Performance Evaluation of Roof Tile Solar PV under Tropical Climate of Surabaya, Indonesia

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Abstract. This paper discusses the applications of roof tiles type of PV modules. Published researches on this topic were reviewed. In addition, performance evaluation of a roof tile type of PV modules was conducted under the tropical climate of Surabaya, Indonesia. The objectives of present study are to review the most updated studies on roof tiles PV, then demonstrate and evaluate the energy output of PV modules based on the real conditions. The PV cells are made of thin film CIGS material. The experiment shows that the 60 Wp capacity of the tested roof tile modules could produce up to 53 Watt of electricity during day time. The produced electricity current was varying and directly proportional to the solar radiation, meanwhile the voltage was relatively stable during the day. The temperature of the module varies from ambient to 75ºC. The application of roof tile PV system would be one option to supply electricity for a large scale, especially in the urban area of Indonesia.

Keywords: PV Panels; roof tile; solar energy; Indonesia

1 Introduction

Indonesia is fortunate to have relatively high and stable daily solar energy throughout the year as it is located around the equator line which. One of the most promising renewable energies is solar energy. This relates to attempting to reduce fossil-based fuels consumption, which the availability is limited and the combustion process gives the greenhouse gas (GHG) emission[1]. The solar PV sector so far has not been well tracked in Indonesia[2], [3]. By the time of writing this paper, the approximately installed PV system in Indonesia is around 40 MW of solar PV system running on-grid. This capacity is relatively small in comparison to the neighboring South East Asian countries such as Thailand (2.6 GW) and Philippines (868 MW)[4]. Regardless of the current situation, the Government of Indonesia under the Ministry of Energy and Mineral Resources (MEMR) has set a target of 23% of renewable energy of total national energy needs by 2025[5] .

There have been many types of building integrated photovoltaic (BIPV) systems in many places. One promising and high potential of BIPV application in Indonesia is the rooftop system[6]–[10]. There are many types of rooftop PV systems now availa-

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ble, however, roof tile PV systems seem relatively new in development, particularly in Indonesia[11].

Several new research publications on the topic of roof tile PV systems have been reported in the literature. The followings are some of the reviewed articles:

Michels, C.et al[12]. identified the thermal performance of the roof based on an experimental test at a coastal city of southern Brazil. The suitability information related to the thermal performance and thermal resistance of the construction system can help the engineers and architects for determining the most appropriate of roof materials which can be used for solar panel implementation in the future. According to the Brazil country case study based on an experimental test rig in this paper, there are four different types of roofs that have been compared and analyzed. All types of roofs are equipped with fiber cement tiles and a polyvinyl chloride (PVC) ceiling, the first one as the reference to compare with others, the second used the tiles painted white, the third used radiant barrier installed and the last used conventional thermal insulation based on expanded polystyrene (EPS). The result shows that the reference roof had higher thermal gain than the others.

Alim, M.A., et al.[13] evaluates the influence of integrating the photovoltaic cells in roof tiles as the building component is one of the technologies that have been developed and investigated extensively in recent years due to the ability for generating the electricity and also serving an envelope of the building construction. Using mortar roof tiles, the integration between solar cells and protective glass and also phase change material (PCM) addition at 3wt% concentration was evaluated. It proves that integrating the PCM to the solar tiles can improve electrical performance even with slightly higher cost.

Wajs, J., et al.[14] were determining the way for increasing the efficiency of photovoltaic (PV) roof tiles implementation. In the renewable energy sector, PV roof tiles as the solar energy system with improved solutions that convert received energy from the roof tiles into electricity or heat. Therefore, the efficiency of PV roof tiles should be evaluated for understanding the heat recovery and the cooling effect when using air as the working medium. The experimental results indicate that the cooling system as the heat recovery process can improve the efficiency up to 24 % due to the heated air can be used for low-energy source applications.

Maestri, A., et al.[15] were compared and analyzed the effect on the variation of the solar reflectance of fiber-cement roof tiles which was implemented in Federal University of Santa Catarina (UFSC) building based on ASTME1918 standards. In order to evaluate the solar reflectance performance, the paint aging of the roof tiles with different ages were tested. It showed that when measured on a summer day, the reflectance performance differed only 0.02 than in the cloudy day.

