zero energy; renewable energy; solar photovoltaics.**

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I. INTRODUCTION

The utilization of fossil fuels has experienced a significant surge since the advent of the Second Industrial Revolution. The combustion of these fuels results in the release of greenhouse gases (GHG), commonly called CO2 emissions. These emissions accumulate in the atmosphere, leading to the reflection of sunlight back onto the Earth's surface. Consequently, this phenomenon contributes to a rise in the Earth's temperature. The symptoms of climate change have intensified in recent decades, resulting in distressing catastrophes and ecological harm. Following the COP21 or Paris Agreement in 2015, the United Nations has resolved to restrict the rise in global temperature to a maximum of 2° Celsius and aim for a target of 1.5° Celsius by the year 2100. The UN aims to achieve net zero emissions between 2050 and 2100. During COP28 in Dubai, a significant achievement was made with the approval of a fossil fuel phase-out agreement. This agreement obliges the participating parties to gradually move away from using fossil fuels in energy systems. The transition will be carried out fairly, organized, and somewhat to achieve a state of net-zero emissions by the year 2050 [1], [2]. It is imperative to minimize the utilization of fossil fuels and instead rely predominantly on renewable energy sources. Net zero energy buildings are a highly effective measure because buildings worldwide generate up to 37% of carbon dioxide emissions; from this percentage, residential is the highest percentage. The carbon dioxide emission rate of buildings is even higher than that produced by the industrial and transportation sectors [3], [4].

A net zero energy dwelling is an exceptionally energy-efficient dwelling that produces renewable energy in quantities equivalent to or beyond the amount of fossil energy it still consumes [4], [5], [6], [7]. Of all building typologies, residences consume more energy than commercial structures globally and in Indonesia [8],[9]. Hence, implementing net zero energy homes proves highly beneficial in mitigating the consequences of climate change [5]. Nevertheless, such implementation still needs to be implemented in Indonesia thus far. This condition invites research questions about the necessary factors to realize a net zero energy house. One of the critical factors is that the house must produce electricity from renewable energy. Research on renewable energy related to the net zero energy house target still needs to be done, especially in Jakarta. Researching net zero energy homes is crucial to contributing to and impacting architects in designing net zero energy houses. It will have implications for future research on net zero energy for other building typologies and alternatives to renewable energy.

One of the studies on solar PV for reaching net zero energy housing was done by [10] and only discussed the result of analyzing energy produced by solar PV for a particular case studies a tropical context. The paper needs to examine the optimal solar PV installation to achieve the net zero energy target. The tilt angle and orientation of solar PV will significantly affect renewable energy production, affecting the achievement of the net zero energy target. Research from [11] discusses the effect of orientation and tilt angle solar PV in Africa, but it doesn't directly apply to net zero energy houses. Most of their cases are solar thermal collectors and solar PV, used as road lighting. Another study from [12] discussing the theory of solar radiation at inclined panels and determining the optimal tilt angle at some locations in Indonesia, again, it does not relate to the net zero energy house target. This study is more specific to analyzing optimum solar PV installation performance that can produce energy optimally to achieve the target of net zero energy houses in Jakarta. The finding is that the diagram of tilt angle and orientation and the diagram of net zero energy house is a novelty of this study.

A net zero energy house operates on two fundamental principles: it must accomplish significant energy conservation and generate renewable energy on-site. Significant energy savings can be achieved by initially reducing the energy demands through passive design [5], [13], [14], [15], [16]. Passive design minimizes the impact of the building's surroundings by employing a design that is suitable for the local climate and harnesses natural resources to optimize the comfort of occupants (climate balanced). In tropical countries like Indonesia, passive design should incorporate solar-responsive design principles, specifically focusing on heat exclusion and heat dissipation [15], [16]. It is crucial to prioritize passive design factors such as orientation, Window to wall ratio (WWR), and shading devices [15], [16], [17]. The utilization of efficient electrical equipment such as HVAC system, Lamps, home appliances are crucial for achieving substantial energy savings [18], [19], [20], [21], [22]. To conserve energy in residential houses, it is imperative to monitor the electricity usage of each electrical appliance and opt for appliances that bear an energy-efficient mark. In Indonesia, the Ministry of Energy and Mineral Resources (ESDM) has established Energy efficiency requirements and energy saving labels for various appliances such as air conditioners, LED lights, refrigerators, rice cookers, and fans [23], [24]. These labels range from one star (least efficient) to five stars (most energy efficient). The image below (Fig. 1) displays the energy-saving sign label for electrical appliances, as required by the Indonesian Department of Energy and Mineral Resources.

The Department of Renewable Energy and Energy Conservation (EBTKE) has developed a household energy calculator. This calculator may determine a household's annual energy consumption by inputting the type of electrical equipment and its power in Watts. Ultimately, the ideal energy source for a house is solar photovoltaic (PV) technology, which can generate renewable energy and offset the consumption of fossil fuels [10], [25], [26], [27], [28], [29]. This research uses solar photovoltaics (Solar PV) as a renewable energy source for achieving net zero energy dwellings. Solar photovoltaics is a process that directly converts sunlight into electrical energy. However, not all the sunlight energy is successfully converted into electrical energy, and this measure is referred to as the efficiency of solar PV panels [30].

