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Beeswax as phase change material to improve solar panel's performance

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Abstract. One of the main obstacles faced during the operation of photovoltaic (PV) panels was overheating due to excessive solar radiation and high ambient temperatures. In this research, investigates the use of beeswax phase change materials (PCM) to maintain the temperature of the panels close to ambient. Solar panels used in this study has 839 mm length, 537 mm wide, and 50 mm thick, with maximum output power at 50 W. During the study, there were two solar panels was evaluated, one without phase change material while the other one was using beeswax phase change material. Solar panels were mounted at 15° slope. Variables observed was the temperature of solar panel's surface, output voltage and current that produced by PV panels, wind speed around solar panels, and solar radiation. The observation was started at 07:00 am and ended at 06:00 pm. The research shows that maximum temperature of solar panels surface without phase change material is ranging between 46-49 °C, and electrical efficiency is about 7.2-8.8%. Meanwhile, for solar panels with beeswax phase change material, the maximum temperature solar panels surface is relatively low ranging between 33-34 °C, and its electrical efficiency seems to increase about 9.1-9.3%.

1. Introduction

In line with the increasing pace of development and the increasing pattern of life, energy consumption in Indonesia continues to increase. This increase occurred almost in all sectors that include industry, transportation, commercial, household, power generation and other sectors. The total national energy consumption in the period 2003-2013 has increased with an average growth rate of 4.1% per year. Total energy consumption increased from 117 million TOE in 2003 to 174 million TOE in 2013 [1].

The commercial sector consists of trade, hotels, restaurants, financial, government agencies, schools, hospitals, communications and others. Data for years 2004-2011 showed that the sector grew on average 8% per year. However, growth in the sector does not have the same pattern of the growth of energy consumption in the commercial sector. The growth of energy consumption in the commercial sector in the period 2004-2011 had an average growth of 4% per year. In 2014, this sector consumes the energy of 5:22 million TOE, or about 3% of total final energy consumption. Based on the master plan of national



energy conservation, the commercial sector has the potential energy savings that can be achieved by 10–30%.

A decrease in energy consumption and its impact can be achieved in various ways, including the use of low carbon building materials, improved insulation, low-energy lighting, embedding renewable technology, intelligent control and use of low carbon fuels. The incorporation of renewable energy in the building component must be done in a way that ensures reliable performance and cost-effective energy saving. A Building Integrated Photovoltaics (BIPV) system consists of integrating photovoltaics modules into the building envelope, such as the roof or the façade. By simultaneously serving as building envelope material and power generator, BIPV systems can provide savings in materials and electricity costs, reduce the use of fossil fuels and emission of ozone depleting gases, and add architectural interest to the building [2].

However, BIPV faces a challenge with the rise in temperature, manifested as electrical efficiency loss and overheating. This efficiency loss is mainly due to a decrease in open-circuit voltage (V_{oc}), which has a negative temperature coefficient. Currently, however, only 15–20% of the solar energy incident on a PV panel can be converted to electricity, with the rest of the energy being transformed into heat. This heat can well be absorbed by the PV device itself, causing its working temperature up to 80°C. PV conversion efficiency is thereby decreased by 0.4–0.65 % for every increased degree [3].

Many researchers, therefore, are seeking to mitigate the influence of high temperature on PV conversion efficiency by rapidly removing heat from PV module surfaces to maintain as good a performance as possible, and hence better meet expectations. Much of the research has focused on natural or forced air circulation, heat pipes and hydraulic or refrigerant cooling [4]–[7].

Study of the use of the PC as a PV panel cooling material both experimentally and analytically also been widely reported [3], [8]–[10]. This system was named PV-PCM or PV/PCM, a hybrid technology integrating a PV panel and a PCM into a single module to achieve a higher module solar conversion efficiency than a PV panel acting alone. This is a promising integration, as the PV converts visible and ultraviolet components of the solar spectrum, while the PCM utilizes the infra-red components and the waste heat from the PV.

The PCM also reduces the PV temperature thereby increasing its efficiency. However, the PV-PCM system is still in the infant stages, with various issues unclear, presenting opportunities for further research [11]. The aim of these experiments is to study the behavior of the PV-PCM systems in outdoor realistic uncontrolled conditions to determine how effective the PV-PCM systems are in ‘real’ conditions. In addition, the PV-PCM systems were characterized in low latitude hot climate of Banda Aceh, Indonesia. Experiments were conducted outdoors of the Engineering Faculty, Syiah Kuala University, Banda Aceh, Indonesia (05.57 N, 95.37 E).

