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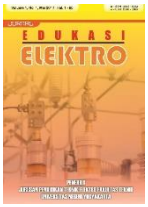

Skillion Roof Design to Get Optimum Solar Radiation in Yogyakarta

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Abstract— Electrical energy is energy that cannot be released from daily activities at home, all electronic equipment requires electrical energy, one source of electrical energy is the electricity company PT. PLN (Persero) and as an alternative source of electrical energy, a home can use solar panels installed on the roof as a small scale power generator or can be called Solar Home System (SHS), but electrical energy obtained is very dependent on the radiation received by the solar panels, therefore, to obtain optimum solar radiation, it is necessary to calculate the azimuth angle and tilt angle which can be used as a reference for installing solar panels. So mathematical calculations are needed to calculate the maximum azimuth angle and tilt angle. Mathematical modeling is used to calculate solar energy installed at coordinates 7.7° south latitude, in that coordinate, average solar radiation can get from Meteorological, Climatological, and Geophysical Agency on horizontal surface, then calculation the declination angle, latitude angle, hour angle, azimuth angle and tilt angle to get value of incidence angle. Value of the declination angle, latitude angle, and hour angle are constant, while the azimuth angles divide into four directions, it's 0°, 90°, 180°, and 270° and the tilt angles are 20°, 25°, and 30° on skillion roof design. The results of the calculation and analysis of the movement of the sun for one year show that, by calculating the average solar radiation in a year, the roof of the house in the form of a skillion with an azimuth angle in the 0° gets the most optimal solar energy at an angle of 20° with an average solar radiation of 442,96 W/m^2 in one year.

Keywords: solar radiation, skillion roof, azimuth angle, tilt angle

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1 Introduction

The sun is a very large source of renewable energy, until now solar energy cannot be used optimally, solar panels are an equipment that can convert solar energy into electrical energy. Indonesia is an archipelagic country with an average solar energy potential of 4.8 kWh/m^2/day, where the installation of solar panels is one of the solutions to electrify areas that do not yet have electricity or can be called Solar Power Plants. Installing a large capacity Solar Power Plant will require a large area of land and large investment costs, but Solar Power Plant can also be installed with a small capacity and does not require a large area of land, namely installing solar panels on the roof of a house or what can be called a solar home system (SHS). SHS is a small-scale power plant using solar panels of 50 – 100 Wp (Watt peak) [1].

The installation of SHS is also a program of the Solar Electricity Initiative Movement (GERILIYA) in supporting the government to achieve the renewable energy target of 23% by 2025. GERILIYA is one part of the process towards a clean energy transition, considering that its potential is the greatest and the price is getting cheaper. Currently, the installed capacity of rooftop solar is

recorded at only 31 MW out of a total potential of around 32 Giga Watt (GW) both in Households, Business, Industry, Social Affairs as well as in Government Buildings [2].

In this study, radiation data was taken from Meteorological, Climatological, and Geophysical Agency by ignoring clouds which then calculated solar radiation for each azimuth angle of 0°, 90°, 180° and 270°, or facing north, east, south, and west. The tilt angle of the roof is also adjusted to obtain maximum radiation [3]. This research was conducted to determine the azimuth angle and tilt angle to obtain optimum radiation, by choosing the best composition of solar radiation that can be received by solar panels throughout the year.