Jan Wajs et. al.[6] conducted an experiment on the energy and exergy performance of air-cooled photovoltaic roof tiles as an example of the BIPVT system. Their experiment results showed the crucial impact of the depth of the cooling duct and the air volumetric flow rate on exergy efficiency. The highest thermal efficiency (27%) and overall efficiency (32%) obtained with the same cooling parameter, at the solar irradiance of 300 W/m2. Exergy efficiency value obtained from exergy analysis was between 5.08% and 9.94%.

Phiraphata et al.[16] have done an experimental study of natural convection in PV roof solar collectors in 2017. This experiment was conducted to compare the effect of using normal PV panels with PV-RSC panels on heat transfer that occurs by natural convection and estimate the convective heat transfer coefficient in a rectangular inclined channel. From the experimental result, it can be proven from the comparison between PV-RSC and normal PV panel that PV-RSC could generate more electric power than normal PV panel by about 30 W. In addition, PV-RSC was increasing the percentage of power generation by about 25% all day. Thus, it can be concluded that the use of PV-RSC as a modern roof is highly recommended and should be promoted because it can reduce heat gain on the roof and can improve normal PV performance.

Greppi and Fabbri [17]proposed a new kind of hybrid industrial solar tile and evaluated their thermal and electrical characteristics. This experiment result showed the evidence of dependency photovoltaic cell efficiency on the cell cooling conditions. Some preliminary results of electrical, thermal power and thermal efficiency obtained for different test days. First day result is open circuit voltage 5.36 V and 4.23 V, thermal power 112.05 W a thermal efficiency 62%, while second day result is open circuit voltage 5.54 V and 4.09 V, thermal power 122.1W and thermal efficiency 65.1%.

Gullbrekken et al.[18] have done a literature review focusing mainly on challenges of cold, pitched roofs in order to provide a state-of-the art overview of recent experiences and building physical challenges related to the use of BIPV in Nordic climate. BIPV systems are photovoltaic modules integrated into the building envelope, such as the roof or the façade. Some practical guidelines for installation and ventilation of the roofing have to include ventilation strategies depending on the size and inclination of the roof. The study also identified that more research is needed to develop BIPV systems with sufficient rain tightness that would be able to handle some challenges like snow and ice falling down.

Duwairi and Qasem [19] studied the effects of implementing corrugated modules PV to enhance thermal efficiency and power output. Their result showed that the corrugated surfaces amplitude had correlations to several other parameters, i.e., the shear stresses inside boundary layers and velocity, the air temperature near corrugated surfaces and its coefficient of heat transfer, the temperature of the corrugated surface, the output power, fill factor, power ratio and efficiency.

Yiqing et al. [9]evaluated the thermal and mechanical impact when they integrate glass fiber reinforced polymer (GFRP) with thin-film flexible PV cells for building application. They used flexible amorphous silicon(a-Si) thin-film PV cells and organic PV bonded to GFRP to imitate building-integrated PV. Then it was exposed to artificial sunlight with various intensity. The surface temperature of this integrated PV cell and voltage responses were recorded. The a-Si PV cells decrease more than the organic PV until 78°C when the organic PV showed significant degradation.

The present work discusses the applications of roof tiles type of PV modules. Selected published papers of researches on this topic were reviewed. Additionally the performance evaluation of a roof tile type of PV modules was conducted under the tropical climate of Surabaya, Indonesia. The objectives of this study are to review the most updated studies on roof tiles PV and to demonstrate and evaluate the energy output of roof tiles PV modules based on the real conditions. Further, to promote solar energy application, particularly in Indonesia, as a clean energy resource that can be integrated into a building's roof.

2 Experimental on a Roof Tile PV System

2.1 Methods

Performances of the roof tiles PV modules were evaluated by operating them under the real conditions. The shape of the modules is curved, which by manufacturer is designed for the building integrated photovoltaic (BIPV) as the roof tiles.

