

Analysis of Suitable Roof Designs for a Photovoltaic Panel: A Case Study of Housing Roof in Gorontalo [†]

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Abstract: The demand for PV on roof installations in the household sector is increasing. In this paper, an investigation on optimizing the energy performance of PV on housing roofs is conducted. Three housing roof designs found in Gorontalo city are selected as the mounting planes for PV on roofs. The designs represent stacked gable roofs, complex gable roofs, and complex hip roofs. The purpose of the research is to find which roof shape is better for PV mounting in terms of sun radiation gain and access, mountable spaces, and orientation flexibility. This research employs Rhinoceros 3D to model the three roofs. The models are designed to face 12 directions, from 0° to 330°. Radiation analysis using Ladybug is utilized to study the roof's performance in obtaining solar radiation in all 12 directions. It was found that the complex hip roof has more evenly distributed solar radiation on the roof planes, is flexible for PV mounting in any orientation, but has few mountable spaces. The stacked gable roof has two out of four suitable planes to gain solar radiation, but they are spacious. The complex gable roof has only one out of five suitable planes since they are narrow and prone to self-shading. Overall, a stacked gable roof provides a better option for PV installation compared to the other roof shapes.

Keywords: housing; mounting space; PV on roof; roof space; solar radiation gain



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1. Introduction

The Indonesian government has set a national energy plan to use a minimum of 25% of the roof area for building solar power plant roofs on residential buildings [1]. However, the roofs of Indonesian housing are varied in design. There is no specific instruction on the obligation to install solar panels on roofs. People will be facing problems such as where they should put their renewable energy facilities in their house. Housing developers construct their housing roofs in a variety of shapes to attract buyers. Some of them are irregular roof shapes, which become a hindrance for PV in roof installation [2].

There are many different studies on the potential of a PV roof to generate energy, with emphasis on roof shapes. Barbón et al. found a general algorithm to optimize the deployment of photovoltaic panels installed on irregular flat roof shapes. The algorithm takes into account the irregular rooftop shape, the self-shading of the photovoltaic panels, and some essential variables [3]. Bayón et al. provided the optimal distribution of PV panels on rectangular rooftop shapes. [4]. Moreover, Ioannou et al. presented the optimal configuration of the PV panel rows installed on a square-shaped rooftop [5]. In addition, Barbón et al. [6] determined the optimal distribution of PV panels on the simple shapes of rooftops. Unfortunately, the studies on the topic of PV on a roof mentioned above only consider a flat rooftop as the place to set up PV.

In terms of PV on housing, Esfahani et al. found that shed roofs gain the maximum solar energy in Perth, Australia [7]. However, a shed roof is a simple one-plane roof and can hardly be found in Indonesia's housing. Hachem et al. conducted a study on the effect of the housing geometric form on façade BIPV solar potential [8]. The research did not consider PV on the housing roof. Palmer et al. identified the most suitable buildings based on roof shading but did not take into account the roof shape [9].

The previous articles dealt with the optimalization of PV panels on regular rooftop shapes and regular pitch roof shapes. There is a need to study PV installation in the irregular-pitch roof shape. This paper discusses the PV potential for the complex shapes of housing roof found in Indonesia. The aim is to evaluate the suitable roofs for PV installation on the common housing roof style found in Gorontalo, Indonesia, with the addition of the influence of the Sun's annual movement around the equator.

2. Materials and Methods

Three complex designs of housing roofs are selected to assess the suitability of PV panel installation, as can be seen in Figure 1. They are stacked gable roofs (A), complex gable roofs (B), and complex hip roofs (C). Stacked gable roofs are the most common roof types found in housing in Gorontalo city [10]. Roof A consists of 3 rectangular planes and an irregular plane. Roof B has a rectangular plane, 2 trapezoid planes, and 2 irregular planes. Roof C has 4 trapezoid planes and 2 irregular planes. Roofs A and B have a higher roof part and provide shade for the lower roof part. Planes on roof A only face 2 directions, while B and C face 4 directions. Each roof shape has advantages and disadvantages for PV installation. Rectangular planes provide a fitting shape for the common rectangular PV panel, while PV panels are more difficult to fit in trapezoid and irregular planes.