Fig. 1 Label energy savings appliances [23]

As sunlight enters the sky, it is influenced by the atmosphere. When sunlight reaches the Earth's surface, It can be subdivided into three components: direct rays, diffuse rays, and reflected rays (see Fig. 2). This radiant intensity exhibits intricate components, including isotropic, circumsolar, and horizon brightening. This impacts the amount of irradiance emitted by the sun's beams, particularly those that come into contact with solar panels. The solar panel's inclined plane receives a certain amount of irradiance, which is referred to as Global irradiance in plane of array (E gen).

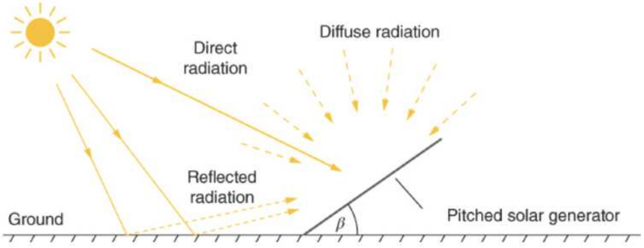


Fig. 2 Component global irradiance in plane of array.

The following formula represents the E gen [31]:

$$E\ gen = E\ direct\_gen + E\ diffuse\_gen + E\ refl\_gen \tag{1}$$

Where:
E gen = global irradiance in plane of array
E direct_gen = direct sunlight radiation on the inclined plane of the solar panel
E diffuse gen = solar radiation scattered on the inclined plane of the solar panel

Photovoltaic (PV) devices are characterized by their solid-state nature, imparting durability and a straightforward design. Consequently, they demand less maintenance. The Solar PV panels are mounted on a stationary structure at a specific inclination angle (tilt angle). Solar photovoltaics is a process that directly converts sunlight into electrical energy. The performance of solar modules is affected by various parameters, including solar irradiation level, angle of incidence, solar spectrum, shading, and other variables. Hence, the installation of solar panels necessitates careful consideration of factors such as the tilt angle and orientation of the panels [11], [12]. A typical house roof made of clay tile typically has a 35-degree slope, but in the area near the equator, the optimum tilt angle of solar PV is low, so knowing the most effective tilt angle is very important. The differences between the roof slope and tilt angle of Solar PV can be solved by using additional support above the roof.

This investigation aims to assess the effectiveness of installing solar photovoltaic (PV) panels on residential rooftops, which would contribute to achieving a net zero energy dwelling. This study generates a graphical representation of solar photovoltaic (PV) production, focusing on the effect of tilt angle and orientation on installing solar PV systems. The annual solar PV production readings are utilized in the net zero energy home model.

II. MATERIALS AND METHOD

The research subject was a rooftop solar photovoltaic (PV) system installed on a building in Pluit, Jakarta, Indonesia. The research object is located at coordinates 6° 07' 32.6" S and 106° 47' 19.1" E. The installation involves 8 solar panels, each with a power output of 455 Wp, resulting in a total capacity of 3.64 kW. The solar panel installation utilizes an On-grid system, is situated on a zincalume roof with a roof inclination of 5° and is oriented towards the North.

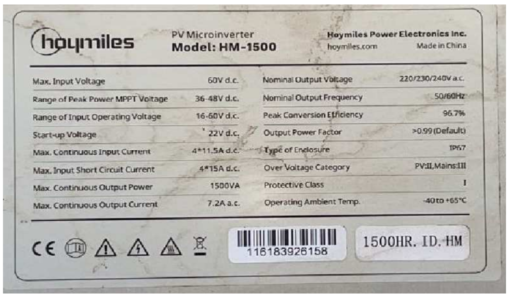
A. Materials

1) Solar PV modules: The solar module is a monocrystalline Trina solar panel with a power capacity of 455 watts peak (Wp) and a module efficiency of 20.8% (see Table 1). Solar PV module efficiency refers to the percentage of sunlight successfully transformed into electrical energy. Solar PV panel technology is comprised of monocrystalline and polycrystalline, where monocrystalline has better efficiency than polycrystalline.

TABLE I
SPECIFICATION SOLAR PV MODULE

Peak Power Watts - P_{MAX} (Wp)	435	440	445	450	455	460
Power Tolerance - P_{MAX} (W)	0~ +5					
Maximum Power Voltage - V_{MPP} (V)	40.5	40.7	40.8	41.0	41.2	41.3
Maximum Power Current - I_{MPP} (A)	10.74	10.82	10.90	10.98	11.06	11.13
Open Circuit Voltage - V_{OC} (V)	49.0	49.2	49.4	49.6	49.8	50.0
Short Circuit Current - I_{SC} (A)	11.31	11.39	11.46	11.53	11.61	11.68
Module Efficiency - ŋ m (%)	19.9	20.1	20.4	20.6	20.8	21.0