2. Methods

This study was conducted outdoors in the Faculty of Engineering, University of Syiah Kuala. The research was conducted from 08-07-2016 to 15-07-2016. Three PV panels are used. One PV panel as a reference, the PV panels with paraffin wax as a phase change material (PV-PCM₁), and a PV panel with beeswax as a phase change material (PV-PCM₂). The study was conducted from 07:00 am to 06:00 pm, where ambient temperatures, wind speed, solar radiation intensities, temperatures at front and back surfaces, V_{oc} and I_{sc} for the reference PV and the PV-PCM systems were measured. PV panel is placed facing north.

Figure 1 shows the experimental setup consisting of the reference PV panels without PCM, PV-PCM₁, and PV-PCM₂ installed outdoors of Engineering Faculty. The temperatures and V_{oc} and I_{sc} were measured with data logger and the multimeters. PCM paraffin wax used had a melting temperature of 46.7°C, and beeswax is 51°C.



Figure 1. An outdoor experimental setup consisting of a reference PV, PV-PCM1 and PV-PCM2 installed.

According to the Cox and Raghuraman 1985, report, the insolation of wavelength above $1.1\mu\text{m}$ is transmitted through the silicon cell without any absorption and this is absorbed by the back sheet of PV module. Electric efficiency (η_e) of PV panel was determined using following equation:

$$\eta_e = \eta_o [1 - \beta(T_p - T_r)] \quad (1)$$

Standard electric efficiency (η_o) is calculated with:

$$\eta_o = \frac{V_{oc} I_{sc}}{G A_p} \times 100 \% \quad (2)$$

where η_o is the nominal electrical efficiency under standard condition, A_p is the area of the PV module, G is the irradiation and it is defined as $1000\text{W}/\text{m}^2$ for the standard condition, V_{oc} is the PV voltage at maximum power point and I_{sc} is the PV current at maximum power point. All the relevant data can be obtained from the specification of PV module shown in table 1, T_o is the temperature of the standard condition, 25°C , T_c is the cell temperature, β is the temperature coefficient of silicon cell, $\beta=0.0045/^\circ\text{C}$.

Table 1. Specifications PV Panel

Type	: Silicon Nitride Monocrystalline
Maximum power (Pmax)	: 50 W
Voltage at Pmax (Vmp)	: 17.5 W
Current at Pmax (Imp)	: 2.9
Warranted minimum Pmax	: 45W
Short-circuit current (Isc)	: 3.2A
Open-circuit voltage (Voc)	: 21.8
Dimensions	:
Length	839mm
Width	537mm
Depth	50mm

3. Results and Discussion

Although experiments were conducted from 08-07-2016 to 15-07-2016, the weather conditions were not stable on all days. On certain days the solar radiation intensity and the ambient temperatures were not high enough due to overcast weather conditions in Banda Aceh which restricted temperatures at the PV surface to such low values that the PCM could not melt properly. For other days the ambient temperatures and the solar radiation were high enough to raise the PV temperature above the PCM melting point which allowed heat absorption and thus melting of PCM to occur.

