COMPARISON OF POTENTIAL ENERGY OF SOLAR RADIATION IN ROOFTOP MODELING USING DIFFERENT BUILDING LEVELS OF DETAIL

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ABSTRACT:

The potential for future energy crises is a problem the world is currently facing. Many countries are switching from fossil to renewable energy to prevent an energy crisis. One of the most developed renewable energy today is solar energy. Easy installation makes solar energy installation not only on a large scale but also on a home scale. Urban areas will be very suitable for building solar photovoltaic (PV) roofs due to minimal open areas. In installing rooftop solar PV, sound planning is needed to predict the energy potential that can be provided by solar energy on the rooftop of a building. Spatial modeling can be done to determine the energy potential and suitable location for rooftop solar PV installation. In building rooftop solar PV modeling, the level of detail of the building will affect the results of the model. The rooftop's shape and the building's height will affect the amount of solar radiation going into the building. However, the higher the level of detail of the building, the higher the cost and processing time will be. This study will review the differences in modeling the potential of rooftop solar PV using different levels of detail. This research will integrate solar radiation data from remote sensing to determine the energy potential of solar radiation and digital surface model data from photogrammetry to create a level of detail for buildings. Integration of solar radiation data and the level of detail of the building will use hillshade analysis. Hillshade analysis can review the shadow effect on the rooftop of a building which will be directly related to the potential of solar energy on the rooftop of the building. This study determines the energy potential on the rooftop of the building with different levels of detail, namely 0, 1, and actual shape, to determine the difference in energy potential in the three scenarios. Hopefully, this research will determine the best level of detail for modeling rooftop solar PV. The best model that can show high accuracy value but at a lower price. Hopefully, this research can also assist policymakers and the public in planning for rooftop solar PV installations to develop renewable energy.

1. INTRODUCTION

Solar energy is a renewable energy widely developed today (Islam et al., 2008; Montoya et al., 2014; Zahedi, 2010). This prevents global climate change and future energy crises (Creutzig et al., 2017; Farghali et al., 2023; Raheem et al., 2016). Solar energy is one of the widely used renewable energy. Solar energy was chosen because solar cells were easily installed (Hosenuzzaman et al., 2015). Solar Photovoltaic (PV) can be installed on large, medium, and home scales (Guerin, 2019; Ihsan et al., 2022a; Tamimi et al., 2013). Installation can be done on the ground, floating in the water, and on roofs of buildings (Ihsan et al., 2021; Kumara, 2012; Sakti et al., 2022). In dense urban areas with limited open areas, rooftop solar PV can be an option to utilize solar energy (Sakti et al., 2022).

Good planning is needed in installing solar PV roofs, knowing the roof's potential. To find information on solar radiation hitting the roof, remote sensing technology can be used to observe solar radiation with specific temporal and spatial resolutions (Principe and Takeuchi, 2019). In determining the potential of solar PV roofs, it will also be influenced by the shape of the roof, rooftop aspects, and the shadow of other objects around the rooftop of the building. In performing shadow modeling, 3-dimensional information is needed (Desthieux et al., 2018; Hong et al., 2017; Suomalainen et al., 2017). Several methods, such as photogrammetry, Lidar, and satellite imagery, can obtain 3-dimensional information. It is necessary to integrate solar radiation data and detailed 3-dimensional information on buildings to determine the potential of solar energy on the rooftop of the building.

Several studies determine the potential of rooftop solar energy by integrating solar radiation and building height information. Research Hong et al. (2017) determined solar PV potential and site availability for solar PV using Hillshade analysis. This study detected the influence of the shadow of the building on the rooftop of the building. Another study was conducted by Suomalainen et al. (2017), who determined the solar PV potential of roofs by reviewing the slope aspect and shadow of surrounding objects. Further research was conducted by Desthieux et al. (2018) to determine the potential of solar PV not only on the rooftop of the building but also on the walls of the building. Research Hong et al. (2017); Suomalainen et al. (2017); and Desthieux et al. (2018) used lidar data to determine building height information. Lidar data is one of the data that can form the rooftop of a building in detail with high resolution. However, high-resolution lidar data requires an extended processing time and high costs over a large area. One alternative to determining building height information is to use open data to reconstruct building height (Frantz et al., 2021; Ihsan et al., 2022b; Misra et al., 2018; Yang and Zhao, 2022). However, spatial resolution is classified as medium to low in open data. Therefore, using spatial data in addition to only one height information in each building also allows the height of the building at 1 pixel to have the same value (Ihsan et al., 2022b). From the point of view of detailed information, the building height data obtained with the level of detail one will differ from the actual form value (Huang et al., 2022). The difference in the detailed shape of the rooftop building with the actual one will result in a difference in the calculation of the potential solar PV on the rooftop of the building.