2) Inverter: A device that converts direct current (DC) to alternating current (AC) is called an inverter. The specific type used in this case is the HM-1500 micro inverter manufactured by Hoymiles. It is accompanied by the S-miles end-user application, which allows users to monitor power and energy measurements derived from solar panel generation. The inverter employs a Maximum Power Point Tracker (MPPT) mechanism. This system utilizes an inverter connected to the on-grid network to optimize the efficiency of the solar PV under all conditions (see Fig. 3). The display monitor is connected by Wireless Fidelity (Wi-Fi), so it can read the production of solar PV to any location connected to the internet.



hoymiles
PV Microinverter
Model: HM-1500
Hoymiles Power Electronics Inc.
hoymiles.com
Made in China

Max. Input Voltage	60V d.c.	Nominal Output Voltage	220/230/240V a.c.
Range of Peak Power MPPT Voltage	36-48V d.c.	Nominal Output Frequency	50/60Hz
Range of Input Operating Voltage	16-60V d.c.	Peak Conversion Efficiency	96.7%
Start-up Voltage	22V d.c.	Output Power Factor	>0.99(Default)
Max. Continuous Input Current	4*11.5A d.c.	Type of Enclosure	IP67
Max. Input Short Circuit Current	4*15A d.c.	Over Voltage Category	PV:II,Mains:III
Max. Continuous Output Power	1500VA	Protective Class	I
Max. Continuous Output Current	7.2A a.c.	Operating Ambient Temp.	-40 to +65°C

116183926158
1500HR. ID. HM

Fig. 3 Specification microinverter

3) Display device: A computer monitor used to record the solar PV yield readings every 15 minutes, on a daily, weekly, monthly, and yearly basis.

4) Additional apparatus: Light gauge steel, also known as cold-formed steel, can be utilized to provide supplementary reinforcement for achieving different tilt angles and orientations of solar photovoltaic (PV) systems.

B. Method

The study was conducted in two stages:

a. Quantifying and analyzing solar photovoltaic (PV) energy production concerning the tilt angle. The experiment was done with tilt angles of 0°, 5°, 10°, 15°, 20°, 25°, 30°, and 45° (see Fig. 4). Due to the existing roof of the location experiment having a roof angle of 5°, solar panels were placed on additional support to achieve various tilt angles.
b. Quantification and analysis of solar photovoltaic (PV) energy production concerning the orientation of solar modules. The experiment was done by orientation North, East, South, and West (see Fig. 5). This second experiment used 10° tilt angles with various orientations of solar PV facing.

Fig. 4 Experiment of various solar PV tilt angles

Fig. 5 Experiment of various solar PV orientation

Measurements were obtained through a computer monitor, and the resulting data was processed in a spreadsheet. Formulations and graphs were created using the MATLAB application. The experiment's outcomes, which involved altering the tilt angle and orientation of the solar PV, were used to model a net zero energy house to decide the feasibility of reaching the objective of a net zero energy house. The net zero energy home calculations yield a model of a net zero energy house, which architects may use as a reference during the initial design phase of a net zero energy house.

III. RESULTS AND DISCUSSION

The experimental findings for altering the tilt angle to achieve optimal solar PV production yielded the following outcomes. Based on the provided table (see Table 2), it may be inferred that the optimal tilt angle for generating solar PV energy during the trial period in September, October, and November 2023 is 10°.

