Experimental study of efficiency of solar panel by phase change material cooling

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Abstract. The dependence of efficiency of photovoltaic panels on their temperature during operation is a major concern for developers and users. In this paper, a phase change material (PCM) cooling system was designed for a 60W mono-crystalline solar panel. Tealights candle was selected as the cooling medium. The solar irradiance was recorded using Kipp & Zonen CMP3 pyranometer and Meteon data logger. Temperature distribution on the surface of solar panel, output voltage and output current of solar panel were measured. The average irradiance throughout data collection was found to be 705W/m$^2$ and highest irradiance was 1100 W/m$^2$. The average solar panel temperature was 43.6°C and a maximum temperature of 53°C was at the center of solar panel. Results showed that average power output and efficiency of the solar panel were 44.4W and 15%, respectively. It was found that the higher the solar irradiance, the lower the efficiency of solar panel and the higher the temperature and power output of solar panel. This is due to the fact that high irradiance results in high power input and high solar panel temperature. But high PV panel temperature reduces its power output. Therefore, the increase of power input outweighs that of power output, which leads to the decrease of efficiency of solar panel with the increase of solar irradiance. Compared with solar panel without cooling, the power output and efficiency of solar panel did not increase with PCM cooling. It indicates that Tealights candle as PCM cooling is not efficient in improving the efficiency of solar panel in this study.

1. Introduction

Solar energy is one of renewable energy sources favorable in Malaysia for its climatic conditions. According to Azhari et al [1], solar radiation for each day on an annual average is 4.21-5.56 kWh/m$^2$. The highest estimated solar radiation is as high as 6.8kWh/m$^2$ during August and November and lowest 0.61kWh/m$^2$ during December. The high radiation is very suitable to use photovoltaic (PV). However, the abundant irradiance will heat up the PV which will reduce the efficiency of the panels [2].

To increase the efficiency of the solar panels, several cooling techniques have been tried. Generally, there are two types of cooling: active cooling, which consumes energy (pump, fan, etc.) and
passive cooling, which uses natural convection/conduction to enable heat extraction [3]. Most cooling methods are based on active water and air cooling, as these are the simplest techniques. However, passive cooling methods are self-operable, more reliable and cost effective than active cooling methods because of the absence of moving parts [4]. It can be divided into three main groups: air or water passive cooling, and conductive cooling. Phase change material (PCM) cooling is a special type of passive conductive cooling. Much research on PV/PCM cooling has been done by numerical simulations [5], laboratory tests and outdoor studies in Pakistan [6], Ireland [7] and India [8] in building integrated photovoltaics (BIPV). However, there is little research done in Malaysia. And not much research on PCM cooling of non BIPV system was conducted. It is known that the power drop and temperature rise of the solar panel largely depend on the climate of the sites [9]. In this paper, a PCM cooling system was designed and tested outdoor with a free standing solar panel. The effects of the phase change material cooling system on the output of the solar panel were studied.

2. Experimental Setup

The first step of fabricating the cooling system is the selection of the PCM. Paraffin and paraffin wax are frequently used as candidates of PCMs due to their non-toxic and inert properties [7]. Tealights candle was used as PCM in this study.

The proposed PCM cooling system is illustrated in Figure 1. Aluminum tubes were fitted into a stainless steel container. The bottom of container was covered with wooden plank, which acts as an insulation layer. The cavities between the aluminum tubes as shown in Fig. 1(a) were filled with PCM. A layer of aluminum sheet was used to cover PCM, which prevents direct contact between PCM and the back of solar panel.

Finally, the cooling system was attached to a 60W monocrystalline solar panel and set at the desired direction and elevation with the help of a rack for outdoor experiments, as shown in Figure 2. Solar irradiance was measured using Kipp & Zonen CMP 3 Pyranometer, Meteon data logger and a laptop. Data collection was started at 11:00 and ended at 15:00. Readings were recorded through the data logger in the computer at intervals of one minute.

The surface temperatures at 9 positions shown in Figure 2 and output of the solar panel were measured using K-type thermocouples and multimeter at intervals of 30 minutes, respectively.
3. Results and Discussion

3.1 Irradiance intensity

Figure 3 shows the profile of irradiance on one day of data collection. It started from 780 W/m² at 11:00, reached a peak at 1026 W/m² at around 13:00 and then dropped to below 400 W/m² due to weather condition.

Distribution of irradiance throughout the data collection period of four days was tabulated in Table 1. It can be seen that most of the data points fell in the range of 700 to 800 W/m² in Day 1, 700 to 900 W/m² in Day 2, 800 to 1000 W/m² in Day 3 and 4. The average irradiance throughout the data collection was 705 W/m² and the highest irradiance was 1100 W/m² at 11:30 on Day 3. Since the power input to solar panel is a product of irradiance and area of the panel, the higher the irradiance the more the power input.
### Table 1. Counts of irradiance.