This study calculated the difference between the model with a level of detail of 0, 1, and the actual shape in determining solar radiation on the rooftop of the building. In addition to reviewing the influence of rooftop shadows, this study will also review the influence of slopes and aspects on the potential for solar radiation to reach buildings. Hopefully, this study can show the significance of the difference between the use of roofs and ways to overcome these differences. With this research, it is expected to be used by policymakers in determining the potential of rooftop solar PV in urban areas.

2. DATA AND METHOD

2.1 Area Study

This study was conducted at the Bandung Institute of Technology (ITB) campus in Bandung City, Indonesia. The study area is around 107º36'40"E, 6º53'25"S. ITB was chosen because its area is in Bandung City, the capital of West Java province, and is one of the samples for smart cities in Indonesia. Hopefully, this research can be developed to determine the potential of rooftop solar PV throughout Bandung, which is expected to help realize smart cities in Indonesia later. The area of research study can be seen in Figure 1.

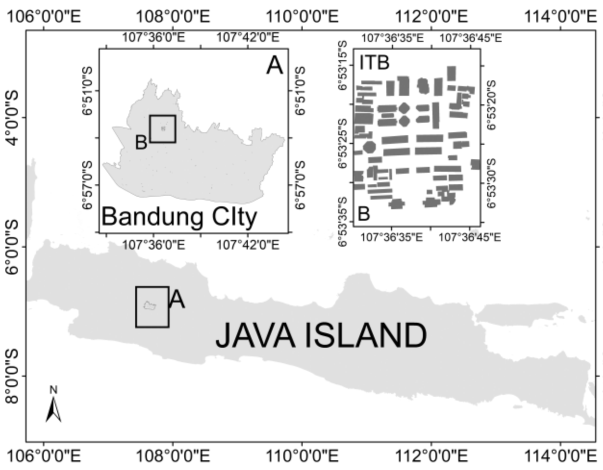

Figure 1. Study area

2.2 Data

Determining the potential of solar energy on the rooftop of buildings only uses two data, namely solar radiation data and the Digital Surface Model (DSM). The solar radiation data used is the monthly average radiation data in the research area which will later be used as the primary data in determining the potential of solar energy in the research area (Abatzoglou et al., 2018). The DSM data used is photogrammetry measurement data with a spatial resolution of 3 cm. With high DSM data resolution, the shape of the rooftop of the building in the study area can be seen. The complete data specifications can be seen in Table 1.

Table 1. Data Specification

Dataset/ unit	Product	Data Format	Time of Data	Resolution	Temporal Resolution	References
Solar Radiation (W)	University of California Merced	Raster	1958-2022	4638.3 m	Monthly Average	(Abatzoglou et al., 2018)
Digital Surface Model (DSM)	ITB	Raster		0.03 m	-	-

2.3 Method

This research will integrate solar radiation with 3D information on buildings using hillshade analysis. Several stages will be carried out to determine the potential of solar radiation on the rooftop of the building. The first stage is by conducting DTM reconstruction, then determining the height of the building, then integrating it with solar radiation data. After that, the solar radiation results will be obtained on the rooftop of the building. The methodology flow chart, in general, can be seen in Figure 2.

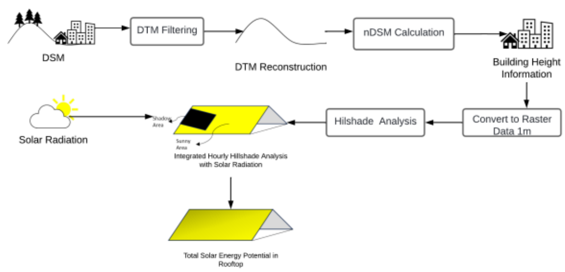

Figure 2. General Methodology

2.3.1 Construction 3D Building

In determining the height of the building, the formation of DTM will be carried out first. DTM will be formed through DSM data. The existing DSM data will be filtered based on slope values so that it will identify non-terrain parts (Ihsan et al., 2022b; Vosselman, 2000). Furthermore, after obtaining non-terrain points, spatial interpolation of TIN (Triangular Irregular Network) was carried out to determine the terrain in the entire study area. After obtaining a new DTM value, the nDSM (Normalized Digital Surface Model) value will be calculated. The nDSM equation can be seen in equation 1, where nDSM is the difference between the DSM and DTM values.