TABLE II

SOLAR PV PRODUCTION FOR VARIOUS TILT ANGLES

Tilt Angle	**0°**	**5°**	**10°**	**15°**	**20°**	**25°**	**30°**	**45°**	**Total**
15-Sep	2.48	2.40	2.54	2.38	2.50	2.48	2.38	2.18	19.34
16-Sep	2.53	2.45	2.60	2.44	2.55	2.52	2.43	2.21	19.73
17-Sep	2.36	2.34	2.42	2.34	2.36	2.34	2.26	2.05	18.47
18-Sep	2.29	2.25	2.33	2.24	2.28	2.26	2.18	1.99	17.82
19-Sep	2.02	2.01	2.06	2.00	2.00	1.98	1.91	1.74	15.72
20-Sep	2.50	2.45	2.55	2.44	2.49	2.46	2.37	2.13	19.39
21-Sep	2.27	2.24	2.31	2.23	2.25	2.22	2.15	1.94	17.61
22-Sep	2.53	2.46	2.58	2.43	2.52	2.49	2.39	2.15	19.55
23-Sep	1.51	1.50	1.52	1.49	1.48	1.45	1.40	1.26	11.61
24-Sep	2.14	2.07	2.15	2.03	2.09	2.05	1.98	1.77	16.28
25-Sep	1.83	1.85	1.89	1.85	1.82	1.81	1.74	1.56	14.35
26-Sep	1.85	1.86	1.85	1.83	1.79	1.74	1.68	1.42	14.02
27-Sep	2.50	2.41	2.53	2.38	2.45	2.42	2.30	2.04	19.03
28-Sep	2.55	2.44	2.57	2.40	2.49	2.44	2.32	2.05	19.26
29-Sep	2.56	2.45	2.56	2.41	2.48	2.44	2.32	2.04	19.26
30-Sep	2.19	2.12	2.20	2.10	2.14	2.10	2.01	1.79	16.65
1-Oct	2.09	2.04	2.09	2.01	2.03	1.99	1.91	1.71	15.87
2-Oct	2.00	1.96	2.01	1.94	1.94	1.90	1.83	1.63	15.21
3-Oct	2.26	2.21	2.27	2.18	2.19	2.15	2.06	1.82	17.14
4-Oct	2.39	2.28	2.38	2.23	2.29	2.24	2.13	1.86	17.80
5-Oct	2.45	2.34	2.44	2.30	2.34	2.29	2.17	1.90	18.23
6-Oct	2.30	2.22	2.29	2.18	2.20	2.16	2.05	1.80	17.20
7-Oct	2.13	2.04	2.12	2.00	2.04	1.99	1.90	1.67	15.89
8-Oct	2.27	2.16	2.25	2.12	2.15	2.10	1.99	1.74	16.78
9-Oct	2.28	2.19	2.26	2.15	2.17	2.12	2.01	1.75	16.93
10-Oct	2.27	2.14	2.24	2.10	2.14	2.09	1.97	1.70	16.65
11-Oct	2.27	2.20	2.24	2.15	2.14	2.09	1.98	1.71	16.78
12-Oct	2.23	2.14	2.20	2.09	2.10	2.04	1.94	1.67	16.41
13-Oct	2.14	2.04	2.11	2.00	2.02	1.96	1.86	1.60	15.73
14-Oct	2.02	1.93	1.99	1.89	1.90	1.85	1.75	1.51	14.84
15-Oct	1.95	1.84	1.91	1.80	1.83	1.77	1.68	1.46	14.24
16-Oct	2.35	2.22	2.31	2.18	2.19	2.13	2.00	1.69	17.07
17-Oct	2.23	2.16	2.21	2.12	2.10	2.05	1.93	1.66	16.46
18-Oct	2.30	2.16	2.26	2.12	2.13	2.07	1.94	1.64	16.62
19-Oct	2.10	2.04	2.09	2.02	1.99	1.95	1.84	1.60	15.63
20-Oct	2.17	2.12	2.13	2.06	2.00	1.95	1.83	1.54	15.80
21-Oct	2.31	2.17	2.26	2.13	2.12	2.06	1.93	1.60	16.58
22-Oct	1.97	1.88	1.93	1.84	1.82	1.77	1.67	1.43	14.31
23-Oct	2.10	2.03	2.06	1.98	1.94	1.88	1.77	1.48	15.24
24-Oct	1.80	1.73	1.76	1.69	1.67	1.63	1.54	1.33	13.15
25-Oct	1.83	2.00	2.01	1.94	1.9	1.81	1.75	1.49	14.73
26-Oct	2.10	2.21	2.31	2.17	2.17	2.09	1.96	1.61	16.62
27-Oct	2.09	2.21	2.29	2.16	2.15	2.08	1.95	1.61	16.54
28-Oct	2.23	2.3	2.44	2.27	2.27	2.19	2.03	1.64	17.37
29-Oct	2.25	2.32	2.45	2.27	2.27	2.19	2.03	1.63	17.41
30-Oct	2.17	2.24	2.36	2.2	2.2	2.12	1.97	1.59	16.85
31-Oct	2.06	2.19	2.25	2.13	2.1	2.03	1.9	1.56	16.22
1-Nov	1.97	2.1	2.12	2.04	1.99	1.93	1.82	1.52	15.49
2-Nov	2.12	2.17	2.27	2.13	2.11	2.04	1.9	1.54	16.28
3-Nov	2.06	2.13	2.2	2.07	2.05	1.97	1.85	1.5	15.83
4-Nov	1.65	1.74	1.76	1.69	1.67	1.61	1.52	1.28	12.92
5-Nov	1.42	1.4	1.41	1.38	1.37	1.33	1.27	1.13	10.71
6-Nov	2.41	2.31	2.35	2.23	2.17	2.09	1.95	1.56	17.07
7-Nov	2.34	2.25	2.28	2.16	2.1	2.02	1.88	1.52	16.55
8-Nov	2.02	1.89	1.95	1.83	1.81	1.74	1.64	1.34	14.22
9-Nov	1.99	1.91	1.93	1.84	1.8	1.74	1.63	1.36	14.20
10-Nov	1.80	1.75	1.77	1.69	1.65	1.6	1.51	1.27	13.04
11-Nov	2.10	2.04	2.06	1.97	1.93	1.86	1.75	1.43	15.14
12-Nov	2.34	2.24	2.28	2.15	2.09	2	1.86	1.45	16.41
Total	127.44	124.94	128.96	122.59	122.93	119.87	113.67	97.85	958.25

The tilt angles between 0 ° and 10° are the most optimal. The line diagram graph (see Fig. 6) clearly illustrates that solar PV efficiency substantially declines when the angles reach 30°, 45°, or higher.

