Solar radiation on photovoltaics panel arranging angles and orientation

Navisra Viviani, Sigit Wijaksono, Yosica Mariana
Architecture Department, Faculty of Engineering, Bina Nusantara University, Jakarta, Indonesia 11480.

Corresponding author: swijaksono@binus.edu

Abstract. For a comply the needs of electrical energy in office buildings, there needs to reduce from fossil energy to renewable energy. Photovoltaic panels are devices that convert sunlight and solar radiation into electricity. For the application, this device it is necessary to study so that the panel can work effectively. The aspects that influence the use, there are the geographical location, the slope of the panel, the orientation of the building, and the shading of surrounding objects. This study examines these aspects to get a mass configuration that can adapt from the application of photovoltaic panels. By using Simulation from the Formit application, this study obtained a mass configuration that can reduce 18% of the electrical energy for office building approach in South Jakarta

Keywords: photovoltaics panels, faced, solar radiation.

1. Introduction
For comply the needs of comfort and safety in office buildings, this will have an impact on the need for a lot of mechanical energy. Based on Jakarta green building data, Office buildings have the highest energy consumption in mechanical cooling by 55% and lighting by 27%. If too much energy consumption, this can affect carbon emissions (CO₂), threatened global warming and climate change. Therefore, to keep on accomplished the needs of energy on office building are needed to conserve energy expended. To reduce an impact on the need for a lot of mechanical energy, there are two strategies that can be used, firstly by reducing energy supply and secondly by processing building designs.

Renewable energy is really needed and these to support the development of EBT for complied the achievement of the 23% energy mix in accordance with the national energy policy of 2025. Solar energy is a renewable energy that has the best potential in its use, because the energy source will never run out. Undang-Undang No 3 Tahun 2014 concerning Industry, states that the energy generation industry, including the solar module industry, is positioned as a priority sector that needs to be encouraged for development until 2035 [1]. Therefore the use of solar energy can be a solution in an effort to save energy in the office building, and also factory [2].

The solar panel device to absorb solar radiation known as photovoltaic panel. In the field of Architecture, photovoltaics has begun to be integrated into building facade and roof. But in optimizing the function, shall pay attention to the climate around the building. The facade and roof are needs to pay attention to climatic conditions in the selection of materials, installation techniques, etc. Thus, this
study appears problematic "How does the application of photovoltaics panel that adapts from its factors of placement, that could reduce the needs for electrical energy in the office building?". This research will be simulated at the site location on Metro Pondok Indah, South Jakarta with the function as the Office building.

For the humid tropical climate in Indonesia in addition to air humidity, and the influence of wind speed, solar radiation is the main factor that will be faced by building facades both translucent building facades and opaque opaque building facades [3]. And in the use of photovoltaic panels, the change in the form of solar energy concerning buildings energy-saving is electrical energy, while the amount of solar radiation reaching the earth also varies geographically.

Based on literature studies to optimize the use of photovoltaic panels as building facade and roof, should be able to maximize solar radiation that radiates to photovoltaic panels. Therefore, the climatic conditions around the building will influence the choice of photovoltaic type, installation technique, orientation of placement, and slope of photovoltaic placement. To calculate the reduction in electrical energy, it will be calculated from the total ac power requirement, because based on Jakarta green building data, the consumption of electrical energy from ac in office buildings is the highest that reaching 55% of 100%. The tilt angle and orientation of PV modules are important factors that affect the performance (Hussein et al, 2004) [4].

From the aforementioned arguments, the steps for this research start from: (1) Study the climate around the selected site location, (2) Analysis of solar radiation that will radiate into the building's surface (Orientation and tilt angle of PV modules), (3) Analysis configuration building mass (4) Analysis of Photovoltaic Installation Techniques that applied into Building Facades (including the slope of best photovoltaic placement angle). And from that analysis, then calculated how much energy-saving can be applied for office buildings in selected site location.

2. The methodology

2.1. The method of study

The methodology used in this research is basically studies a literature review on the application of photovoltaic panels to the building facade. The diagram below shows the methodology applied in this study based of literature review (Figure 1).

![Diagram of methodology](image)

**Figure 1.** The diagram of methodology

2.2. Simulation

The methodology used to assess the effectiveness of photovoltaic systems is carry out tests using computer simulations of solar radiation and then the results of the simulations are compared to find the advantages and disadvantages of orientation, panel type, installation and slope techniques in photovoltaic installation. The application used to measure solar radiation is FormIt. The study selected site location in Kebayoran Lama, at Jalan Metro Pondok Indah, Jakarta Selatan. The studies location is in Sub Zone as a place of office and service activities, has an area of 4,657,76 m².
2.3. Calculation
With the aim of energy-saving it is necessary to calculate how much energy efficiency can be applied to office building in selected site location as a validation of accomplishment the results. This calculation is to get the quantity of panels that can be applied to building façade and roof. And what percentage of energy efficiency is achieved.