$$nDSM = DSM - DTM \qquad (1)$$

2.3.2 Analysis of Solar Radiation in Rooftop

In determining solar radiation on the rooftop of the building, shadow analysis will be carried out using hillshade analysis. Building height data will be obtained from DSM calculations, then hillshade calculations will be carried out for each hour. Hillshade calculation every hour (07:00 – 18:00) is intended to see the angle between the sun and the rooftop surface so that the shadow effect for the rooftop surface can be determined every hour. Hillshade calculations will use inputs requiring solar altitude and zenith, which in this study were obtained from the calculation of the NOAA Solar Position Calculator (NOAA, n.d.). The hillshade equation can be seen in equation 2 (Arcgis, n.d.).

Furthermore, after getting hillshade analysis every hour, an integration will be made between hillshade values and solar radiation data. Integration is done by combining hillshade values with solar energy potential. In integrating, the first stage calculates the average hillshade value for 12 hours. The equation used in calculating the average hillshade can be seen in equation 3 (Sakti et al., 2022). After getting the average value of the hillshade will then be integrated with the average value of solar radiation to get the daily potential on the rooftop of the building. The equation used in calculating the potential of solar energy on the rooftop of a building can be seen in equation 4 (Sakti et al., 2022).

Hillshade = 255 x {[Cos(Zenithrad) x Cos(Sloperad)] + [Sin(Zenithrad) x Sin (Sloperad) x Cos(Azimuthrad) x Cos(Aspectrad)]} (2)

$$\overline{H} = \sum_{i=7}^{18} \frac{H_i}{12} \tag{3}$$

$$\sum S'_H = \sum_{i=7}^{18} \left(\frac{H_i}{\overline{H}} \times S\right) \tag{4}$$

3. RESULT AND DISCUSSION

3.1 LOD 0, LOD 1, LOD 2 Building Height Reconstruction

From the results of the formation of DTM from DSM data, information on building height in the research area has been made. Figure 3 represents the height of the building in the study area, where Image 3A is LOD 0, Image 3B is LOD 1, and Image 3C is the actual shape. LOD 0 has no building height information or only 2-dimensional polygons. LOD 1 has one building height information for 1 type of building. At the same time, the actual shape is the appearance of the actual rooftop shape of the existing building. When viewed, there is a significant difference in the rooftop shape in the 3B and 3C images. The rooftop is prism-shaped (with a pointed tip), while in 3B, it is only flat. This can be the difference value for the potential of solar energy that will hit the surface of the rooftop of the building related to the shape of the building.

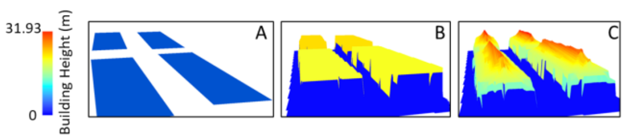

Figure 3. Different LOD Reconstruction

3.2 Solar radiation in 5 year

Figure 4 represents the five-year average solar radiation (2018-2022) in the study area. When viewed on a monthly cycle for five years, it can be seen that September and October are months with high potential. This high potential can be caused by the solar circulation cycle, where the study area is in the southern hemisphere so that the moon when the sun is closer to the southern region. The average daily potential in the study area was around 4000 Wh/day – 6000 Wh/day.

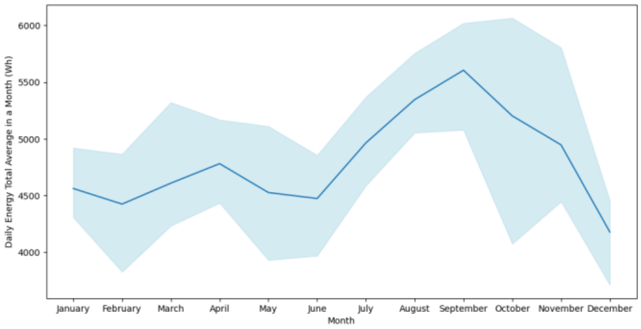

Figure 4. Solar Radiation Potential

3.3 Hillshade Analysis

Figure 5 shows the shadow analysis on LOD 1 and its actual shape in October. Hillshade processing is done every hour for one day when the sun shines. The study area is around the equator, where the sun shines about 12 hours a day throughout the year. The results found that by using LOD 1 and the rooftop of the building, the influence of the shadow of other buildings on the rooftop can be identified. However, LOD 1 could not identify the influence of the shape of the rooftop on the shadow that occurred on the surface of the building. This is because, in LOD 1, the rooftop is considered flat.