The design picture of a single module is shown in Figure 1. The module itself consist of transparent glass on the top cover, upper film, PV cells, lower film, and glass at the bottom. The PV cells made of thin film CIGS material[21]. The power capacity each module is 30 Wp. The parameters and the specification of a single module is presented in Table 1.

Figure 1. The design picture of a single roof tile PV module [21]

Table 1. Parameters and specification of the tested PV module

Parameters	Specification
Module Type	HW-MQSB-V1, Han tile (Three arch camber tile)
Maximum Power, *Pmax*	30 W
Power Tolerance	-0.5/+1W
Open circuit voltage, *Voc*	10.6 V
Voltage at maximum power, *Vmp*	8.6 V
Short circuit current, *Isc*	4.0 A
Current at maximum power, *Imp*	3.5 A
Weight	9.5 kg
Dimension	687.6 x 500 x 11 mm
Maximum System Voltage	1000 V

In the experiment, two PV modules were put in series and connected to a battery through a solar charge controller. The modules are tilted 20º from horizontal and facing North. This situation is fit to the astronomical position of Surabaya. The energy obtained is used to power of a DC load. The voltage and the current were recorded every 15 minutes using a power meter. Measurements were conducted from 09:00 to 15.30 for several days. This period of day time is commonly the most effective of a PV System in Surabaya. The diagram and the photograph of the equipment are shown in Figure 2 and Figure 3, respectively.

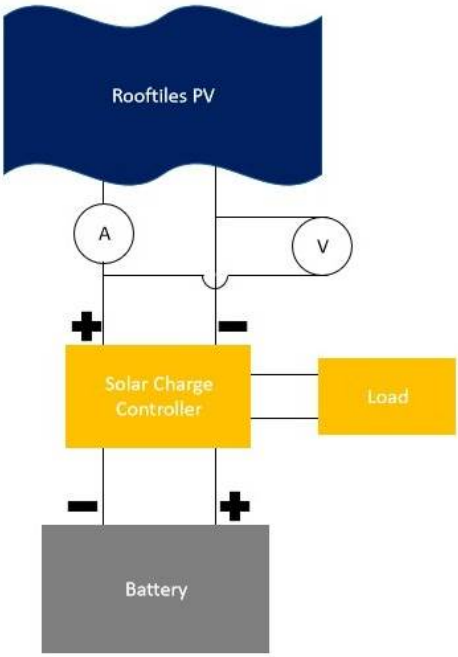

Figure 2. Diagram of measurement equipment

In addition, solar radiation is recorded during the experiment using a portable pyranometer, placed nearby the solar modules. The temperature of the panels was observed using an infrared camera which integrated with a mobile phone application. The experiments were conducted in the open space area of the University of Surabaya Indonesia.

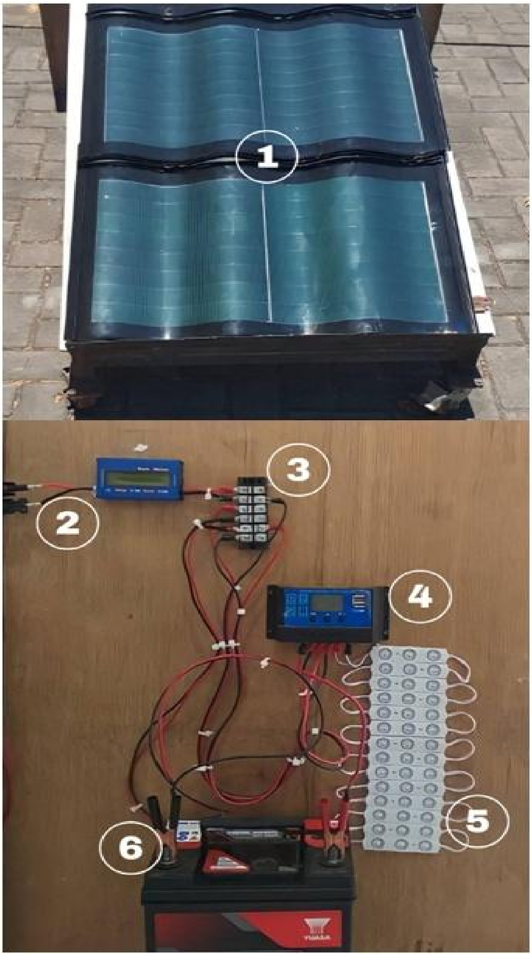

Figure 3. Photograph of measurement equipment: 1-solar modules, 2-power meter, 3-connector, 4-solar charge controller, 5- DC load, 6- Battery