3. Result and Discussion
3.1. Study the climate around the selected site location
Based on literature studies, the use of photovoltaic is influenced by the climate of the building location. For this studies selected site location, it is located in Jakarta City, for this area the annual temperature is above 18 °C and can reach 38 °C during the dry season, therefore Indonesia is included in the tropical climate group which has a humid and dry climate. With this the use of photovoltaics can works well in selected site location.

Figure 2. (a) Sunrise and Sunset charts in Jakarta, (b) Sunpath in Jakarta. Source: Gaisma.com

Figure 2a illustrates that solar radiation in Jakarta is relatively the same every month, so the solar energy received will also be the same every month. Therefore the use of photovoltaic panels can be maximized in the hottest surface. In Figure 2b, the movement of the sun at this location has a maximum solar rotation from east to west. So, the greatest heat from the sun comes from the east and west, in accordance with the movement of the sun. Therefore the use of photovoltaics to get the greatest solar radiation to maximize energy utilization can be integrated on the west and east sides of the building. For the use of photovoltaic panels, it is also important to note the angle based on falling sunlight. Geographically the location of the point of sun fall in Jakarta is from the north with a distance that is still below the equator, just not falling upright in Jakarta, therefore it is necessary to tilt the angle of the placement solar panels leading to the point of the sun's fall. Based on book of Lencer, 2007, for panel placement in hot climates the maximum slope is at an angle of 15°.

3.2. Solar radiation that will radiate into the building's surface
The basic shape of the building to be simulated is based on D.K Ching's book in Architecture Form, Space, & Order edition 4 (2015), there are 3 basic shapes, namely a square, a circle, and a triangle. Then for the floor height and area follow the existing KDB and based on the Architect’s Data Book volume 2 states that a typical floor area for an office building is ideally 1000-1600 m². Table 1 shows the basic shape of the box to be simulated using orientations 0°(north-south) and 45°(northeast-southwest) based on the GSB site. And it is also the result of a study of regulations and site conditions, by obtaining a square building with a size of 30 m x 30 m with an area of one floor is 1200 m² and the total building area is 9000 m² for 10 floors.
Based on the simulation results, the reception of solar radiation whose value has decreased the least is on the roof, west, and east. This clearly states because the direction of the sun moving on the earth is from west to east, and Indonesia is located on the equator so that the roof also has a high value of solar radiation because it is highlighted continuously.

Table 1. Solar Radiation Simulation Square Results

| Side surface | Solar Radiation (kWh/m²) |
|--------------|--------------------------|
| Southeast    | 680.4 kWh/m²             |
| Southwest    | 707.1 kWh/m²             |
| Northwest    | 833.2 kWh/m²             |
| Northeast    | 828 kWh/m² at the top    |
|              | 590 kWh/m² at the bottom |

Table 2. Data from Simulation of Solar Radiation in the form of a Basic Circle and Triangle shape

| Month  | Circle Shape | Triangle Shape |
|--------|--------------|----------------|
|        | Highest Radiation (kWh/m²) | Solar Radiation (kWh/m²) |
|        | Tilt angle 1 | Tilt angle 2 | 0° | 120° | 250° |
| April  | 90° = 597.7 | 270° = 599.2 | 181.0 | 544.5 | 487.3 |
| Juni   | 57° = 543.0 | 300° = 568.5 | 427.5 | 294.7 | 253.5 |
| September | 75° = 584.2 | 275° = 564.0 | 203.6 | 473.5 | 457.7 |
| Desember | 120° = 612.7 | 250° = 589.1 | 65.3 | 612.7 | 492.7 |

The results of the analysis of the square shape with angular orientation 0° and 45° obtained the most optimal west and east sides. It's just that the orientation angle is still not certain optimal, and it needs to be tested to determine what basic shape of the building mass is optimal for applying photovoltaic panels. So after the square shape, the circular shape will be tested to find out at what angle the solar radiation is radiating to the building surface. Then after getting the correct angle of orientation, add a triangular analysis, and evaluate the shapes of squares, triangles, and circles, which configuration of
the base mass is more appropriate. Table 2 shows the simulation result of the basic circle shape, with a total of 10 floors per floor area of 1000 m².

