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SMALL SCALE EXPERIMENT: THERMAL PERFORMANCE COMPARISON BETWEEN FIBER-CEMENT ROOF AND PHOTOVOLTAIC ROOF IN MALANG, INDONESIA

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Abstract

Irradiation on the surface of photovoltaic module heats up the photovoltaic module itself and the room underneath the roof of integrated photovoltaic building in the tropics area. Room heating reduces thermal condition and photovoltaic module surface heating reduces its performance in generating electricity. This paper discusses an experiment of measuring the surface temperature of photovoltaic modules and fiber-cement roof surface as a comparison. This experiment also measures the impact of rising temperatures in each space underneath. It used small-scale mock-ups exposed to direct sunlight. The result of the experiment shows that photovoltaic roof surface temperature is lower than fiber-cement roof temperature. The temperature of room under photovoltaic roof is also lower than the one under fiber-cement roof. Empirical calculation shows that loss of electrical power found is only up to 1.7%.

Abstrak

Eksperimen Skala Kecil: Komparasi Kinerja Termal Atap Fiber Semen dan Atap Fotovoltaik di Malang Indonesia. Pada bangunan fotovoltaik terintegrasi pada atap di daerah tropik, sinar matahari yang jatuh pada permukaan modul fotovoltaik berpeluang memanaskan modul photovoltaic itu sendiri dan memanaskan ruangan di bawahnya. Pemanasan ruangan menurunkan kondisi termal sedangkan pemanasan modul menurunkan kinerjanya dalam menghasilkan listrik. Paper ini membahas eksperimen pengukuran suhu permukaan modul fotovoltaik dan permukaan atap asbes semen sebagai pembanding. Kegiatan ini juga mengukur dampak kenaikan suhu pada masing-masing ruang di bawahnya. Eksperimen menggunakan *mock-up* berskala kecil yang dipaparkan ke sinar matahari langsung. Hasil eksperimen menunjukkan bahwa suhu permukaan atap fotovoltaik lebih rendah daripada atap fiber semen. Suhu ruang di bawah atap fotovoltaik juga lebih rendah daripada suhu ruang di bawah atap fiber semen. Perhitungan empiris menunjukkan bahwa kerugian penurunan daya listrik yang ditemukan tidak lebih dari 1,7%.

Keywords: electrical power loss, fiber-semen roof, roof integrated photovoltaic, small scale experiment, thermal performance

1. Introduction

The element of every building located in the tropics that is most exposed to the sun is the roof [1-2]. Therefore, photovoltaic module on buildings in the tropics would be more effective when it is integrated on the roof. The problem is that the photovoltaic module has a specific nominal operating cell temperature (NOCT): when the temperature increases far above NOCT, it degrades its performance [3-5]. Viewed from another aspect, a roof with high temperature often affects the temperature of the room underneath.

Fiber-cement roofing is one of the most favorite choices for local people in selecting roofing materials for their houses or buildings. It has been reported that the use of this material has caused indoor temperature to be high; how far the temperature would be, however, has not been confirmed. The use of photovoltaic module as roofing material has also been predicted to have a greater impact on indoor-temperature than the use of fiber-cement roof because photovoltaic modules are dominated by glass material. Heating on the roof heats the room temperature by convection, conduction and radiation through the ceiling. Roof space is a subsystem of building roof system where the heat behavior affects the temperature of the room underneath [2].

The experiment aims to obtain information on the temperature and the fluctuation of integrated photovoltaic modules of the roof of building; to obtain information on the temperature and the fluctuation in of fiber-cement roof; and to calculate the photovoltaic module power loss due to increased surface temperatures.

2. Experiment

The procedure of the experiment basically started with making two mock-ups as small-scale test specimens. These specimens were then exposed directly to sunlight for a period of time. Then, measurement of temperatures was conducted for each roof surface and each room underneath at the same time and on a periodical basis. The measurement results were tabulated, processed, and compared. The final step was computing the power reduction using the coefficient of power per temperature referring to the results of previous studies.

The experiment required 2 mock-ups as test objects: a mock-up room with fiber-cement roof and a mock-up room with photovoltaic modules roof. Mock-up made from fiber-cement was used as a reference because this material is more popular. All mock-ups were made of the same size as follows: length 120 cm, width 99 cm, and height 145 cm. Length and width of the mock-up was decided by practical considerations, following the solar module size. The fiber-cement was equal in size because the size of fiber-cement can be easily customized. Perspective picture and photos of the 2 mock-ups are shown in Figure 1 and Figure 2.