Researchers also review from existing literature to learn how to determine the optimum tilt angle value, such as in England with coordinate north latitude about 53° which gets optimum solar radiation at a tilt angle of 40° and an azimuth angle of -6° [4]. In Gaza, Palestine has optimum tilt angle to produce maximum energy generation is 32.1° for south facing at coordinate north latitude 31.5° [5]. Then, in Iraq, the optimum tilt angle varied from 0° to 64° during the year, Iraq location is in coordinate north latitude about 32,29° [6]. The estimated yearly tilt angles some city in Saudi Arabia are as follow: 27.3° for Dhahran, 26.0° for Riyadh, 22.7° for Jeddah, 32.7° for Arar, and 20.1° for Abha with coordinate north latitude from 18,2° to 26,3° [7]. In Bukit Jimbaran Bali with coordinate South Latitude 8,806°, explain that the optimum value of tilt angle for fixed position of solar panels is between 12° to 18° in the direction of azimuth 0° [8]. And this research was conducted to find the optimum azimuth angle and tilt angle for the skillion roof design in Yogyakarta at coordinate south latitude 7.7°. The city of Yogyakarta was chosen because of several factors, such as Yogyakarta as a student city to educate the public and the application of solar panels on roofs, Yogyakarta has many villages and tourist attractions which are located quite far from the city center, so using solar panels on the roof is one solution to get electrical energy and as support government programs to achieve the renewable energy target.

2 Theoretical Basis

2.1 Effect of Earth's Orbit on the Sun

Sunlight is a form of electromagnetic radiation, and visible sunlight is only a small part of the electromagnetic spectrum as waves that have specific wavelengths. Not only is it a wave, in 1900, Planck and Einstein discovered that light also consists of energy particles called photons [9]. The earth rotates on its axis resulting in day and night which can be referred to as the sun's hour angle to the earth, the tilt of the earth or the declination angle of ±23.45° to the sun, resulting in changes in seasons each year and differences in seasons in each latitude location, this will also affect the azimuth angle and elevation angle in one year.

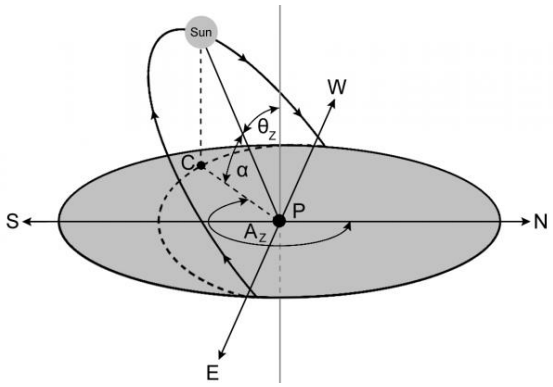

Fig 1. Elevation angle and azimuth angle of the sun to the earth (point P)

2.2 Solar Panel Laying

Solar panels have been very developed to date, the application of solar panels on a house roof is very simple and can be integrated with housing structures, architecturally it can be used on roofs, lip planks and facade walls. The installation itself is done using a fixed array, namely a row of solar panels placed on the supporting structure of the roof of the house. This installation is done because it is the cheapest to implement and costs little [10].

However, to get maximum energy on the roof of the house, mathematical calculations are needed, because the power generation on the solar panels is directly proportional to the solar energy received by the solar panels, so it is necessary to pay attention to the placement of the solar panels at an azimuth angle, a certain tilt angle in predetermined latitudinal coordinates [11].

2.3 Skillion Roof

Skillion roof has a single sloping surface, there are many types of this roof applied as garage until minimalist houses with modern designs, for the tilt angle of the roof if you take materials from zinc then around 20°-25° and tiles at 30°-40° [12]. Skillion roof can be depicted as figure 2:

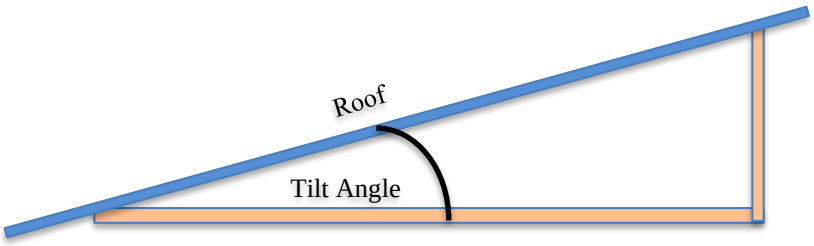

Fig 2. Skillion roof

2.4 Solar Radiation

1) Latitude Angle (φ)

The Latitude Angle is horizontal lines that measure distance north or south of the equator.