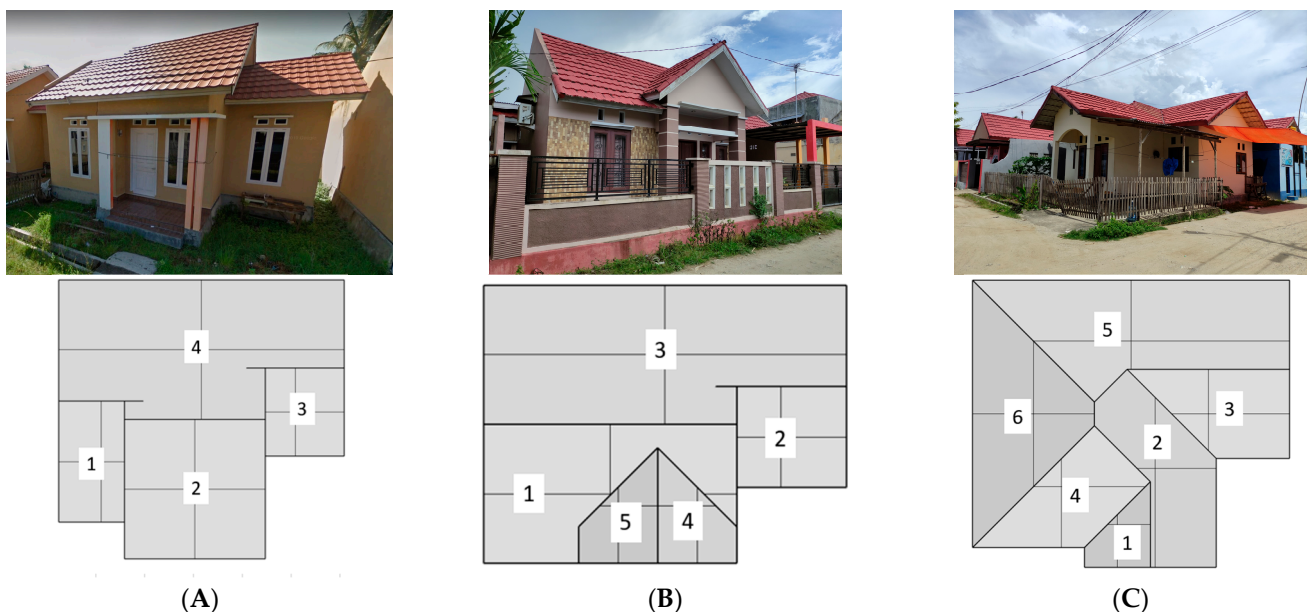


Figure 1. Housing found in Gorontalo city, and the roof plan. Roof (A) is stacked gable roof, (B) is complex gable roof, and (C) is complex hip roof.

Prior to this study, an investigation on the best roof orientation in Gorontalo showed that west-facing surfaces obtain the most solar radiation compared to other orientations [11]. Housing roofs could be facing any direction, but among the 3 roofs, roofs B and C have one of their planes facing west. However, even though the planes are facing west, the existence of self-shading on roofs A and B could reduce the annual solar radiation gains. Therefore, a study on solar radiation gains in several directions of the selected housing is necessary to find out which roof shape provides the most suitable space for PV installation on roofs.