3.4 Solar Energy Potential in LOD 0, LOD 1, and Real Shape

The potential of solar energy integrated with hillshade obtained energy potential on the rooftop of the building. Figure 6 is the energy potential on the rooftop of the building compared between LOD 0, LOD 1, and the actual shape. The result of LOD 0 is that all buildings will have the same potential value. This is because no shadow influence will interfere with the potential of solar energy on the rooftop of the building. In LOD 1, several parts of the rooftop have a lower potential than other rooftop parts. This is because the part of the rooftop with a lower potential decreases due to the shadow of the surrounding higher buildings. When viewing the distribution, the energy potential in LOD 1 and LOD 2 in some parts looks the same, especially in buildings with the same height as the surroundings so that higher building objects around them do not affect the shadow on the object. In this incident, it can be seen that actually if the study area has buildings of the same height or rarely (building density is not dense), the use of LOD 0 to determine the potential of solar PV will be the same as the use of LOD 1 so there is no need for height modeling if the information used is only LOD 1. The results of the comparison between LOD 1 and the actual shape show that the shape of the rooftop will affect the amount of sunlight that hits the rooftop surface. The part of the rooftop is triangular, and the part near the end has a lower potential than the other parts. This is because the shadow of the end of the rooftop of the building will often cover the part close to the end of the rooftop of the building. In the results of the actual shape, it is found that the shape of the rooftop will affect the amount of potential energy over time following the sun's movement.

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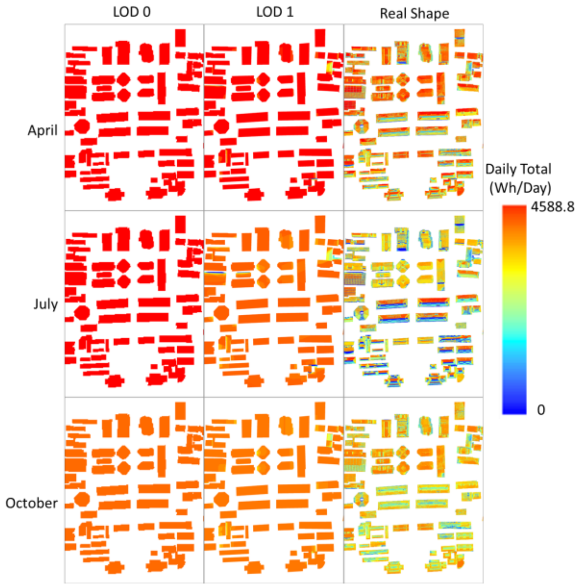

Figure 6. Solar Radiation in Rooftop Area

3.5 Aspect and Slope Effect for Solar Potential

Figure 7 compares solar radiation potential in LOD 1 and the actual shape. From the results of the solar energy potential obtained in LOD 1 and its actual form, it was found that the RMSE value of the energy potential was 1418 wh/day, with an R^2 value of 0.148 using 198 different building and time comparison data. This difference occurs because different rooftop shapes that vary will affect the potential energy obtained on the rooftop of the building. This study tries to calculate linear equations to improve the quality of the estimation of the energy potential of LOD 1 to the actual form shown in equation 5. In equation 5, an RMSE value of 367 Wh/day is obtained. This can increase the estimated solar energy results close to the actual value.