2) Hour Angle (ω)

The hour angle, denoted by (ω), is the displacement of the sun east or west from the local meridian, has a negative value in the morning, a positive value in the afternoon and zero in the afternoon. The hour angle is determined by the following formula: [14]

$$\omega = \frac{minute\ before\ noon}{4} \quad (1)$$

3) Declination Angle (δ)

The declination angle, denoted by (δ), is the angle between the equator and the line drawn from the center of the earth to the center of the sun.

$$\delta = -23.45° \; x \cos(\frac{360}{365} \; x \; (d + 10)) \quad (2)$$

Where *d* is a day in a year

4) Azimuth Angle (γ)

The solar azimuth angle is the horizontal angle between a reference direction with North = 0°, East = 90°, South = 180° and West = 270°.

5) Tilt Angle (β)

Tilt angle means the angle of inclination of a solar collector measured from the horizontal.

6) Incidence Angle (θ)

The angle of incidence, denoted by (θ), is the angle between the panel normal to the sun's rays, by determining the surface azimuth angle of the solar panel (γ) at 0° for the north direction, 180° for the south direction and the tilt angle of the solar panel (β). generally defined as follows: [15]

$$\theta_i = cos^{-1}\left\{\begin{matrix}[sin(\delta)sin(\phi)cos(\beta)] + [sin(\delta)cos(\phi)sin(\beta)cos(\gamma)] \\ +[cos(\delta)cos(\phi)cos(\beta)cos(\omega)] - [cos(\delta)sin(\phi)sin(\beta)cos(\gamma)cos(\omega)] \\ -[cos(\delta)sin(\beta)sin(\gamma)sin(\omega)]\end{matrix}\right\} \quad (3)$$

Explanation:
δ : Declination Angle
φ : Latitude Angle
ω : Hour Angle
β : Tilt Angle
γ : Azimuth Angle
If θ > 90°, the sun is behind the roof or panel.

7) Radiation on Incidence Angle

Radiation on an inclined plane is symbolized by H(β) which is then multiplied by the area of the roof of the house to get the total radiation.

$$H(\beta) = Hcos(\theta_i) \quad (4)$$

Where:
H : Average Solar Radiation (W/m^2)

3 Methodology

The method used in this research is mathematical calculations. The stages of the researcher in conducting this research are by determining the location that will be used as a reference for calculating solar radiation, then find the value of the incidence angle between the sun and the roof surface. The incidence angle can be calculated by inputting the values of declination angle, latitude angle, hour angle, tilt angle and azimuth angle as formula (3). Declination angle, latitude angle and hour angle are constant, while for azimuth angle and tilt angle are variable parameters whose values will change, with azimuth angle at 0°, 90°, 180°, 270° and tilt angle 20°, 25°, 30°. The amount of radiation received by the roof surface can be calculated using the trigonometry formula between the incidence angle and the roof surface as formula (4). The calculation results are then recapitulated and analyzed to determine the value of optimum solar radiation.

3.1 Location

The research was conducted in one of Indonesia's regions, namely Yogyakarta at coordinates 7.7° south latitude denoted by (φ) and 110.3° east longitude. From this location, the average value of solar radiation in a year is obtained as follows [13].

Table 1. Solar Radiation in Yogyakarta

No	Month	Solar Radiation (kWh/m^2)
1	January	4,45
2	February	4,65
3	March	4,66
4	April	4,69
5	May	4,44
6	June	4,05
7	July	4,33
8	August	4,96
9	September	5,25
10	October	5,32
11	November	4,71
12	December	4,15

4 Result And Discussion

4.1 Azimuth Angle

The effect of the azimuth angle and tilt angle on the radiation obtained in each direction of azimuth angle 0°, 90°, 180°, and 270° throughout the year with tilt angles of 20°, 25°, and 30°.