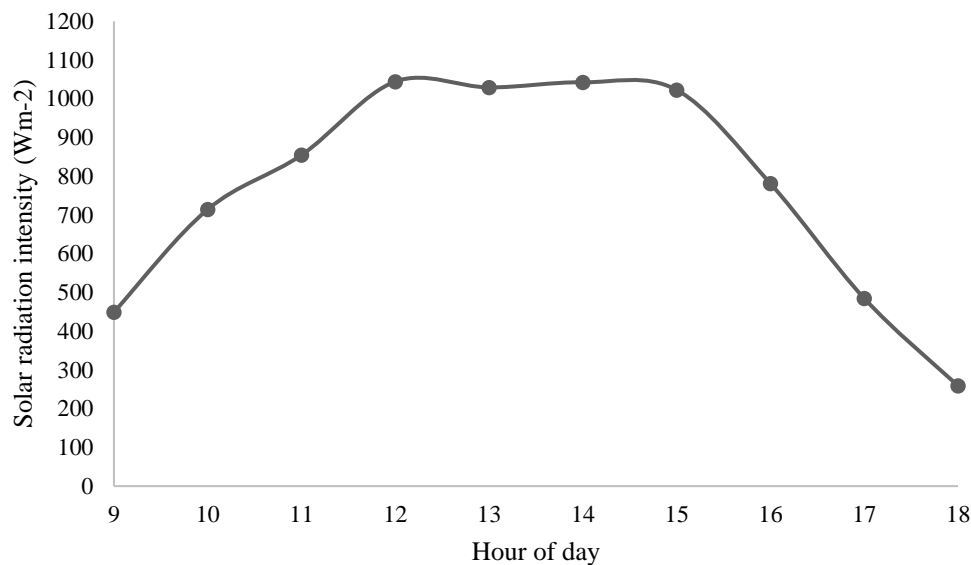


Figure 2. Solar radiation intensity, Banda Aceh on 9-07-2016

Figure 2 shows that solar radiation intensity ranged from 448 W/m² at 9:00 am to 259 W/m² at 06:00 pm with a peak at 1042 W/m² at 02:00 pm. The best case data with higher solar radiation intensities (1042 W/m²) peak and ambient temperatures (34°C peak) was obtained at 09-07-2016. The stable conditions resulted in higher temperatures at the reference PV front surface. This made more heat available at PV enabling higher heat harnessing by the PCM at the back of PV resulting more temperature reduction.

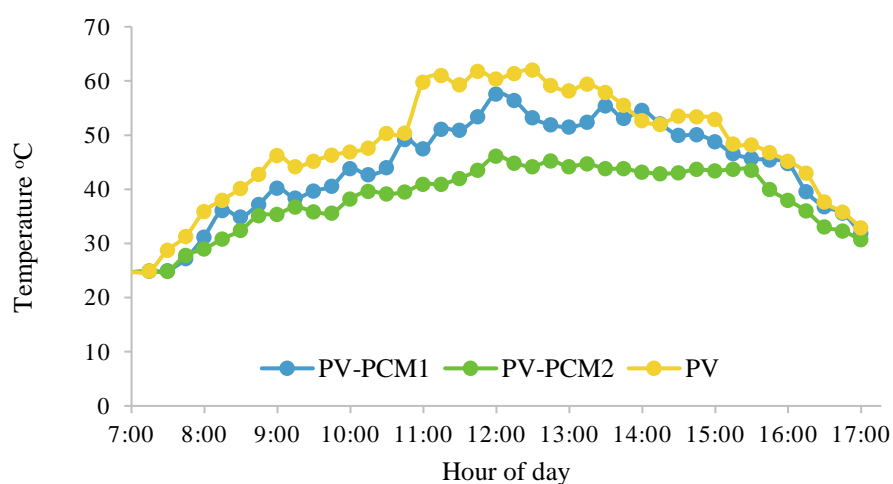


Figure 3. The average temperature at the front surface of reference PV, PV-PCM1, and PV-PCM2.

Figure 3 shows the average temperature evolution on the front surface of the reference PV, PV-PCM1 and PV-PCM2 measured. Temperature at the PV front surface increased rapidly from 24°C (at 07:00 am) to 40 °C in 1 hours and 30 minutes (at 08:30 am) and remained above 40 °C for 7 hours and 30 minutes (up to 04:00 pm) with a peak temperature of 629 °C at 12:30 pm. As shown in Figure 3 PV-PCM₁ and PV-PCM₂ followed the same trend in temperature rise as the reference PV temperature, however, the PV-PCM systems maintained lower temperatures than the reference PV throughout the experiment. After 12:00 pm the temperature of the reference PV dropped rapidly due to combined effect of (i) decreased incoming heat caused by decreasing solar radiation intensity and (ii) increased heat loss to ambient due to a rapid increase in wind speed. The temperature in the PV-PCM systems showed less of a decrease, primarily due to the stored latent heat and thermal mass of the PCM in the PV-PCM systems, which releases stored heat with small temperature changes.