$$\text{Solar Potential} = \text{LOD1} \times 0.2748 + 1604.8 \tag{5}$$

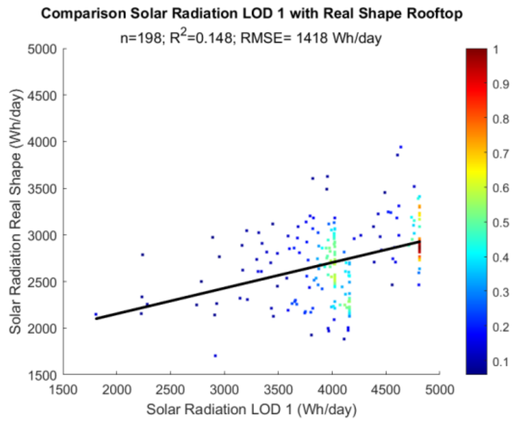

Figure 7. Comparison of Solar Radiation in LOD 1 and Real Shape

This study tries to identify slope and aspect influence on the research area. Figure 8 shows the effect of slope and aspect on the potential of solar radiation on the rooftop of the building. On the rooftop of the building, it can be seen that the higher the slope value, it will cause the potential energy value of the rooftop to decrease. This is because the higher the slope, the longer the sun's irradiation will decrease because the bottom of the rooftop will be more covered by the shadow of the rooftop above. Meanwhile, the aspect does not significantly influence the potential energy obtained. Indonesia's location around the equator can cause a not-so-significant influence between the aspect angle of the rooftop and the sun. The result shows that