The study in this article deals with radiation gain on pitch roofs under the following conditions: (i) irregular roof shapes; (ii) self-shading of the roof; (iii) roof orientations. The roofs' performance will be simulated using Ladybug's components in Rhinoceros 3D. Simulation flow can be seen in Figure 2. Roof models are set to face 12 directions from 0° to 330° . In this paper, the directions will be expressed in azimuth ($0^\circ, 30^\circ, 60^\circ, 90^\circ, 120^\circ, 150^\circ, -30^\circ, -60^\circ, -90^\circ, -120^\circ, -150^\circ$, and 180°). Simulation is performed for a year-round analysis, from 6 to 18. The performance indicator is annual solar radiation (kWh/m^2) falling on grid points of roof planes. The grid size is 0.5 m, and the visualization of the grid size on the roof plane is given in Figure 3. Each plane of a roof is numbered; thus, the performance of each plane is comparable. The simulation results of each roof type and orientation are plotted into box and whisker charts and then compared. To analyze the plane for mounting capacity, a packing method is employed to determine how much PV can fit in a roof plane. A 550 Wp panel (size of $2279 \text{ mm} \times 1135 \text{ mm}$) is selected as the size to fit in the plane area. The above analysis objective is to find which housing roof shape provides more consistent solar gain and which roof shape provides more space for PV panels.

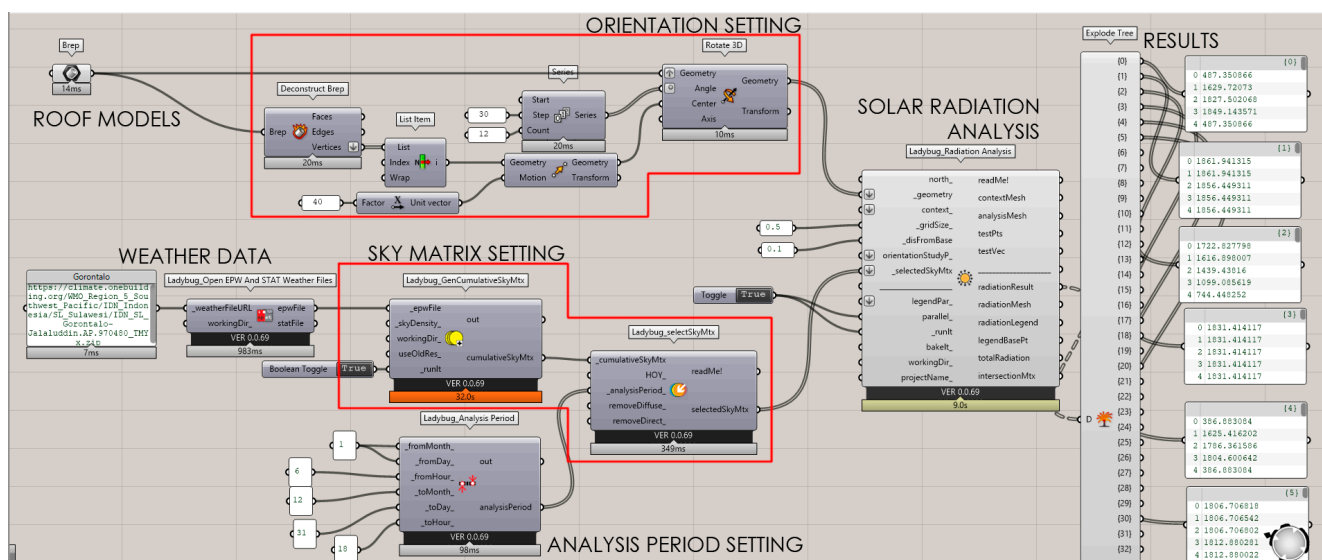


Figure 2. Simulation flow using Ladybug.



Figure 3. Grid points with the grid size of 0.5 on plane 1 of roof A.

3. Results and Discussion

An analysis of the suitable roof design for PV installation is discussed in two subsections. The first part reviews solar radiation gain on the planes of the three housing roof designs. The second part examines the mounting capacity of the roof planes.