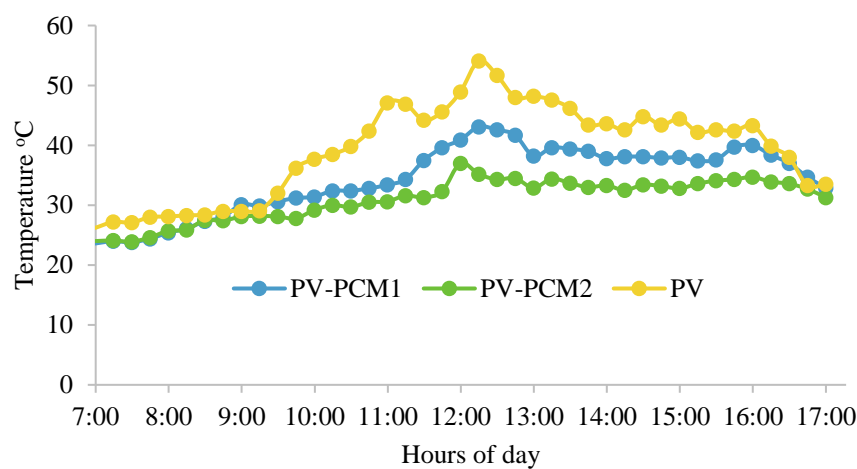


Figure 4. Average temperature at rear surface of reference PV, PV-PCM1, and PV- PCM2

Figure 4 shows the temperature evolution on the rear surface of the PV panels. It is seen that the rear surface of the PV reference temperature at 54 °C maximum occurred at 12:00 pm At that moment the front surface temperature is 62 °C, there is a difference 8°C. While the PV-PCM1 maximum temperature 43.1°C, while on the front surface 60.4°C, then the difference between 17°C, while the PV-PCM2 difference of 9.15°C.

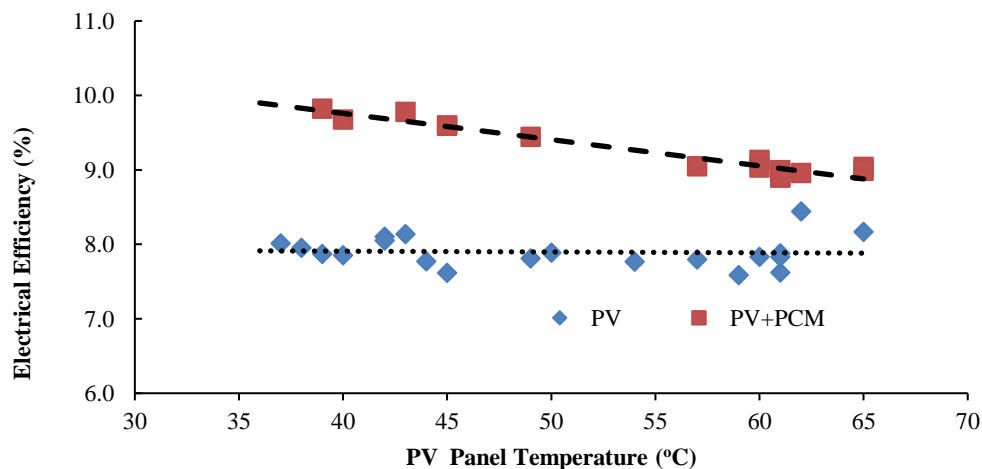


Figure 5. Relation of electrical efficiency with PV panels surface temperature

Figure 5 shows the impact of front temperature of PV panel on PV electricity efficiency. Electricity efficiency was determined using eq. (1). The graphic shows that electricity efficiency of PV panel without PCM is ranged between 6.1 % - 6.5 %. While for PV panel with PCM the efficiency is ranged at 7.0 % - 7.8 %. This proved that air cooling is capable of increasing the efficiency of PV panel.

4. Conclusion

The result of observation conducted on July 09 2016, that the changes of PV panel surface temperature, which solar radiation intensity for PV panel with and without PCM mechanism is shown in figure 4. The graphic shows that maximum intensity of solar radiation was achieved at 12.00 pm which is at 1024 W/m², followed by a maximum temperature of PV panel surface without PCM at 62°C. The significant impact of lowering surface temperature is shown during PCM cooling, where maximum temperature was only at 60.4°C. As a comparison, PV panel without PCM recorded that during 09:00 am to 02:00 pm, the temperature rose up to 28°C, while PV panels with PCM only 11°C. Beeswax has a better ability to absorb heat compared to the paraffin wax. This emphasized that test device is working properly. Both PCM evaluated showed promising potential for the desired application, with higher potential in low latitude hot in Banda Aceh.

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