# Optimization of Tilt Angle and Orientation of Building Integrated Photovoltaic as Roofs in Tropical Areas with High Precipitation

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## Abstract

Indonesia has determination to accelerate roof solar photovoltaic (PV) infrastructure in term of green house gas emission reduction target of 29% in 2030 in Indonesia's National Determined Contribution. Proper orientation and tilt angle of solar PV installation will give optimum energy to meet the infrastructure's need, but shading (e.g. cloud cover) will reduce energy converted in solar PV system. This study aims to compare orientation and tilt angle of roof integrated solar photovoltaic in tropical areas with high precipitation. The method in this study used REVIT software to simulate the roof with different orientations and tilt angle in the study case of Bogor City, Indonesia. The implementation of designing solar panels as a roof (Building Integrated Photovoltaics) needs consideration particularly in tropical areas with high precipitation. The meteorological condition which is related to cloud cover will significantly affect the performance of solar panels at certain times in the area. The characteristics atmosphere in Bogor area tend to have cloud formation at 1 p.m. It will lead to decreased irradiation absorption during the afternoon period (1 p.m. to 6 p.m.). Based on the simulation results, solar irradiance during morning period is significantly higher by 23.68% than afternoon period. The optimal orientation and tilt angle of roof solar PV in tropical areas with high rainfall tends to have 5° and directed to the East.

**Keywords:** High precipitation, photovoltaics, roof, tropical

## 1. Introduction

The application of photovoltaic as an alternative electric energy generator in residential areas is an effort to minimize environmental damage in Indonesia. This effort is in line with Indonesia's commitment to reduce greenhouse gas emissions by 29% (Suharsono et al., 2019). Possible solution for photovoltaics system in populated area is building integrated photovoltaics as roof. Permen ESDM 49/2018 /no.13/2019 is a government regulation that discusses roof PLTS. The goals and benefits based on the Minister of Energy and Mineral Resources 49/2018/no.13/2019 for the community are saving electricity bills and opening up the role of society in the use and management of renewable energy (ESDM, 2020).

Photovoltaics production requires enormous amounts of energy, it is necessary to consider that Indonesia can reduce global greenhouse gas emissions by using photovoltaic as an alternative electricity generation is a design and maintenance of photovoltaic. The maintenance and the design of photovoltaic integrated on the building is an effort to replace the energy used to produce photovoltaic, because by maintaining the life of the photovoltaic and optimizing the energy production performance of the photovoltaic can replace the energy that used for photovoltaics production (Laleman et al., 2011).

Photovoltaic is a device that is highly dependent on solar irradiation. Sky conditions are one of the main factors in solar irradiation. The higher the cloud cover in the atmosphere, the lower the solar irradiation. The application of photovoltaic on the building is related to weather and climate, so the knowledge of local weather and climate is necessary. Knowledge of weather and climate will be one of the considerations to determine the design for applying photovoltaic. One of the efforts to optimize the application of photovoltaic as an alternative power plant is by applying the right passive design to buildings (Aelenei et al., 2012). The application of photovoltaic as a roof (Building Integrated Photovoltaics) or attached to the roof (Building Attached Photovoltaics) needs to pay attention to the angle of inclination and orientation of the roof so that the photovoltaic can produce optimal energy. The slope angle and orientation of each region will have different variables, depending on the characteristics of the area (Masili & Ventura, 2019).