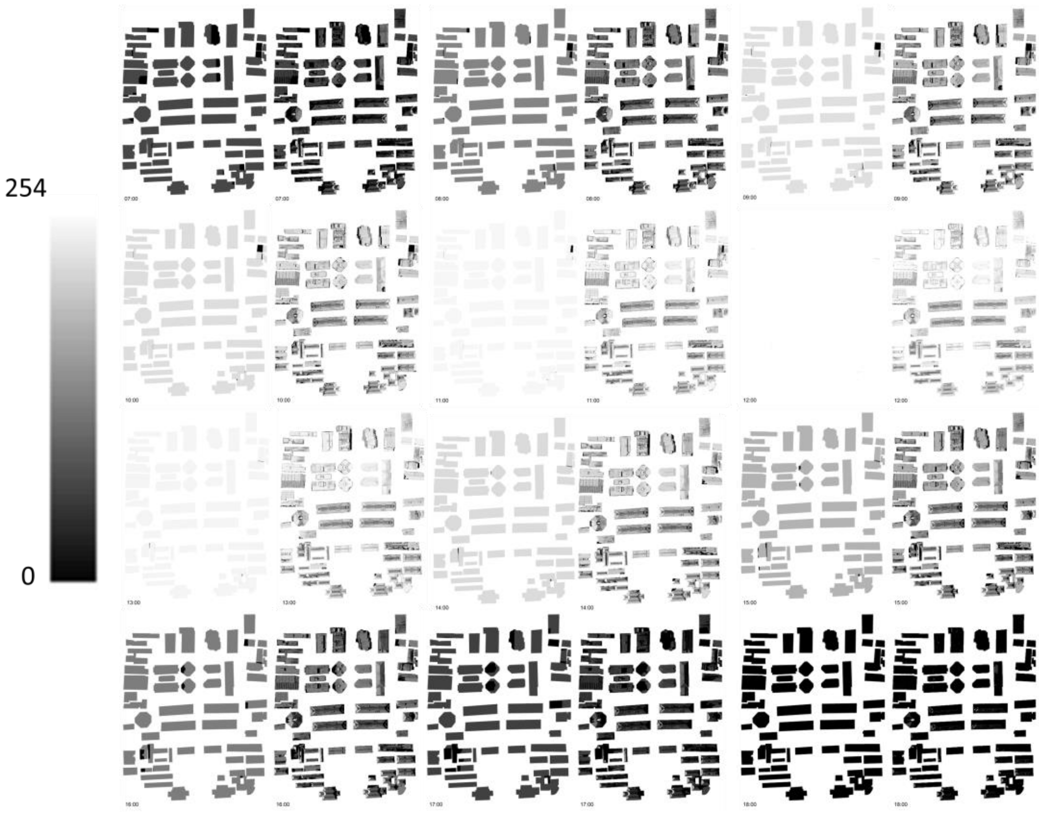

Figure 5. Hillshade Analysis in October Around 12 Hours

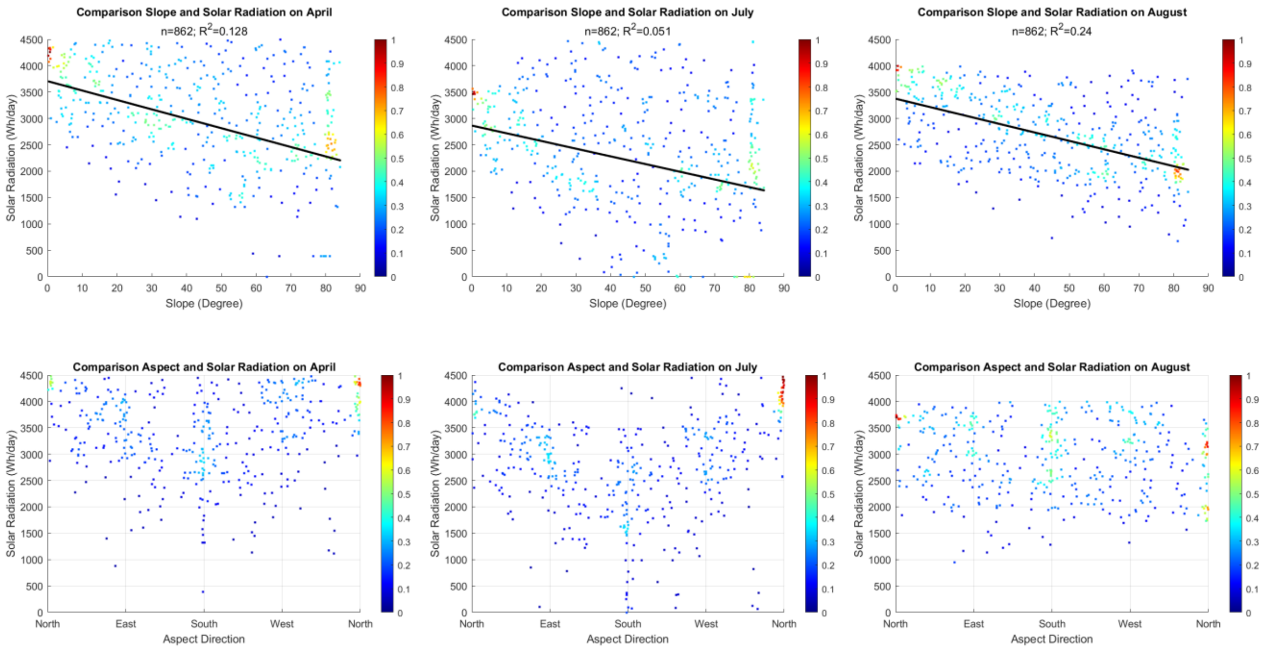

Figure 8. Comparison Aspect and Slope with Solar Radiation Potential in Rooftop

the north and south face the potential energy more significantly than the east and west. This is because the time of sun in north and south faces is longer than in east and west faces depending on the rooftop shape. In addition, the slope is also a significant influence in determining the potential of a specific front angle. If the slope is small, close to 0 (flat), then the influence of the front angle of the rooftop and the potential produced will not be significant. So buildings in any direction will have the same potential, except that the surface will be covered by other buildings or other parts of the roof.

3.6 Limitation and Future Possible Study

The results show that the potential of solar radiation is highly dependent on the research area and solar circulation, so that each location can have different values. The small area of the research makes the value of difference different in other locations. The small research area means that not many rooftop shapes can be analyzed. Analysis can be carried out on a broader and more diverse area to obtain the value of the difference in solar radiation at different levels of detailed information. The shadow analysis used on the object is still just another building influence.

Furthermore, it can be improved by reviewing the influence of topographic height and vegetation or trees around the building. This study is still comparing the potential of solar PV on rooftops from the same data. The potential differences can be analyzed when using data with different types of details, such as open-source data with medium spatial resolution, so that several buildings in the same pixel are considered to have the same height.

4. CONCLUSION

The difference between the use of different LODs has been calculated to determine the potential of solar energy on the rooftop of buildings. The difference in energy potential from the results of the LOD 1 model and actual shape is 1418 Wh. The difference is smaller than the difference between the LOD 0 model and the actual shape of the building height until 1845 Wh. The big difference between LOD 1 and the rooftop shape can be reduced by upgrading one using a linear modem. The RMSE value after the approach between LOD 1 and the rooftop shape obtained an RMSE value of 367 Wh / day. In the energy potential on the rooftop of the building, buildings on LOD 0 and LOD 1 do not have such significant differences in buildings that have the same height as other buildings or no other taller buildings that make shadows cover the rooftop of the building. This study reviewed the influence of slope on the potential energy obtained. A high slope will cause the resulting potential to be lower due to the shadow caused by the upper rooftop covering the shadow of the rooftop below.

ACKNOWLEDGEMENTS

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