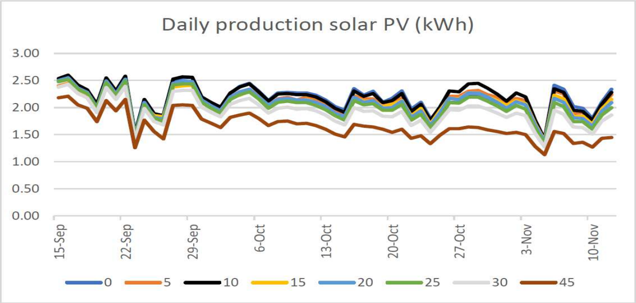


Fig. 6 Experiment of various solar PV tilt angles

Additionally, solar PV production diminishes by at least 12% to 24% or even more. Consequently, it is necessary to adjust the installation of solar PV systems in residential homes to allow for a relatively low tilt angle, while keeping the overall roof slope angle unchanged for medium-sized residential residences with concrete tile roofs, specifically at 30° or higher. Further simulation is required to acquire annual production figures for calculating the net zero energy target based on measurements of solar PV production, specifically regarding tilt angle.

Based on the data provided in the table (see Table 3), it can be inferred that the optimal orientation for solar PV panels during the trial period in November and December 2023 was facing South.

TABLE III
SOLAR PV PRODUCTION FOR VARIOUS ORIENTATIONS

Orientation	U1	U2	T1	T2	S1	S2	B1	B2	Total
17-Nov	2.13	2.15	2.22	2.23	2.29	2.32	2.12	2.13	17.59
18-Nov	1.95	1.98	1.99	2.00	2.10	2.16	1.97	1.98	16.13
19-Nov	2.29	2.32	2.42	2.44	2.50	2.54	2.28	2.29	19.08
20-Nov	2.11	2.14	2.15	2.17	2.22	2.28	2.07	2.09	17.23
21-Nov	2.15	2.18	2.25	2.26	2.34	2.37	2.16	2.17	17.88
22-Nov	1.90	1.92	1.97	1.99	2.04	2.06	1.89	1.90	15.67
23-Nov	1.10	1.11	1.10	1.11	1.12	1.13	1.09	1.09	8.85
24-Nov	1.60	1.61	1.66	1.67	1.65	1.66	1.54	1.55	12.94
25-Nov	0.55	0.55	0.55	0.56	0.56	0.57	0.54	0.54	4.41
26-Nov	2.22	2.25	2.27	2.29	2.40	2.46	2.26	2.27	18.42
27-Nov	1.17	1.18	1.20	1.21	1.20	1.21	1.14	1.15	9.46
28-Nov	2.00	2.03	2.04	2.06	2.11	2.13	2.02	2.02	16.41
29-Nov	2.41	2.45	2.50	2.51	2.62	2.73	2.46	2.47	20.15
30-Nov	1.13	1.14	1.10	1.11	1.20	1.26	1.15	1.16	9.25
1-Dec	0.57	0.57	0.56	0.57	0.57	0.57	0.55	0.56	4.52
2-Dec	2.17	2.21	2.27	2.28	2.40	2.46	2.22	2.23	18.24
3-Dec	1.60	1.62	1.70	1.71	1.70	1.73	1.54	1.55	13.15
4-Dec	0.51	0.51	0.51	0.51	0.51	0.51	0.49	0.50	4.04
5-Dec	2.22	2.26	2.37	2.38	2.46	2.49	2.24	2.25	18.67
6-Dec	1.94	1.97	2.04	2.05	2.15	2.20	1.98	1.98	16.31
7-Dec	1.22	1.23	1.21	1.21	1.27	1.31	1.23	1.23	9.91
8-Dec	1.64	1.66	1.79	1.80	1.79	1.79	1.59	1.59	13.65
9-Dec	1.20	1.21	1.22	1.23	1.26	1.28	1.19	1.20	9.79
10-Dec	1.37	1.39	1.37	1.37	1.42	1.44	1.37	1.38	11.11
11-Dec	2.28	2.31	2.46	2.46	2.56	2.61	2.29	2.30	19.27
12-Dec	1.71	1.73	1.76	1.76	1.86	1.90	1.74	1.74	14.20
13-Dec	2.17	2.20	2.31	2.30	2.43	2.50	2.19	2.20	18.30
14-Dec	2.25	2.28	2.42	2.42	2.53	2.60	2.27	2.28	19.05
Total	47.55	48.16	49.42	49.66	51.26	52.27	47.58	47.79	393.68

This aligns with the sun's movement in Jakarta, which predominantly lies in the South direction. The results for the East, West, and North directions are similar. This is because when the slope angle is relatively shallow, the impact of orientation on solar PV production is minimal. This information can also serve as input for housing developers. If the house is required to face either East or West (although not suggested for a passive design strategy), it is best to install solar photovoltaic (PV) panels in that direction. However, it is important to ensure that the tilt angle of the panels remains low, specifically between 0° and 10°.