2.2 Results and Discussion

Theoretically solar radiation on the earth's surface can vary between 0 – 1000 W/m^2, but in reality, solar radiation rarely reaches its maximum value due to various factors, including weather, dust, and other particles in the air. Solar radiation varies over time. During the measurements made in this study the maximum solar radiation was about

800 W/m^2, and was relatively constant throughout the day from 9.30 to 15.30. It was observed that the weather was relatively sunny. At the time of measurement, Surabaya was in the dry season. Although the weather looks clear, in fact the measured solar radiation (global radiation) was in the range of below 800W/m^2. Global radiation consists of direct, diffuse, and reflected components. Each location has its own characteristics of radiation. Previous research [22] showed that in Surabaya the solar radiation component is dominated by the diffuse component. This can lead to low global radiation, even though the observed weather is clear sky. Typical solar radiation from 9.30 to 15.30 when the measurement takes place is shown in Figure 4. Measurement was conducted on 15 October 2021

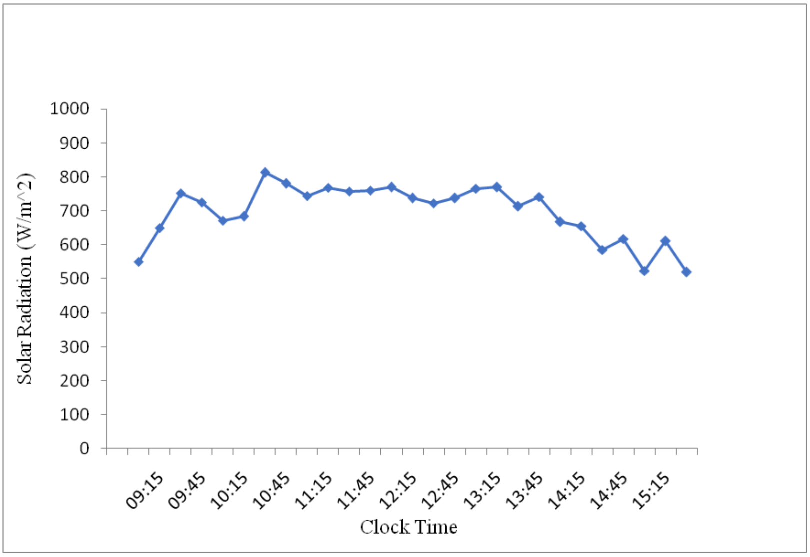

Figure 4. Solar radiation in Surabaya October 15, 2021

The voltage of the measured solar roof tile module was found to be relatively stable at 12.55 volt, with condition that the two modules were connected in series. By assuming that the two solar roof tile modules are identical, then the operating voltage of each solar module was about 6.25 Volt. This value is relatively low in comparison with V_{mp} as written in the module specification (Table 1). In the module specification, the value of V_{mp} is 8.6 volts. Meanwhile, the electric current produced is correlated with the level of solar radiation received by the module. The maximum electric current recorded was 2.72 A. This value is also relatively low when compared to the module specifications where I_{mp} = 3.5 A. The voltage and current generated from the two modules in series under the same day (the same solar radiation) is shown in Figure 5.