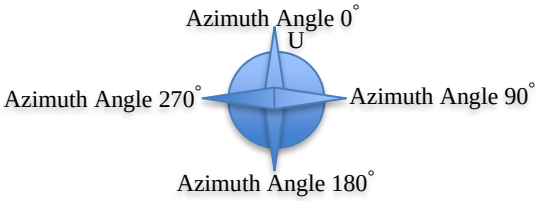

Fig 3. Azimuth Angle

1) Azimuth Angle 0^o

The surface azimuth angle is at 0° or in the north direction, the highest average radiation for one year is obtained at a tilt angle of 20° of 442.96 W/m^2, with the highest radiation of 483.09 W/m^2 in March and the lowest radiation of 399 .80 W/m2 in October. If seen from fig 4. when the tilt angle is greater, the average solar radiation obtained will be smaller, at a tilt angle of 30°, the average radiation is 417.85 W/m^2.

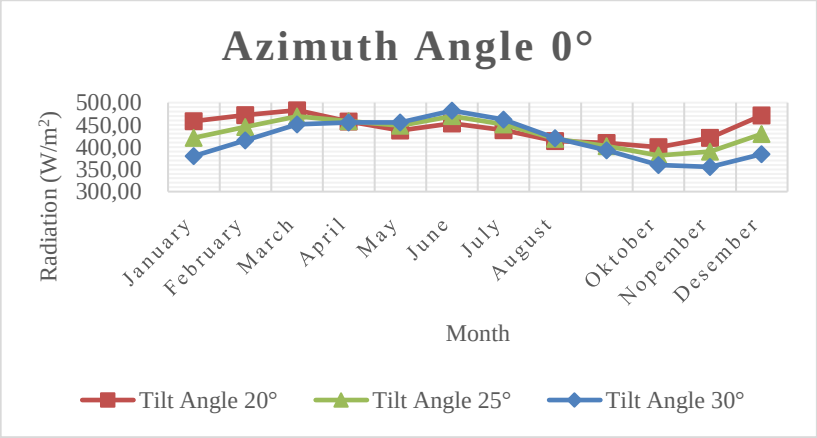

Fig 4. Effect of tilt angle on solar radiation at azimuth angle 0°

2) Azimuth Angle 90 °

At an azimuth angle of 90°, namely the direction of the roof facing east, the highest average radiation for a year was 596 W/m^2 at a tilt angle of 20°, with the highest radiation in December at 686.63 W/m2 and the lowest in June at 238. 31W/m^2. Apart from that, the disadvantage of panels facing east is that the radiation obtained will decrease in the afternoon because the sun is moving towards the west. In Fig 5., the slope angle does not change the shape of the radiation curve, it's just that the radiation gets smaller.