Based on the study of solar radiation on the basic shape of the circular building mass, it can be seen that the distribution of solar radiation spreads unevenly so that the surface area to be installed with photovoltaic panels will be less. Then there is the orientation angle that gets the greatest radiation value at the 4 months that are tried. The result gives an orientation value that is different from the value of the radiation released. Meanwhile, compared to the previous square shape, the surface area that is exposed to direct solar radiation is more.

Next is a triangle shape to be the basic shape for the simulation and to follow the simulation angle from the previous circular shape simulation. The triangle used is equilateral. When doing the simulation, the search for the right angle to all sides to receive the best solar radiation obtained angles 0°, 120°, and 250°. But also each side of a certain month has decreased, which makes photovoltaic panels not optimally receiving solar radiation.

So that from the three basic forms of simulation, it can be concluded that the optimal basic shape for receiving solar radiation is square. For the circle shape, it can also be a reference for the basic shape because the curved side can be extended again according to the right angle. Next is from the basic shape that has been chosen, which is the basic shape of the square that will be transformed into its mass shape, in changing its shape based on the amount of solar radiation that will be received by the side of the building and adjusting the floor area requirements according to KDB.

From the data above, which is the simulation result of the transformation of the mass form of a building, we get an ellipse shape as the last shape. To determine the mass of the building between mass 3 and 4, it is necessary to know the total surface area of the mass for which the photovoltaic panel is attached. Then the next step is to look for aspects that affect the angle of the panel, find the correct panel installation technique, and finally calculate the total photovoltaic panels that can be installed.

### 3.3 Analysis of Photovoltaic Panel Tilt Angle

Based on Roberts & Guariento in the book Building Integrated Photovoltaics: A handbook (2009) [7], the slope of the photovoltaic panels that will be integrated into the facades and roofs of buildings needs to be considered because based on the geographical location of the sun's falling point in each location is different. Table 3 shows the simulation results of the slope of the photovoltaic panels which will be integrated into the building facades, namely the west and east sides of the building mass. The tilt angle of the panels possibilities arranged based on these theories:

1. Folding roof configurations based on solar’s altitude and 10-15° interval (Hussein, et al, 2004) [4], placed between 10-75° (for North orientation), 3-71° (for South orientation), 3-75° (for East orientation), 10-78° (for West orientation).

2. Monocrystalline PV module 360 Wp

| Month | Tilt angle 10° West | Tilt angle 10° East | Tilt angle 15° West | Tilt angle 15° East |
|-------|---------------------|---------------------|--------------------|--------------------|
|       | Max | Min | Max | Min | Max | Min | Max | Min |
| JAN   | 922.4 | 918.3 | 929.9 | 921.8 | 922.0 | 922.0 | 925.5 | 925.5 |
| FEB   | 947.3 | 947.3 | 949.5 | 929.2 | 946.3 | 946.3 | 937.3 | 937.3 |
| MAR   | 942.3 | 942.3 | 949.5 | 925.3 | 932.3 | 932.3 | 937.3 | 936.3 |
| APR   | 905.7 | 898.4 | 901.3 | 901.3 | 902.0 | 902.0 | 904.9 | 904.9 |
| MAY   | 843.5 | 814.4 | 832.9 | 824.6 | 829.4 | 817.9 | 828.1 | 828.1 |
| JUN   | 766.6 | 736.5 | 756.5 | 734.3 | 756.5 | 746.5 | 737.6 | 739.5 |
| JUL   | 795.9 | 795.9 | 795.9 | 795.9 | 799.3 | 799.3 | 799.3 | 799.3 |
| AUG   | 851.0 | 834.2 | 869.8 | 869.8 | 841.4 | 841.4 | 873.3 | 873.3 |
| SEP   | 926.0 | 904.9 | 928.3 | 928.3 | 915.0 | 911.4 | 928.3 | 928.3 |
| OCT   | 938.3 | 924.7 | 942.3 | 942.3 | 931.4 | 924.9 | 938.6 | 938.6 |
| NOV   | 936.1 | 922.5 | 936.8 | 923.8 | 924.9 | 920.5 | 929.4 | 920.1 |
| DEC   | 901.6 | 889.9 | 908.9 | 908.9 | 890.4 | 855.4 | 908.9 | 908.9 |
From the analysis result data, the slope of the panel 10° for both the west and the east side is the optimal angle for the slope of the panel, because it receives a higher solar radiation value than the angle of 15°. The result of a slope of 10° for both the east and west sides is the optimal angle for the use of photovoltaic panels on the building facade.