Further simulation is required to acquire annual production figures for calculating the net zero energy target based on measurements of Solar PV Production, especially regarding tilt angle and orientation of solar PV, as shown in Fig. 7. For calculations of net zero energy house, both operational energy and energy production by the solar PV are in annual calculations. Manual calculations for solar PV production will need a lot of calculation time because they will calculate the solar irradiance per hour during peak sun hour and accumulate to the annual production number. To address this issue, a simulation was generated utilizing the PVWatts application developed by the National Renewable Energy Laboratory (NREL).

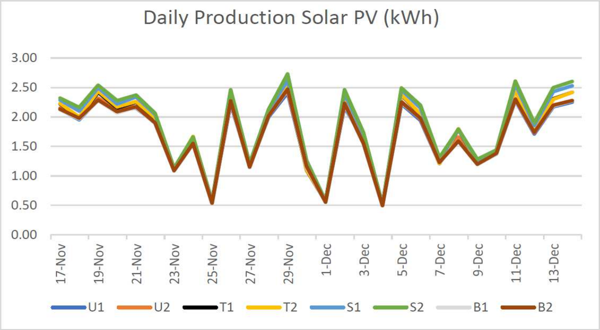


Fig. 7 Experiment of various solar PV orientations

Subsequently, the outcomes were analyzed using the MATLAB program to produce diagrams that Architects, Housing Developers, and other stakeholders involved in residential construction can use. The table below (Table 4) displays the outcomes of the solar PV production simulation diagram concerning tilt angle and orientation (sign for orientation from North 0° to clockwise direction, Northeast 45°, East 90°, Southeast 135°, South 180°, Southwest 225°, West 270°, and Northwest 315°.

TABLE IV
PRODUCTION OF SOLAR PV, TILT ANGLE AND ORIENTATION

T.Angle (°)	Orient (°)	kWh/ year
0	0	1397
0	45	1397
0	90	1397
0	135	1397
0	180	1397
0	225	1397
0	270	1397
0	315	1397
5	0	1412
5	45	1408
5	90	1398
5	135	1387
5	180	1382
5	225	1385
5	270	1395
5	315	1406
10	0	1416
10	45	1409
10	90	1389
10	135	1367
10	180	1356
10	225	1363
10	270	1384
10	315	1405
15	0	1410
15	45	1400
15	90	1370
15	135	1337
15	180	1320
15	225	1333
15	270	1364
15	315	1394
20	0	1394
20	45	1381
20	90	1342
20	135	1299
20	180	1276
20	225	1293
20	270	1335
20	315	1374
25	0	1369
25	45	1354
25	90	1308
25	135	1253
25	180	1222
25	225	1248
25	270	1301
25	315	1346
30	0	1336
30	45	1320
30	90	1267
30	135	1201
30	180	1161
30	225	1196
30	270	1260
30	315	1310
35	0	1294
35	45	1279
35	90	1222
35	135	1143
35	180	1092
35	225	1139
35	270	1215
35	315	1266
40	0	1245
40	45	1232
40	90	1174
40	135	1082
40	180	1018
40	225	1079
40	270	1167
40	315	1218
45	0	1189
45	45	1180
45	90	1123
45	135	1018
45	180	938
45	225	1016
45	270	1116
45	315	1164
50	0	1127
50	45	1124
50	90	1068
50	135	952
50	180	857
50	225	952
50	270	1062
50	315	1106
55	0	1059
55	45	1064
55	90	1014
55	135	886
55	180	776
55	225	888
55	270	1007
55	315	1045
60	0	987
60	45	1003
60	90	957
60	135	821
60	180	700
60	225	824
60	270	952
60	315	982
65	0	912
65	45	940
65	90	901
65	135	758
65	180	634
65	225	762
65	270	895
65	315	918
70	0	840
70	45	880
70	90	850
70	135	701
70	180	578
70	225	706
70	270	843
70	315	856
75	0	783
75	45	833
75	90	812
75	135	660
75	180	539
75	225	666
75	270	806
75	315	809
80	0	741
80	45	800
80	90	788
80	135	635
80	180	516
80	225	641
80	270	781
80	315	775
85	0	697
85	45	766
85	90	765
85	135	611
85	180	495
85	225	616
85	270	756
85	315	740
90	0	629
90	45	707
90	90	713
90	135	565
90	180	455
90	225	570
90	270	705
90	315	681

The computation of solar PV production for Net Zero Energy Home calculations can be performed using the diagram or table provided below. Energy conservation can begin by modifying passive design components like window-to-wall ratio (WWR), shading devices, and orientation. Next, energy conservation can be implemented by utilizing high-efficiency electrical appliances. When renewable energy generation equals or exceeds the residual fossil fuel consumption, the savings resulting from passive architecture and energy-efficient home appliances must be supplemented with solar photovoltaic (PV) systems to attain net zero energy conditions.

A three-dimensional model was generated from the simulation of a net zero energy house and solar PV generation (see Fig. 8). Model of net zero energy houses that accommodate good passive design and optimal solar PV installation (see Fig. 9). The simulation results have yielded a simulator of a net-zero-energy house (see Fig. 10), which can serve as a valuable reference for architects, housing developers, and all stakeholders in the residential building field. This model incorporates crucial factors that must be implemented to achieve a net zero energy house.