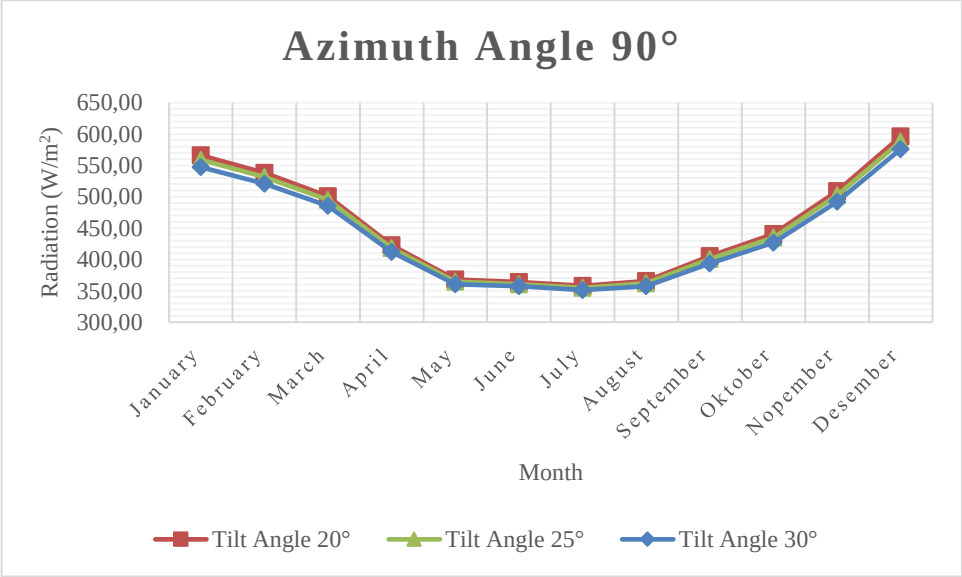

Fig 5. Effect of tilt angle on solar radiation at azimuth angle 90°

3) Azimuth Angle 180°

At an azimuth angle of 180°, the roof is facing south, with an angle of 20°, the highest average solar radiation is 422.50 W/m^2, with the highest radiation in December of 686.63 W/m^2 and the lowest radiation in June of 238,12 W/m^2. Due to the latitude angle, which is in the south area, it is really not good if the panel is directed to the south because the declination angle is more in the north.

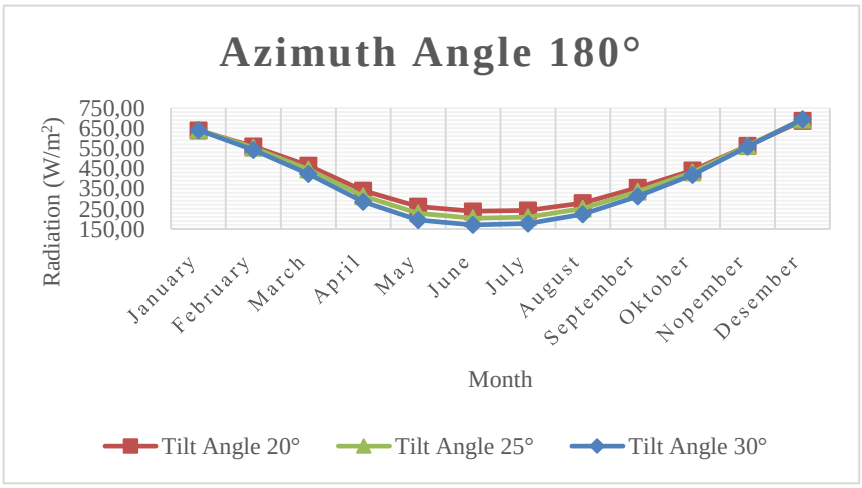

Fig 6. Effect of tilt angle on solar radiation at azimuth angle 180°

4) Azimuth Angle 270°

The radiation obtained on the surface of the azimuth angle of 270° or westward is the same as the radiation on the surface of the azimuth angle of 90°. The drawback is when the roof faces west, it will not get radiation during in the morning.