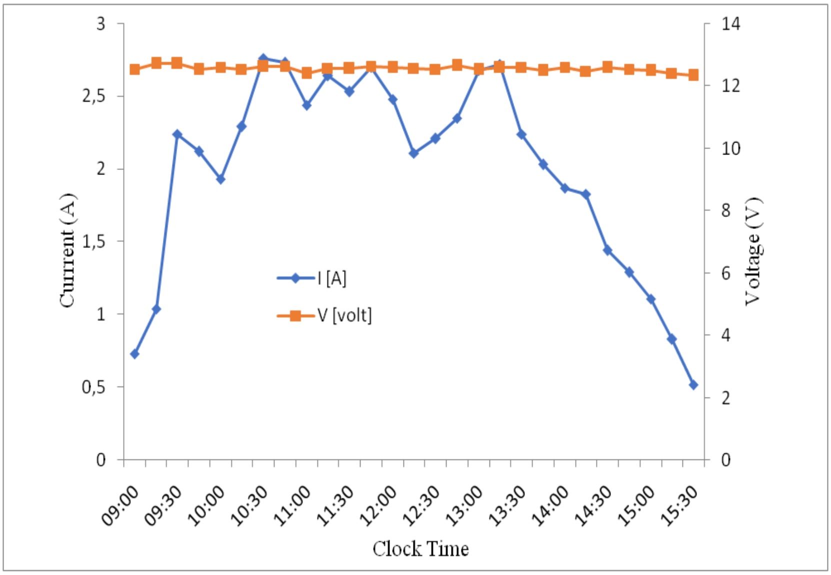

Figure 5. Voltage and current of 60 Wp roof tiles modules

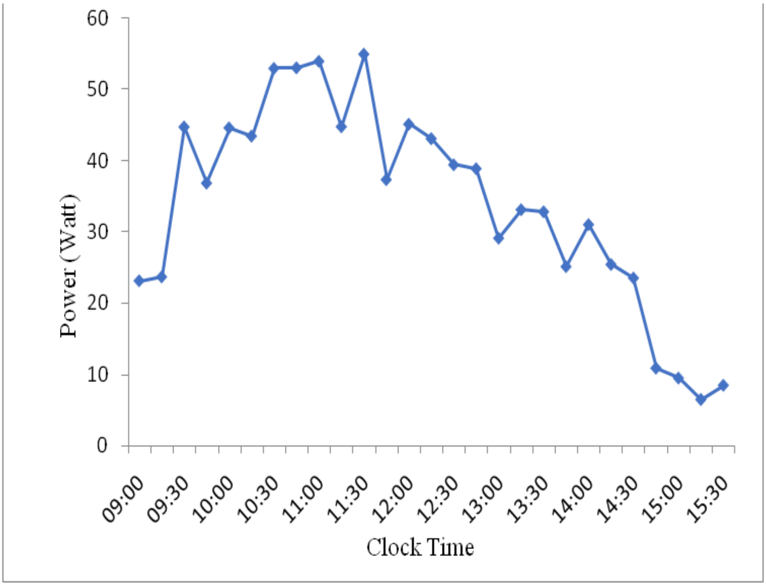

Figure 6. Output power of 60 Wp roof tiles module

The output power of the 60 Wp measured solar roof tiles module system varies throughout the day. The maximum output power produced was about 53 Watts when the maximum solar radiation occurred around 11.30. The output power continued to decrease in the afternoon even though the solar radiation was relatively stable. Figure 6 shows the results of the output power measurement for 60 Wp solar roof tiles modules in one day from 09.30 to 15.30. The decrease in output power might be caused by various factors, especially due to a decrease in electric current and/or voltage, as the value of power is the multiplication of the values of voltage and current. Theoretically, the voltage generated by the solar module is correlated with the temperature of the PV cells. This could be the cause of a decrease in output power since noon where the module temperature had been relatively high and constant. Observations show that the temperature of the solar module increased since its operation in the morning to a maximum point at around 11.00 o'clock and it is relatively constant for the rest of the time for the same day.