## 2. Methods

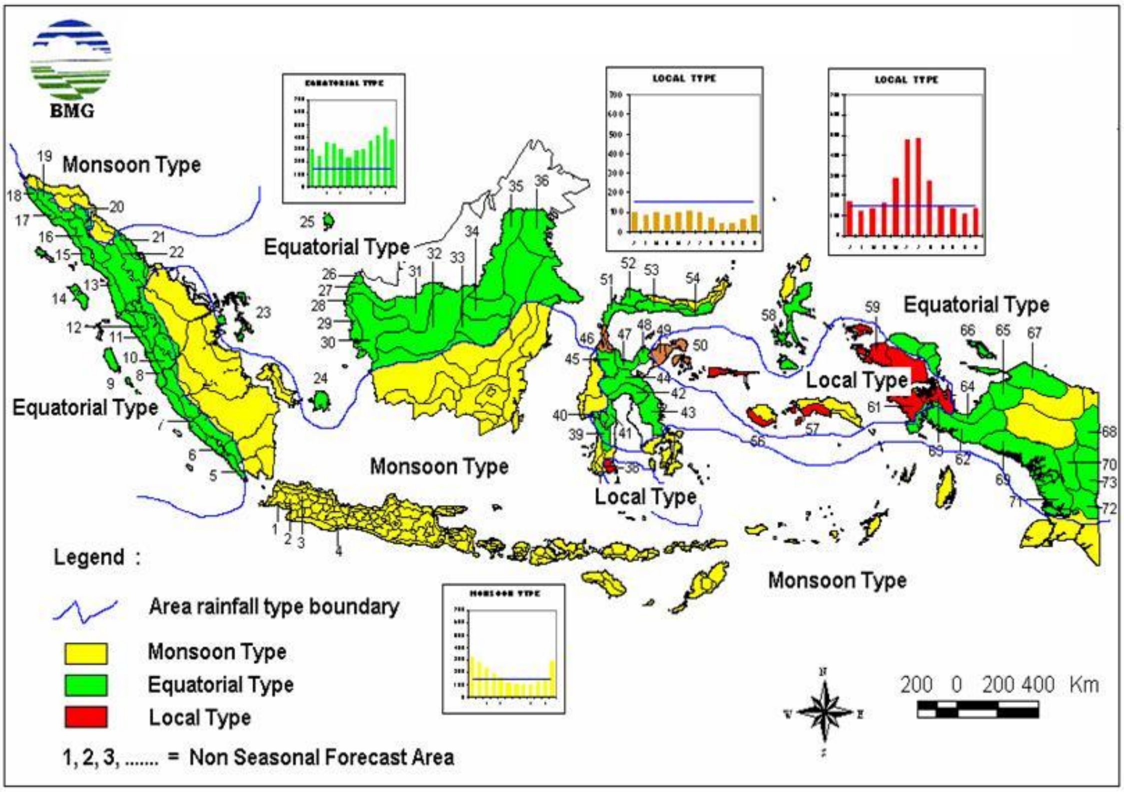
This study uses quantitative analysis methods through simulations using REVIT software regarding optimal irradiation of photovoltaic roofs in tropical areas with high rainfall. Roof simulations are carried out with several variations in the orientation and angle of the roof. The simulation was carried out in one year with a total of 8760 frames in one condition. The location of the simulation is in the location of Leuwiliang, Bogor, Indonesia due to the characteristics of the weather and climate which are under the high rainfall tropical areas. The analysis was carried out after the local weather data collection stage had been obtained. Simulation using REVIT software to determine the optimal photovoltaic integrated roof design requires several variations of the variable angle of inclination and orientation. The variations of the tilt angle variable in the simulation are 5$^{o}$ , 10$^{o}$ , 15$^{o}$ , 20$^{o}$ , 25$^{o}$ , and 30$^{o}$ . Meanwhile, the variations of the orientation variables are East, West, North, and South. All of these variables will be simulated using REVIT software over a period for one year.

Weather data that will be used in this study is rainfall data in the Bogor area. The data used is data taken through measuring devices from the national research agency located in Bogor. The rainfall data used is the measurement data for two years, namely in 2019 and 2020. The weather data will be processed by looking at the average rainfall occurrences for one day. After obtaining the rainfall pattern in Bogor within one day, an analysis of the orientation and the optimal angle of inclination will be carried out for the application of solar panels as roofs in tropical areas with high rainfall.

## 3. Results and Discussion

Tropical climate is a type of climate that is in an area with high temperatures and rain events almost occur at any time of the year. Indonesia has seasonal variations that can be seen in rainfall, so that Indonesia has two seasons including the rainy season and the dry season. Weather and climate in Indonesia is formed by the interaction between macro weather systems and local weather systems (Wirjohamidjojo & Swarinoto, 2010).

*Figure 1. Rainfall pattern in Indonesia*

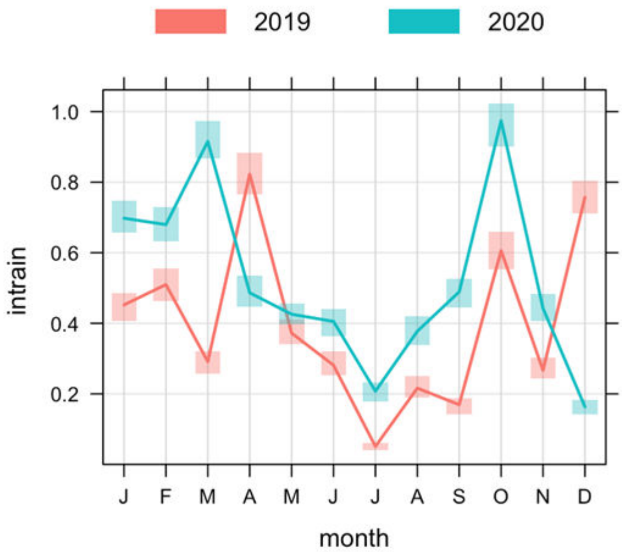



*Source: BMG, Meteorology Agency Indonesia*

Indonesia is a country consisting of several islands. Figure 1 shows the pattern of rainfall in the Indonesian region. Rain patterns in Indonesia are divided into three, the type of rainfall patterns in Indonesia are the monsoonal type, the equatorial type, and the local type. each type has a different annual rainfall pattern. The monsoonal type has a low average rainfall in the middle of the year and a high average rainfall at the beginning and end of the year. The equatorial type has a high average rainfall throughout the year, but the high average rainfall occurs in October. local types in Indonesia are divided into two, which are in the Papua to Sulawesi region (Yulihastin & Febrianti, 2010).