Next is the determination of the optimal panel slope and direction for the use of photovoltaic panels on the roof of the building. Table 4 shows the data results from simulating the slope and direction of the photovoltaic panels on the roof of the building. The selected angle is a summary of several journals, namely 10°, 15° and 25°. The direction of the solar panels is based on a north-south orientation.

| Month | Annual radiation received tilt 10° roof | Annual radiation received tilt 15° roof | Annual radiation received tilt 25° roof |
|-------|----------------------------------------|----------------------------------------|----------------------------------------|
|       | N        | S        | E        | W        | N        | S        | E        | W        | N        | S        | E        | W        |
| JAN   | 892.2    | 956.2    | 929.9    | 922.4    | 858.5    | 956.2    | 925.5    | 922.0    | 719.1    | 934.5    | 895.9    | 884.8    |
| FEB   | 934.5    | 957.2    | 949.5    | 947.3    | 912.0    | 957.2    | 937.3    | 946.3    | 810.6    | 907.3    | 918.9    | 905.4    |
| MAR   | 946.5    | 942.0    | 949.5    | 942.3    | 938.3    | 927.0    | 937.3    | 942.3    | 890.3    | 836.9    | 917.9    | 913.2    |
| APR   | 931.3    | 869.0    | 907.3    | 905.7    | 931.3    | 836.0    | 904.9    | 902.0    | 901.3    | 700.3    | 875.9    | 873.1    |
| MAY   | 885.9    | 787.1    | 843.5    | 832.9    | 896.5    | 748.2    | 828.1    | 829.4    | 891.5    | 592.9    | 803.6    | 793.7    |
| JUN   | 827.7    | 695.4    | 756.5    | 766.6    | 844.6    | 674.9    | 739.5    | 756.5    | 861.6    | 478.3    | 717.4    | 743.2    |
| JUL   | 836.3    | 704.9    | 795.9    | 795.9    | 853.4    | 661.0    | 799.3    | 799.3    | 870.6    | 509.3    | 775.7    | 775.7    |
| AUG   | 893.8    | 799.4    | 869.8    | 851.0    | 904.4    | 767.7    | 873.3    | 841.4    | 886.6    | 633.9    | 838.1    | 827.2    |
| SEP   | 927.3    | 911.3    | 928.3    | 926.0    | 923.7    | 892.9    | 928.3    | 915.0    | 872.6    | 790.0    | 895.5    | 893.5    |
| OCT   | 927.0    | 941.6    | 942.3    | 938.3    | 912.3    | 937.8    | 938.6    | 931.4    | 827.6    | 878.3    | 908.4    | 900.3    |
| NOV   | 892.2    | 949.3    | 936.8    | 936.1    | 862.5    | 949.3    | 929.4    | 924.9    | 739.8    | 926.8    | 895.4    | 906.2    |
| DEC   | 838.4    | 940.0    | 908.6    | 901.6    | 797.6    | 951.3    | 908.9    | 890.4    | 649.2    | 932.5    | 871.7    | 870.9    |

From the data above, the slope of the panel for 10°, 15°, 25° on the roof on the north side has a high value from the other side and also experiences an insignificant decrease every month, so the north side for the slope of the panel is optimal.

Based on these three data, when viewed from the highest radiation value at each slope of the panel, the 10° angle is the superior slope of the panel compared to the other 2 angles. Then the three data have the conclusion that the north side is the optimal side for the direction of the panels on the roof. With this, it can be concluded that the slope of the photovoltaic panel for the roof can use an angle of 10° with the direction to the north.

### 3.4 Photovoltaic Panels Installation Techniques that integrated into Building Facades

In the studies on literature review, there are a lot of distribution of installation techniques, but can be categorized into 2. Categories that are attached to the walls of buildings or categories that are separate from building skins. While in the selection of these techniques also need to consider the effects given. These effects can be in the form of views, exits, aesthetics, and energy efficiency that is released. Therefore, it is necessary to analyze from its installation technique, this study of literature based on Anders, K. C in the book Building Integrated Photovoltaics (1993) [8]:

1. Categories that are attached to the walls of buildings - *Photovoltaics Sawtooth Curtain Wall*
2. Categories that are separate from building skins - *Photovoltaics Awning System*

From this analysis it can be concluded that the installation system greatly influences the solar energy obtained, it can be seen from the simulation results that the installation of a photovoltaic system that is tilted and functions as a sun shading will have more a positive impact. Because the falling sunlight is captured by the slope, then the glass surface is lower than the solar radiation so that it will save even more energy. Therefore, the installation system also influences the effectiveness of the use of photovoltaic. Based on the data above, it is found that the number of panels that can be
integrated from the two forms of building mass, namely at mass 4 and mass 5. The result has several panels that are very close to only a difference of 30 panels, wherein mass 3 the number of panels that can be integrated is 620. Panels, while at mass 4 are 650 Panels. With this, the two-building forms can be an option for the use of photovoltaic panels because the difference is not far away.