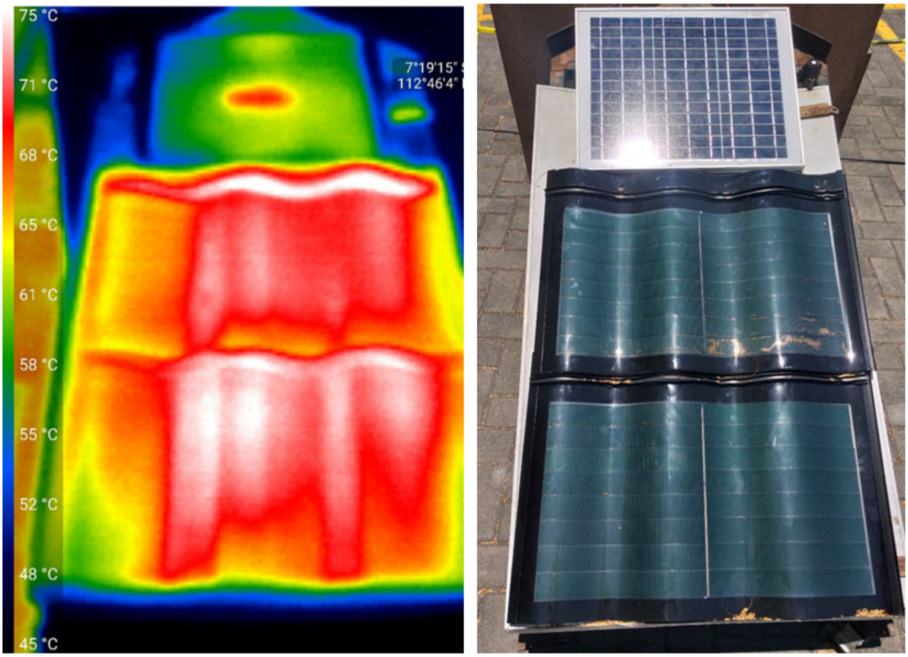

Figure 7. Temperature of modules and photograph of the system

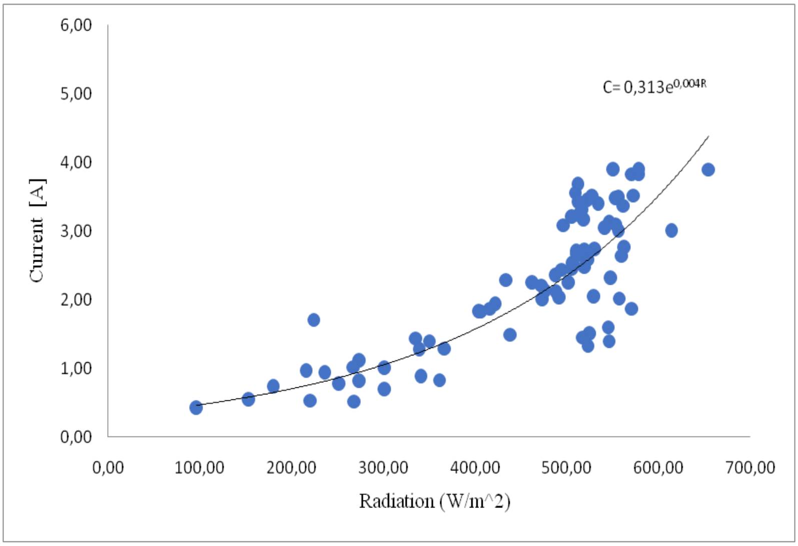

Figure 8. Correlation between radiation and current

The temperature of the solar modules was observed during the experiment. Temperature observations were also carried out simultaneously on a conventional solar module (monocrystalline silicon) 30 Wp. It was found that the temperature of the roof tile solar module was relatively higher than that of the conventional solar module (Figure 7). The temperature of the tile solar module reaches 70ºC during the day, at the same time the temperature of the conventional module is around 60ºC. This can be a consideration in the solar roof tile roof system application, whether it affects the room temperature in the installed building. More research is recommended for this case.

As mentioned, that the electric current generated from the solar module is correlated with the level of radiation. The plotting of the results of the measurement of electric current versus the radiation level of the solar roof tile modules is shown in Figure 8. It was found that the electric current increases exponentially with the increase in solar radiation.

3 Conclusion

The roof tile solar module has been developing, both in research and application. The roof tile solar module is on application of BIPV which has high potential for the use of solar energy. Measurements in Surabaya, Indonesia showed that 60 Wp solar roof tile modules made from CIGS material could produce up to 55 Watt of power, therefore it can be concluded that, from an energy perspective, the application is reliable. The high temperature of the module during operation should be put into consideration in buildings, especially for locations with hot weather such as Surabaya. Promoting and socialization of the use of solar roof tiles needs to be carried out in order to achieve clean energy fulfilment from solar.

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