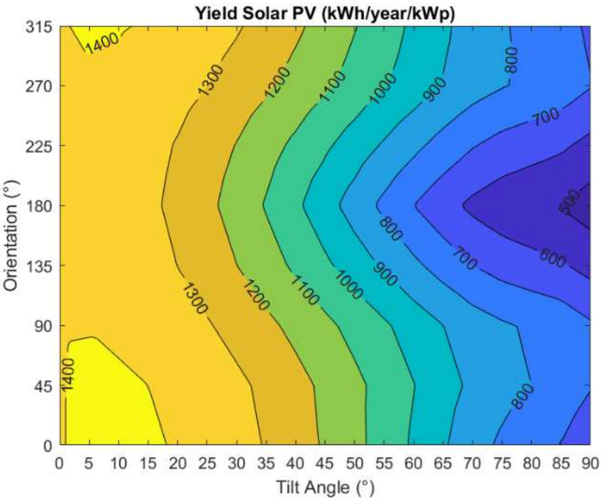


Fig. 8 Solar PV yield, tilt angle, and orientation

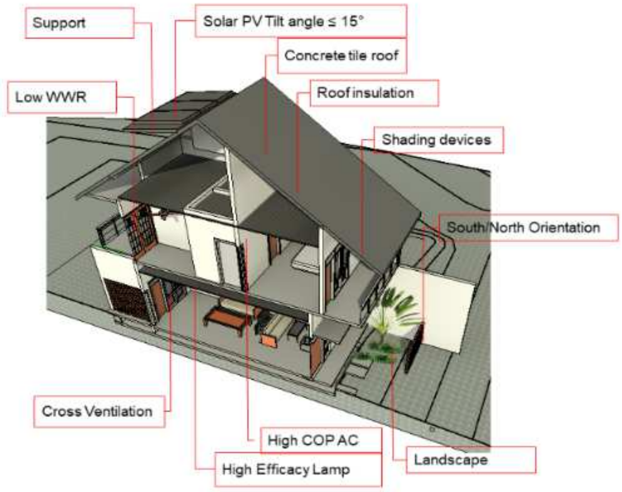
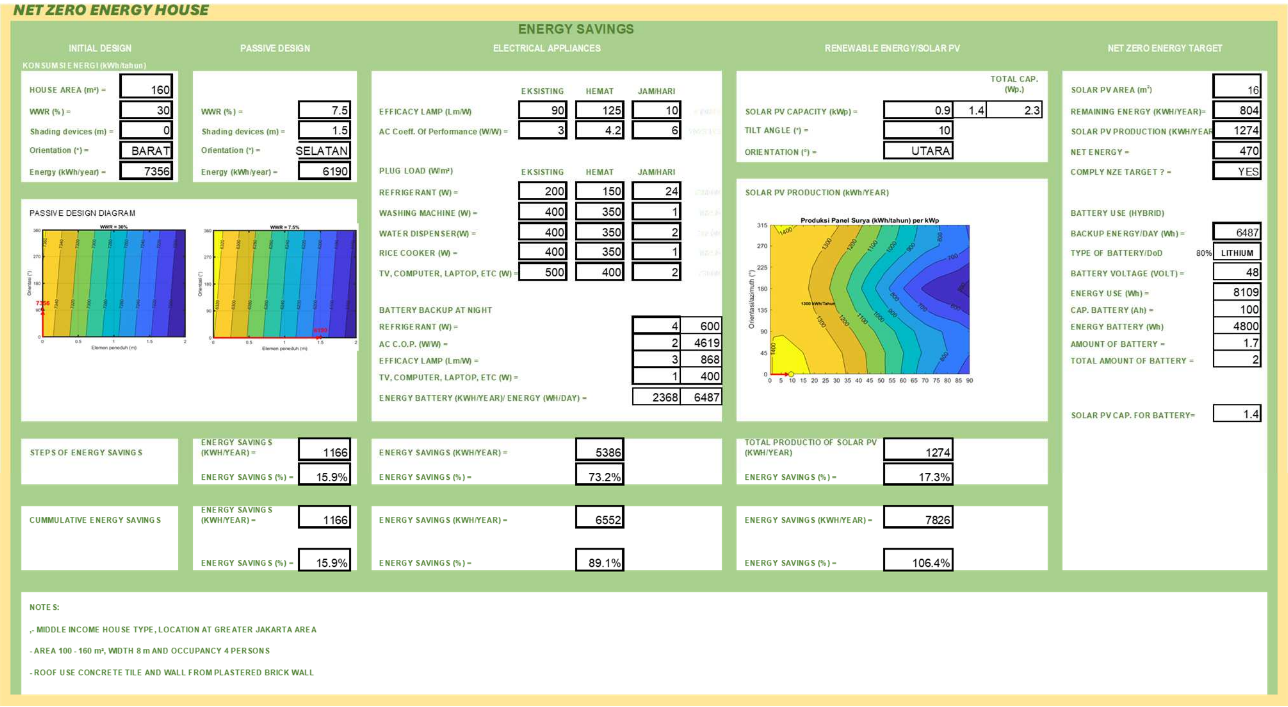