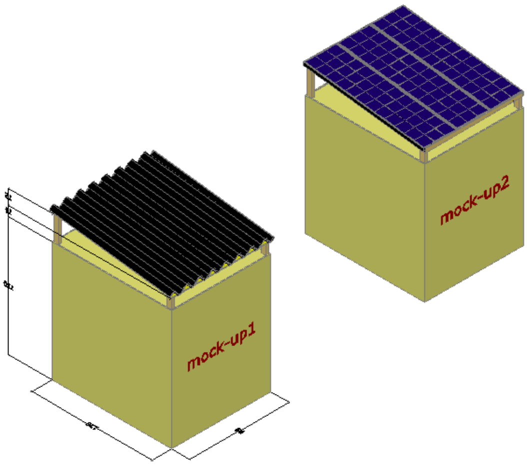

Figure 1. Picture of the Mock-ups

Figure 2. Photo of the Mock-ups

The frames of mock-ups were made from Meranti wood. The areas were covered with 12 mm thick plywood. The top of the mock-ups had space to represent the roof ventilation space. The first mock-up was a mock-up of fiber-cement roof, whose roof was as wide as its plan. The second mock-up was roofed by 3 pieces of photovoltaic modules. Photovoltaic modules used was polycrystalline module M75 with NOCT 25 ^{o}C and 8.5% efficiency, the power peak at 750 W/m^2 sunlight intensity was up to 22.792 Watt and its coefficient of power per temperature = 0.039 W/^{o}C [5].

Mock-ups were put on a shadow-free area throughout the day. The positions of mock-ups were also arranged so as not to overshadow each other even though the position of the sun shifted throughout the day. The surface of the roof of each mock-up and the space underneath were mounted with a thermocouple tool to measure temperature. Measurements were done every 5 minutes, starting at 09:47 AM until 14:00 PM or 10:14 to 14:27 solar time. To give an overview of the dynamics of the intensity of the sun, measurements of the intensity of sun irradiation (global radiation) using a Pyranometer were also carried out at the same time with temperature measurement.

Measurements were taken on June 19, 2009 (day 170) in Malang, East Java, Indonesia, from latitude location (-8) degree, longitude location of 112 degree, standard local time longitude (WIB) of 105 degree, equation of time (E) (-0.886275727) and the difference between solar time and local time (time correction) = 27.11 minutes.

Results were obtained by calculation using time correction factor (TC) formula [6].

$$TC = \pm 4\,(L_{st} - L_{loc}) + E, \qquad (1)$$

where "+" is used for western hemisphere and "–" is for eastern hemisphere, and E is Equation of Time.

$$E = 229.2\,(0.000075 + 001868\cos B - 0.032077\sin B - 0.014615\cos 2B - 0.04089\sin 2B), \qquad (2)$$

where

$$B = (n-1)\,(360/365) \qquad (3)$$

while n is the number of days since the start of the year.

3. Results and Discussion

The measurement results have been tabulated and analyzed. The discussion has four points:

Weather conditions on the day of measurement. On the day of measurement, the weather was sunny in the morning until noon. Radiation intensity increased normally. From morning until 13:27, closing did not occur by the overcast sunlight. Starting at 13:32, overcast began blocking sunlight on site. However, it does not necessarily overcast preclude but come and go (Figure 3).

It can be concluded that when there is overcast then the radiation received decreases drastically [7]. This corresponds to previous research.

Temperature and its fluctuations on the roof surface. Temperature and its fluctuations on each roof surface are described in Figure 4.

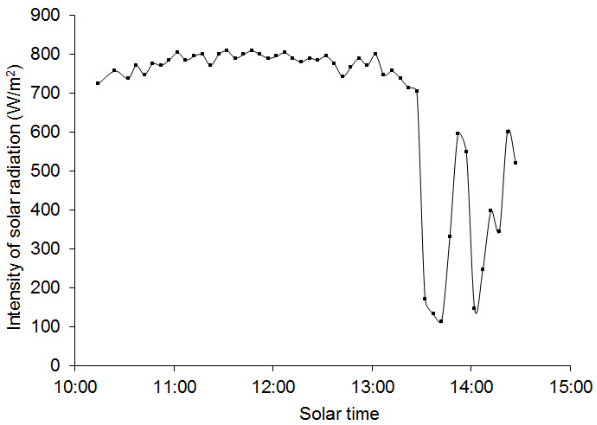

Figure 3. The Intensity of Received Solar Radiation

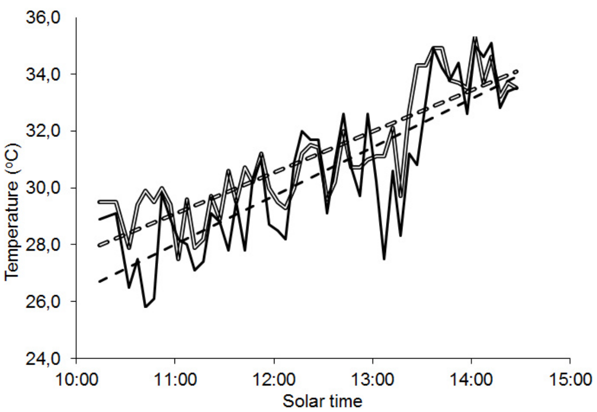

Figure 4. Surface Temperature of Fiber Cement Roof (═) and Photovoltaic Modules Roof (─), Trendline of Fiber Cement Roof Temperature (═ ═) and Trendline of Photovoltaic Modules Roof Temperature (— —)