3.5 Calculation of Reduction in Electrical Energy Requirements
The input power received by the solar module from solar radiation does not enter 100% of the inverter, because it is affected by component and embed losses. Table 5 are the stages of calculating solar panel output quoted from the scientific journal Hariyati, Qosim, &Hasanah with the title Integrated Photovoltaic Concept on Grid with the STT-PLN Building (2019) [9], with the use of panel with capacity of 350 Wp polycrystalline PV.

| PV Power | 350 Wp |
|----------|--------|
| Type of losses | Magnitude of Losses | Power |
| Losses from Manufacture (Power Tolerance) | 3% (0.97) | 339.5 W |
| Losses from dirt | 5% (0.95) | 322.525 W |
| Losses from temperature module | 5.7% (0.943) | 304.141W |
| Losses from Cables | 5% (0.95) | 290 W |
| Total Losses | | 60 W |
| **Total Power Output of PV** | **300 W – 60 W** | **290 W** |

From the calculation results of the electrical energy requirements for air conditioning and the energy output of the photovoltaic panels, into the accumulation of panels that can be used at the selected mass, it becomes a comparison for a larger proportion. Table 6 shows the calculation result of each mass.

| Table 6. A decrease in Electrical Energy for Mass 3 and 4 |
|---------------------------------------------|
| Total Panel (PCS) | Mass 3 | Mass 4 |
| Energy PV Output – PI (290 W/h) | 179800 | 188500 |
| Energy max (4.33 h) | 778534 | 816205 |
| The percentage drop from the AC | 30.1 % | 31.6 % |
| The percentage of a total reduction (55% AC) | 16.6 % | 17.4 % |

Based on the data above, which is a calculation of energy reduction, it can be concluded that Mass 4 has a greater percentage of the overall reduction in the need for electricity use. The percentage obtained from mass 4 is 17.4% of the need for electrical energy to become renewable energy with photovoltaic panels in office buildings. This percentage has passed the reduction target according to RIKEN data (2011), the potential for commercial buildings to use renewable energy with a target of 10% -30%. This mass form succeeded in reaching 17.4%, for mass number 3 it had also passed the minimum target of 16.6%. Overall, the mass shapes 3 and 4 can be a reference for buildings to use photovoltaic panels on the roof or facade.

4. Concluding Remarks
In this study, the location chosen was on Jalan Metro Pondok Indah, South Jakarta. Various analysis with the limitation of the panel laying research that avoids shading of the surrounding objects, and the amount of solar radiation emitted to the building using simulations from the Formit application. Three basic shapes are simulated, namely squares, circles, and triangles. Of the three basic building shapes that are simulated, the square shape is the most effective in capturing solar radiation because of the received surface area. In the square shape itself, the optimal side for the use of photovoltaic panels is
the 90' and 20' (East and West) orientation for the facade. Then the circle shape gives the orientation angle which value is higher in a certain month, the angles are 57', 90', 120', 300', 270', 275' for each month. From the angle of orientation obtained, this determines the change in mass configuration, so that the building mass adapts to the received solar radiation. Then the effective slope of the photovoltaic panels for the roof is 10' towards the north, while the slope of the photovoltaic panels integrated into the building facade is the most effective angle is 10'.

Obtained 2 building masses as a building shape option according to the results of the analysis, then both were tested based on the panel installation technique, the selected panel output power was 350 Wp, and the slope of the panel. This is done to get the total panels that can be used in the office building. The final result obtained is the form of mass configuration with a total of 750 photovoltaic panels used. The reduction effectiveness value for the installation of photovoltaic panels reaches 361.6% of the calculation of the need for air conditioning load. Or equivalent to 17.4% of the total electricity needs. With this, it can be stated that in the installation of an effective photovoltaic panel it is necessary to pay attention to the installation technique, the type of photovoltaic panel selected, the orientation of the photovoltaic placement, and the tilt for the correct placement of the photovoltaic to reduce the work of the air conditioning system. The use of electricity for the convenience of using continuous air conditioning will cause fossil energy to run out while using photovoltaic panels will help reduce the use of fossil energy electricity in office buildings.

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