*Figure 2. Rainfall in Bogor area monthly*

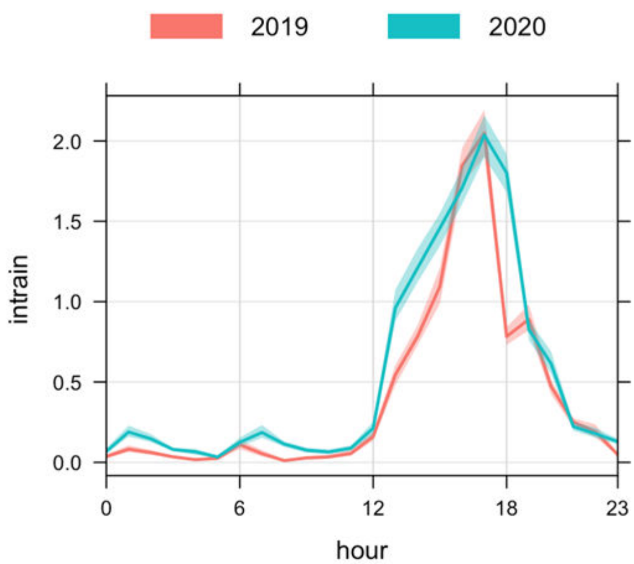
*Source: CCROM-SEAP*




Based on Figure 1 regarding rainfall patterns in Indonesia, the results of collecting rainfall data through measurement tools located in Bogor show results that are following the rainfall pattern in Figure 1. The rainfall pattern in Bogor is a monsoonal type of rainfall. Based on the data obtained, low rainfall occurs in June, July, August, and September (in 2019). This data can be used as a reference for potential irradiation that occurs in the Bogor area.

The rainfall pattern is an important factor in considering a photovoltaic integrated building design. Rainfall measurement data is one of the important data to consider a roof design that is integrated with photovoltaic to obtain optimal energy. The rainfall data required to consider an integrated photovoltaic roof design is the relationship between rainfall and time. The relationship between rainfall and time can show the optimal orientation and angle of inclination.

*Figure 3. Rainfall in Bogor region hourly*

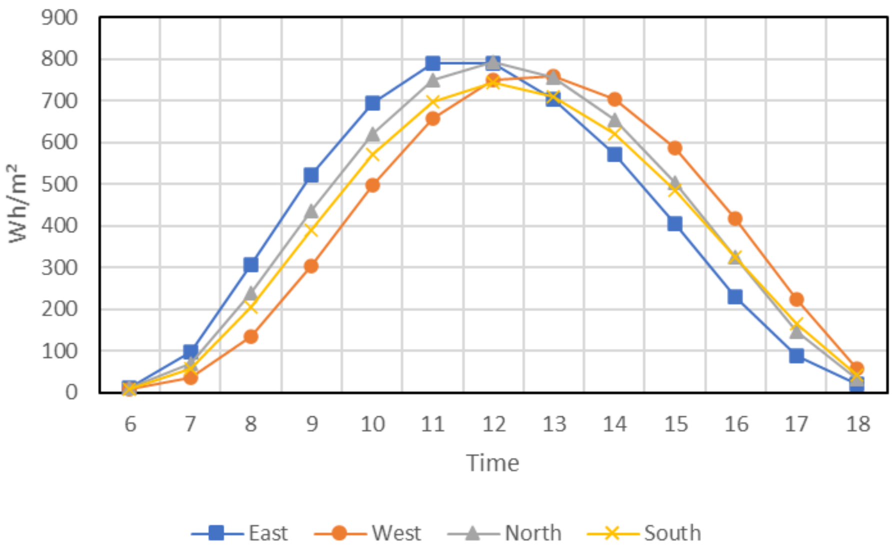


*Source: CCROM-SEAP*

Figure 3 is data from the measurement of rain in the city of Bogor (mm/hour). Based on Figure 3, the average rain event in Bogor increases significantly during the day. This data shows that the incidence of rain in the Bogor area tends to occur during the day. This incident shows that irradiation during the day in the Bogor area is not optimal due to cloud cover in the high atmosphere layer. This condition will affect the integrated photovoltaic roof design.