3.1. Analysis of Solar Radiation Gain

The comparison of simulation results in 12 directions can be seen in Figures 4–6. From the charts below, it can be noticed that the annual solar radiation gain on plane 1 in roof A has a wide span of values ranging from 106 to 1961 kWh/m². Plane 3 in roof A also delivers similar results, from 150 to 1946 kWh/m². Likewise, plane 1 in roof B has varying values from 106 to 1961 kWh/m², while plane 2 in roof B ranges from 152 to 1955 kWh/m². On the other hand, there is no specific plane in roof C that has such a large interval of values. Even though on different directions, the solar radiation gain on the planes of roof C shows different result, the values generally range from 1715 to 1963 kWh/m².

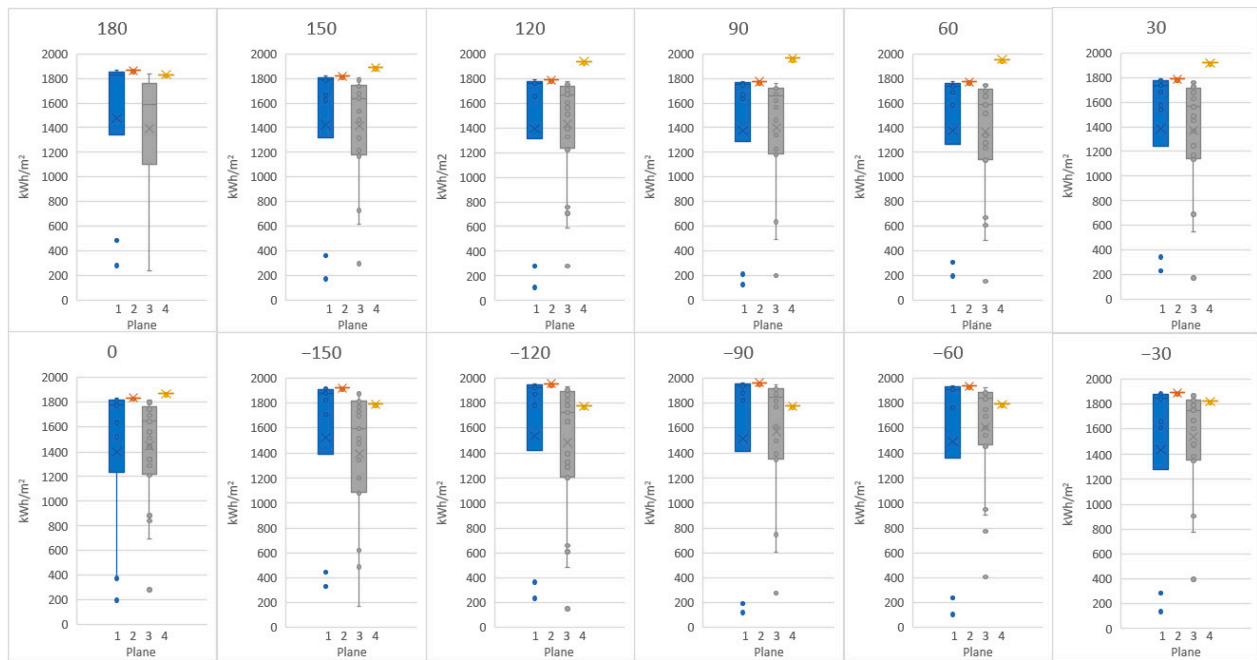


Figure 4. Annual solar radiation gain on roof A.