| Range (W/m²) | Day 1 | Day 2 | Day 3 | Day 4 |
|--------------|-------|-------|-------|-------|
| 0–199        | 0     | 1     | 16    | 0     |
| 200–299      | 21    | 27    | 9     | 12    |
| 300–399      | 19    | 19    | 5     | 14    |
| 400–499      | 13    | 23    | 11    | 1     |
| 500–599      | 10    | 23    | 15    | 4     |
| 600–699      | 33    | 29    | 19    | 10    |
| 700–799      | 114   | 36    | 40    | 28    |
| 800–899      | 31    | 48    | 65    | 89    |
| 900–999      | 0     | 29    | 55    | 83    |
| 1000–1099    | 0     | 6     | 6     | 0     |

### 3.2 Efficiency of Solar Panel

The efficiency of the tested solar panel was calculated by using the following equation [10]:

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{V_mI_m}{lS}$$  \hspace{1cm} (1)

Where: $V_m$ – maximum voltage (V), $I_m$ – maximum current (A), $I$ – intensity of radiation (W/m²), $S$ – area of panel (m²), in this study $S = 0.41m^2$.

Figure 4 shows that the efficiency of the solar panel decreased with the increase of irradiance. The highest efficiency was 35% at 11:30 at an irradiance of 391 W/m². The average efficiency of the solar panel during the four days’ data collection was found to be 15%. Efficiency of a solar panel is the ability of the solar panel to convert light energy to electrical energy. It is reported that the majority of the solar radiation is converted to heat energy [11]. When radiation intensity increases, both the input and output power of the solar panel will increase. On the other hand, the temperature rise of solar panel will reduce the output power. Therefore, output power did not change much. This results in the inverse proportion of efficiency of solar panel to the irradiance.

Due to the fact that solar panel can only harness a limited amount of energy from the irradiation of the sun, the excessive solar radiation will only contribute to heat up the solar panel which in turn causes the drop of efficiency of the solar panel. This can be clearly seen in Figure 5, which shows the relationship between average temperature and efficiency of the solar panel. When panel temperature is higher, the efficiency is lower. The highest efficiency is 35% at 11:30 at an average panel temperature of 32 ºC.

### 3.3 Temperature of Solar Panel
Table 2 shows the temperature distribution on the front surface of the solar panel with PCM cooling. It can be seen that T5 has the highest value among the 9 points, from 41 to 46 ºC. That means the center of solar panel is the hottest point. The average solar panel temperature of the four days’ data collection was found to be 43.6ºC and a maximum temperature of 53ºC was recorded at the center of solar panel on Day 4.

| Temperature (ºC) | 11:00 | 12:00 | 13:00 | 14:00 | 15:00 |
|------------------|-------|-------|-------|-------|-------|
| T1               | 35    | 46    | 45    | 41    | 43    |
| T2               | 35    | 46    | 44    | 43    | 44    |
| T3               | 35    | 47    | 44    | 41    | 43    |
| T4               | 39    | 40    | 44    | 42    | 41    |
| T5               | 41    | 46    | 46    | 42    | 41    |
| T6               | 39    | 43    | 42    | 41    | 40    |
| T7               | 37    | 42    | 42    | 41    | 40    |
| T8               | 37    | 43    | 42    | 40    | 39    |
| T9               | 36    | 40    | 41    | 40    | 40    |

The comparison of the temperature at the center of PV surface (T5) between solar panels with and without PCM cooling is tabulated in Table 3. There is no significant difference of temperature between the panels with and without PCM cooling. The average efficiency of the solar panels with and without PCM cooling was 14.6 and 15.0%, respectively.

PCM can absorb/discharge a large amount of energy during phase change. The capacity of a PCM for temperature control depends on its properties, heat transfer methods and system configuration (Huang, et al, 2011). PCM used in this study has a melting temperature of 48ºC – 50ºC, while the solar panel operates around 45ºC with a maximum temperature at 53 ºC. This indicates that PCM may be partially melted, which results in little contribution of latent heat to heat removal from PV panel. The non-melt PCM only absorbs sensible heat. Aluminum tubes in this study were designed to increase the surface area of conductive heat transfer from PCM and act as ducts for natural convection by wind induced air flow. But non-melt PCM has low thermal conductivity and the wind speed during the experiments was below 2 m/s. These lead to uneffective heat transfer from the solar panel. In order to fully utilize the advantages of phase change, PCM with lower melting point is recommended for further study.

| Temperature (ºC) | 11:00 | 12:00 | 13:00 | 14:00 | 15:00 |
|------------------|-------|-------|-------|-------|-------|
| With PCM cooling | 41    | 46    | 46    | 42    | 41    |
| Without PCM cooling | 39   | 45    | 44    | 41    | 41    |

4. Conclusion
PCM Cooling System was designed to study its effects on the efficiency and temperature reduction of solar panel in Malaysia climate. The measured average irradiance was 705W/m², and the maximum irradiance was up to 1100 W/m². The average solar panel temperature was 43.6ºC with the highest value of 53ºC and lowest 35ºC. Comparison between solar panel with and without PCM cooling
showed that Tealights candle as PCM in this study was not effective in reducing temperature and improving efficiency of solar panel. The reason is that the melting point of tealights candle is around the operating temperature of solar panel, which limits the contribution of heat removal from the panel by phase change. A PCM with a lower melting point than 40ºC is recommended for Malaysia climate.

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