Fig. 9 Three-dimensional net zero energy house


NET ZERO ENERGY HOUSE

ENERGY SAVINGS

INITIAL DESIGN

KONSUMSI ENERGI (kWh/tahun)

HOUSE AREA (m²) = 160
WWR (%) = 30
Shading devices (m) = 0
Orientation (°) = BARAT
Energy (kWh/year) = 7356

PASSIVE DESIGN

WWR (%) = 7.5
Shading devices (m) = 1.5
Orientation (°) = SELATAN
Energy (kWh/year) = 6190

PASSIVE DESIGN DIAGRAM

ELECTRICAL APPLIANCES

	EKSISTING	HEMAT	JAM/HARI
EFFICACY LAMP (Lm/W)	90	125	10
AC Coeff. Of Performance (W/W) =	3	4.2	6
PLUG LOAD (W/m²)			
REFRIGERANT (W) =	200	150	24
WASHING MACHINE (W) =	400	350	1
WATER DISPENSER(W) =	400	350	2
RICE COOKER (W) =	400	350	1
TV, COMPUTER, LAPTOP, ETC (W) =	500	400	2

BATTERY BACKUP AT NIGHT		
REFRIGERANT (W) =	4	600
AC C.O.P. (W/W) =	2	4619
EFFICACY LAMP (Lm/W) =	3	868
TV, COMPUTER, LAPTOP, ETC (W) =	1	400
ENERGY BATTERY (KWH/YEAR)/ ENERGY (WH/DAY) =	2368	6487

RENEWABLE ENERGY/SOLAR PV

			TOTAL CAP. (Wp.)
SOLAR PV CAPACITY (kWp) =	0.9	1.4	2.3
TILT ANGLE (°) =	10		
ORIENTATION (°) =	UTARA		

SOLAR PV PRODUCTION (kWh/YEAR)

NET ZERO ENERGY TARGET

SOLAR PV AREA (m²) 16
REMAINING ENERGY (KWH/YEAR)= 804
SOLAR PV PRODUCTION (KWH/YEAR 1274
NET ENERGY = 470
COMPLY NZE TARGET ? = YES

BATTERY USE (HYBRID)

BACKUP ENERGY/DAY (Wh) = 6487
TYPE OF BATTERY/DoD 80% LITHIUM
BATTERY VOLTAGE (VOLT) = 48
ENERGY USE (Wh) = 8109
CAP. BATTERY (Ah) = 100
ENERGY BATTERY (Wh) 4800
AMOUNT OF BATTERY = 1.7
TOTAL AMOUNT OF BATTERY = 2

SOLAR PV CAP. FOR BATTERY= 1.4

STEPS OF ENERGY SAVINGS

ENERGY SAVINGS (KWH/YEAR) = 1166
ENERGY SAVINGS (%) = 15.9%
ENERGY SAVINGS (KWH/YEAR) = 5386
ENERGY SAVINGS (%) = 73.2%
TOTAL PRODUCTIO OF SOLAR PV (KWH/YEAR) 1274
ENERGY SAVINGS (%) = 17.3%

CUMMULATIVE ENERGY SAVINGS

ENERGY SAVINGS (KWH/YEAR) = 1166
ENERGY SAVINGS (%) = 15.9%
ENERGY SAVINGS (KWH/YEAR) = 6552
ENERGY SAVINGS (%) = 89.1%
ENERGY SAVINGS (KWH/YEAR) = 7826
ENERGY SAVINGS (%) = 106.4%

NOTES:

,- MIDDLE INCOME HOUSE TYPE, LOCATION AT GREATER JAKARTA AREA

- AREA 100 - 160 m², WIDTH 8 m AND OCCUPANCY 4 PERSONS

- ROOF USE CONCRETE TILE AND WALL FROM PLASTERED BRICK WALL

Fig. 10 Simulator Net zero energy house

IV. CONCLUSION

This study develops a Solar PV yield model that focuses on the tilt angle and orientation of the solar module. This figure is highly beneficial for the implementation of solar photovoltaic (PV) systems on rooftops. In the case of medium-sized residential dwellings, the roof is typically made of concrete tiles roof and has a slope angle of 30° or greater. Therefore, additional support is necessary to achieve a slope of 15° or lower. The support structure might consist of light gauge steel, which is securely placed into a concrete tile roof.

The net zero energy house diagram is a valuable tool for architects to aid in the initial design of a net zero energy house, particularly in assessing the Window to Wall Ratio (WWR), implementing shading devices, and identifying the optimal building orientation. Utilizing electrical appliances with an energy-efficient designation aids in achieving the objective of a net zero energy residence. The tilt angle and orientation of solar photovoltaic (PV) systems also impact the form of the building architecture. Subsequent investigations can be conducted for additional Indonesian cities in the future, as each locale possesses distinct climatic characteristics and implications for future research on other building typologies and alternatives for renewable energy.

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