The temperatures of fiber-cement roof and photovoltaic roof fluctuated with a tendency to increase (Figure 4). This increase is reasonable because the higher position of the sun increases the intensity of irradiation. At 13:32, when overcast began to blow, the temperature of fiber-cement roof fell fewer than the surface temperature of photovoltaic modules. The drop in temperature had only been for a moment because after that the radiation fluctuations occurred again and still dynamic.

Moreover, in essence, photovoltaic module temperature was lower than the surface temperature of fiber-cement roof. Trend lines from each curve give the assertion that, in general, the temperature of photovoltaic roof was lower than the temperature of the fiber-cement roof.

Calculation of average in between both of them also gave the same explanation. The average temperature of the fiber-cement roof was 31.1 °C, greater than the average surface temperature of photovoltaic modules, which was 30.4 °C. The value of the correlation between the two sets of temperature data was calculated for 0.87, which means that whenever there was an increase in temperature of fiber-cement roof, there was an increase in surface temperature of photovoltaic modules. Correlation numbers of 0.87 could be interpreted that the heating happened normally.

The fall in the intensity of sunlight did not necessarily lower the surface temperature of fiber-cement roof, but there was a pause (time lag). Decrease in temperature after a pause occurred in photovoltaic modules and in fiber-cement, but a longer time lag occurred in the fiber-cement roof. This was due to the thermal capacity from fiber-cement roof, which was higher than the thermal capacity of photovoltaic modules.

Room temperature. The experiment results also show that temperature of the room under the roof of photovoltaic was lower than room temperature under fiber-cement roof. This is consistent with the previous discussion, that the fiber surface temperature is higher than the surface temperature of photovoltaic modules. This is also strengthened by the thermal properties of corrugated fiber-cement i.e. U-value (6.10 W/m^2K) [8], which is greater than U-value of photovoltaic modules glass (3.0 W/m^2K) [8]. With this trend, it can be stated that the temperature of the room underneath is strongly influenced by surface temperature and thermal properties from each roofing material. Figure 5 provides the explanation.

Trend lines drawn from each of the curves confirm that the room temperature under the photovoltaic roof is colder than the room temperature under the fiber-cement roof. The difference is at the range of 1.1 to 1.2 °C at the same time.

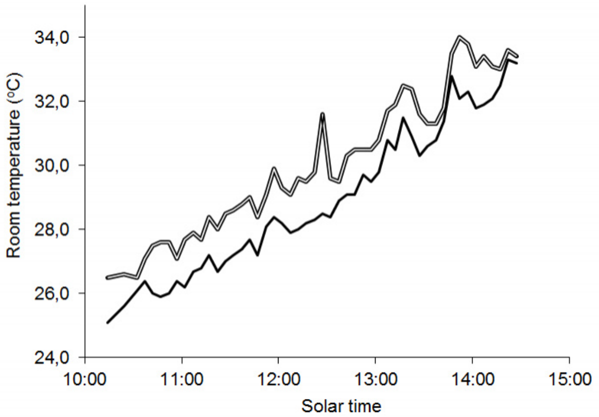

Figure 5. Room Temperature under Fiber-cement Roof (═) and under Photovoltaic Modules Roof (─)

Power losses. Loss of electrical power occurs when there is an increase in temperature [4]. As mentioned above, NOCT was at 25 ^{o}C while the maximum temperature reached 35 ^{o}C during experiment. Since the coefficient of power/temperature were known of (-0.039) W/°C [5] and power peak was up to 22.792 Watts, then the potential loss of electrical power could reach (35-25) °C x (-0.039) W/°C = (-0.39) Watts per module or (-1.7)%. This number (-1.7%) was obtained from -0.39 Watts per module divided by 22.792 Watts per module. This number is relatively not high, but it is still a loss.

4. Conclusions

It has been noted that photovoltaic roof surface temperature is, in fact, lower than the surface temperature of fiber-cement roof. Results of this experiment also show that room temperature under photovoltaic module roof is cooler than room temperature under fiber-cement roof. This contrasts the earlier predictions. Although heating caused loss of electrical power output of photovoltaic module, it might be too small: only 1.7% of total electrical power collected.

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