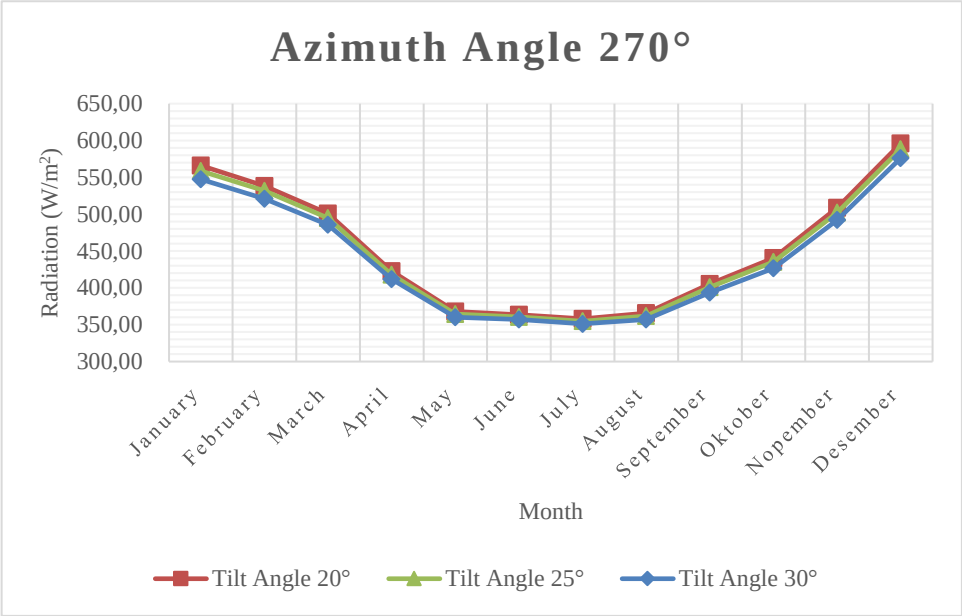

Fig 7. Effect of tilt angle on solar radiation at azimuth angle 270°

4.2 Data Compare

Each image shows that solar radiation from January to December has different values, this is due to the movement of the sun every month for one year, apart from that, determining the azimuth angle also affects the radiation received by the surface of the solar panel, this radiation is then taken data on average radiation in one year, the greatest radiation in one year and the lowest radiation in one year, the following table is obtained:

Table 2. Compare of Solar Radiation

Azimuth Angle	Tilt Angle	Average Solar Radiation (W/m^2)	Maximum Solar Radiation (W/m^2)	Minimum Solar Radiation (W/m^2)	Standard Deviation
Azimuth 0°	20°	442.96	483.09	399.80	26.18
	25°	432.05	469.66	381.24	28.62
	30°	417.85	482.06	355.47	41.25
Azimuth 90°	20°	452.80	596.13	358.05	82.24
	25°	447.65	588.37	354.71	80.73
	30°	440.01	576.13	351.23	77.70
Azimuth 180°	20°	422.50	686.63	238.12	153.16
	25°	405.79	693.21	203.33	167.25
	30°	386.58	694.53	170.02	179.41
Azimuth 270°	20°	452.80	596.13	358.05	82.24
	25°	447.65	588.37	354.71	80.73
	30°	440.01	576.13	351.23	77.70

Based on Table 2, it can be compared that the largest average solar radiation in one year is a roof with an Azimuth Angle of 90° and 270° of 452.80 W/m^2 at a tilt angle of 20°, the greater the radiation obtained, the greater the electrical energy that can be generated by the solar panels, but it is necessary

to consider the value of the standard deviation obtained, the standard deviation is calculated to see how far or how close the data value is to the average. The smaller the standard deviation value, the closer it is to the average value, the larger it is, the wider the data variation. However, at Azimuth angle of 90° and 270° has the greater average solar radiation, the standard deviation is large enough, it means that there are several months that get less solar radiation than the average radiation, which means that certain months will get less electrical energy. So, we can choose the smallest standard deviation, and from the table is Azimuth angle 0° and tilt angle 20° has small standard deviation it means the solar panel will get great radiation and great electrical energy every month in one year than the other azimuth angle.

4 Conclusion and Recommendation

From the research conducted, the roof design of the skillion roof design that gets the optimum radiation from solar panels is a roof design with an azimuth angle of 0° and a tilt angle of 20° with smallest standard deviation and has an average solar radiation of 442.96 W/m^2, a maximum radiation of 483.09 W /m^2 and a minimum radiation of 399.80 W/m^2. This design can be used as a reference or recommendation for azimuth angle and tilt angle for installing solar panels on the roof of a household or building to get optimum radiation every month of the year in Yogyakarta. And with installing solar panels on the roof, not only contributes to supporting the government in conserving energy and also not depending on electricity companies. For further research, we can calculate and analyze the calculate investment costs and savings costs if installing solar panels on the roof.

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