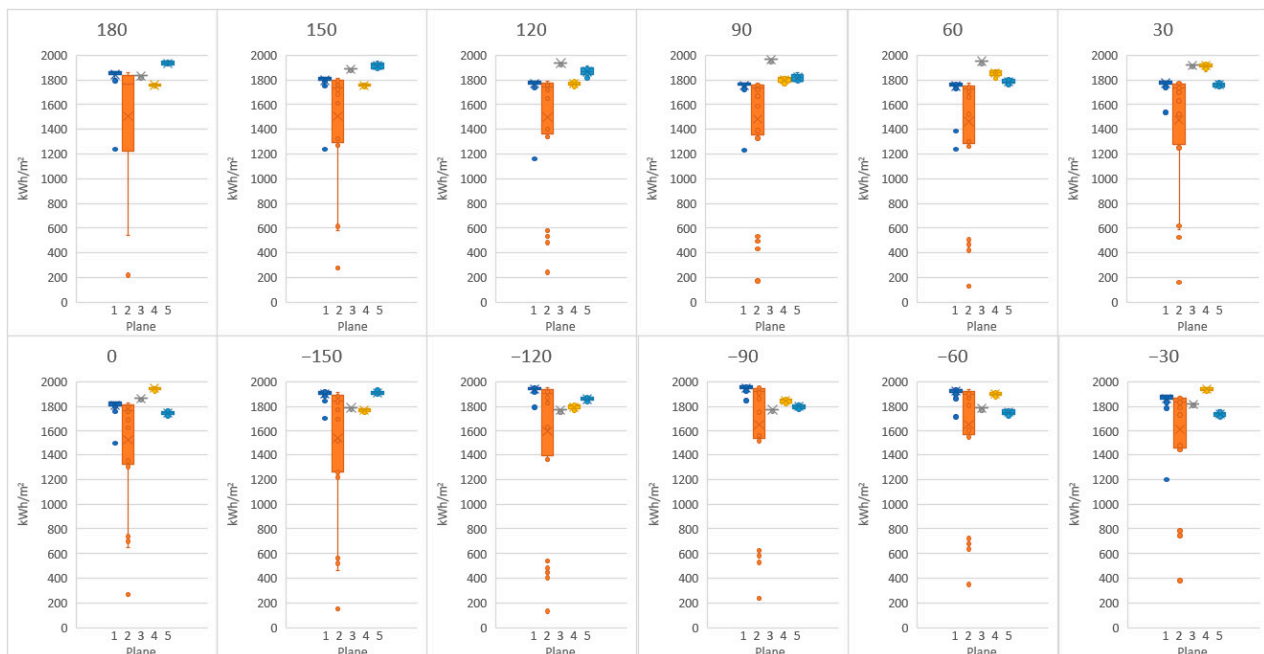


Figure 5. Annual solar radiation gain on roof B.