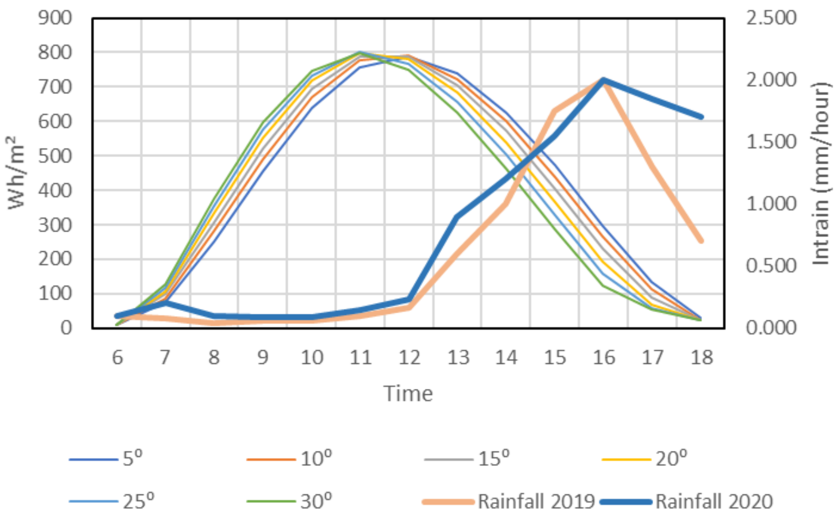
Bogor is a region in Indonesia that has the characteristics of high rainfall. Rain events in the Bogor area tend to occur at 1 o'clock in the afternoon. This is caused by the formation of clouds as a result of warming the earth's surface. The cause of rain events in the Bogor area is the formation of convective clouds due to the formation of unstable air masses. This causes the occurrence of rain in the Bogor area with high rainfall (Farihah, 2016).

*Figure 4. Roof irradiation average on various orientations in Bogor region*




Based on the simulation results shown in Figure 3, the average irradiation obtained by the roof decreased at 1 p.m. The average decrease of irradiation with a roof tilt 15⁰ between the morning and at noon in a year is 23.68%. The percentage of irradiation reduction is obtained by calculating the cumulative irradiation of the average irradiation obtained from 6 am to 1 pm and 1 pm to 6 pm. the total cumulative irradiation from 6 am to 1 pm was 14,127 Wh/m² and the cumulative total irradiation at 1 pm to 6 pm was 6,619 Wh/m². The simulation results show that the optimal irradiation for the application of solar panels is in the morning.

*Figure 5. Roof irradiation average and rainfall on various tilt in Bogor region*




The results of irradiation simulations based on variations in the angle of the roof and the incidence of rain can be seen in Figure 5. The relationship between the angle of the roof and irradiation is inversely proportional. The greater the slope angle of the roof, the lower the irradiation tolerance received by the roof. The peak of irradiation at all angles of the roof slope occurs at 12 pm, so this condition needs to be taken into consideration to determine the roof tilt. Rainfall events in Figure 5 are obtained through measurement results from the CCROM-SEAP. The rainfall data in Figure 5 is the measurement for 2 years. Rainfall events that occur at 1 pm can reduce solar irradiation, this condition needs to be taken into consideration to determine the angle of the roof in the application of photovoltaic as a roof in the Bogor area.

The effect of low roof slope angle on irradiation causes reduced irradiation in the morning. The average reduction in irradiation at all angles of the roof slope reached 67.8%. The highest decrease in average irradiation is 76.5% with the roof tilt at a 30° and the lowest decrease in irradiation is 57.9% with a roof tilt of 5° . The cumulative irradiation based on the variation of the highest slope angle is at the slope angle of 5° and 10° , which is 5270 Wh/m² in one day.

## 4. Conclusion

Based on the results of analysis on simulations and measurements of rainfall in tropical regions with high precipitation, it can be concluded that the optimal orientation and angle of roof is the eastern orientation and the angle of inclination is not more than 15 degrees. The East orientation is the optimal orientation for applying photovoltaic as a roof in the Bogor area due to rain events that tend to occur during the day. The angle of the roof tilt in the application of photovoltaic as a roof in the Bogor area has a slope angle limit that should not be more than 15 degrees due to the low tolerance for summer. The results of the analysis in this study indicate that the application of photovoltaic as a roof or mounted on a roof. The application of photovoltaic in the Indonesian region or other regions needs to consider weather and climatic conditions due to the diversity of rainy seasons.

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