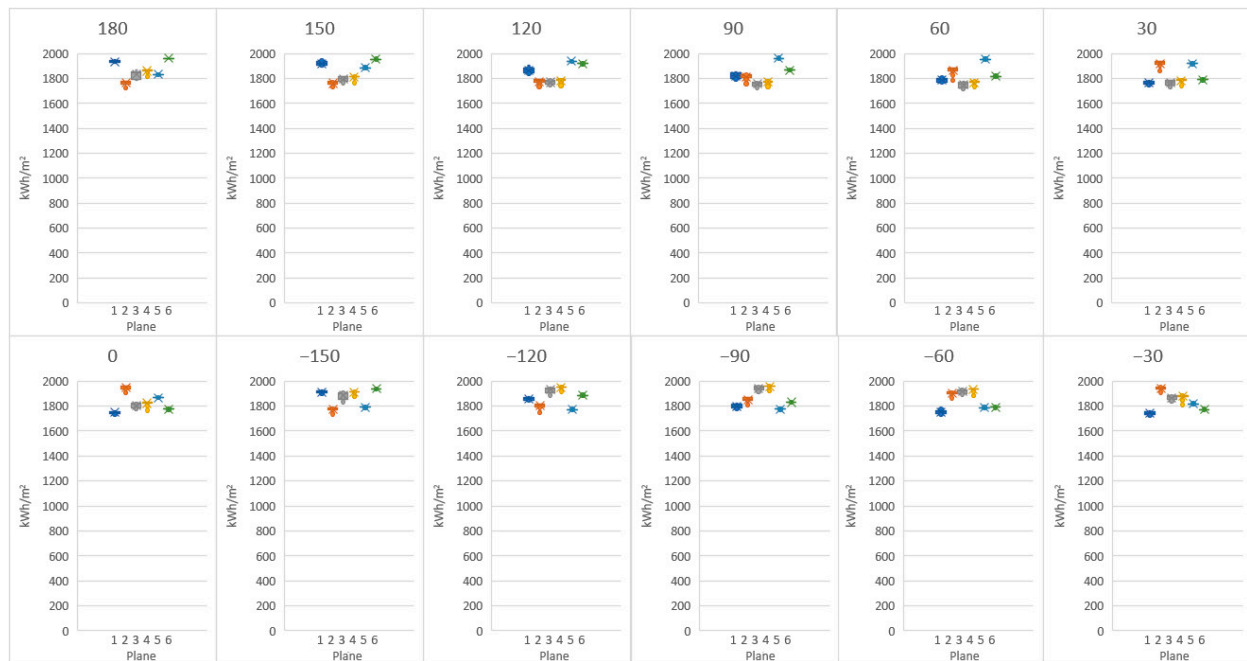


Figure 6. Annual solar radiation gain on roof C.

The enormous deviation of solar radiation gain in roofs A and B is provided by the effect of self-shading. The inconsistency of the solar radiation gain on a plane renders the roof's solar performance low. It is preferable to install a PV panel on a roof with a lower deviation to maximize energy production. Consequently, planes 2 and 4 are recommended as PV installation planes for roof A. Planes 2, 3, and 4 are recommended for roof B. As for roof C, there is no self-shading effect found on the roof, and so all of the planes are acceptable for PV installation.

3.2. Analysis of PV Mounting Capacity

There is only a slight difference in the solar radiation gain in different orientations of roof C, which promotes it as a high-performance roof compared to the other roof design. However, when it comes to PV mounting, there are unmountable planes due to the trapezoidal and irregular plane shape of roof C. Roof planes for PV mounting are selected based on the area with no self-shading. As can be seen in Figure 7, there is more space to mount PV panels on roof A compared to roofs B and C. The utilized method of PV packing on the roof, as demonstrated below is still lacking, as some occupiable space is not filled with PV panels. Still, the results favor roof A.

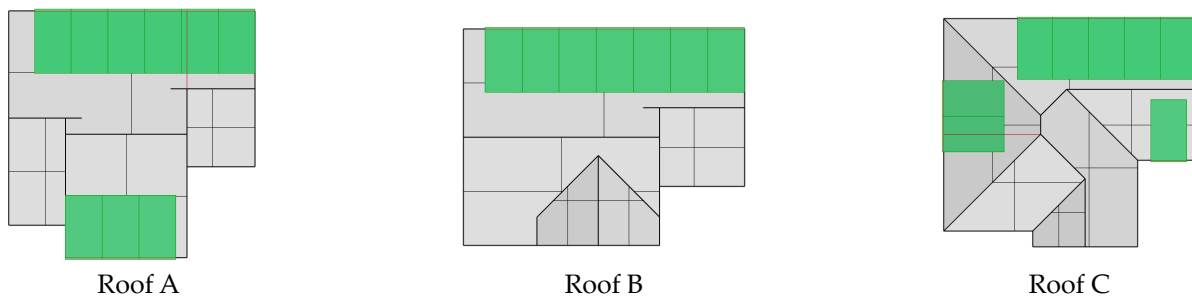


Figure 7. PV mounting capacity on each roof. There are 9 PV panels on roof A, 7 on roof B, and 8 on roof C.

4. Conclusions

A stacked gable roof is the most common roof shape found in the design of detached housing in Gorontalo. Some roof shapes, such as complex gable and complex hip roofs, were also observed in the city. They can be differentiated by the plane shape, directions, and the existence of self-shading. Research on the potential of PV installation on the three roofs results in a stacked gable roof as the best roof shape to provide renewable energy to the housing with the condition that PV panels should not be mounted on the planes that are shaded by the other roof parts.

Complex hip roofs have planes facing four directions. There is no self-shading effect on the roof, and all of the planes are suitable for PV installation. Nevertheless, the presence of trapezoid and irregular planes poses a hindrance for the installation of larger PV panel sizes and limits increased energy production.

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